FINAL REPORT

Sub-Audio Magnetics: Miniature Sensor Technology for Simultaneous Magnetic and Electromagnetic Detection of UXO

ESTCP Project MR-200322

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ESTCP

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MM-0322 includes hardware and software development, testing and performance evaluation. Initial funding saw the development of a fast sampling magnetometer (called the TM-6), a necessary step for the realization of a new ordnance detection method called SAM UXO. Initial trials highlighted the worth of developing a purpose-designed transmitter (called the MPTX). Additional funding and development led to further trials aimed at evaluating this new detection method using the new transmitter and receiver technologies, at APG and YPG. Unique attributes of the SAM UXO system include the use of large loops for the transmitter (40 m or 110 m square), and a single pass receiver that simultaneously measures both TMI and TFEMI as two perfectly co-located datasets, using just one sensor. There has been a significant improvement in data quality and detection capability through the use of the new transmitter. Although the system is not well suited to detecting small ordnance items, it will satisfactorily detect medium to large items, and is especially suited to the detection of large deep ordnance items. The system is ready for commercial applications.

15. SUBJECT TERMS

UXO Detection, Instrumentation, Magnetometry, Time Domain Electromagnetic, Sub-Audio Magnetics, Total Field Electromagnetic Induction.

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Acronyms

Amp	Ampere
APG	Aberdeen Proving Ground, Maryland (acronym in the text refers to the facility itself)
APG1	Refers to the first trial at APG in June 2004
APG2	Refers to the second trial at APG in June 2007
ATC	Aberdeen Test Center
BAR	Background Alarm Rate
BRAC	Base Realignment and Closure
CEHNC	Corps of Engineers Huntsville Center
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
cm	Centimeter
DERP	Defense Environmental Restoration Program
DGM	Digital Geophysical Mapping
DGPS	Differential Global Positioning System
DoD	U.S. Department of Defense
EM	Electromagnetic
EP	Engineering Prototype
ERDC	USACE Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EQT	U.S. Army Environmental Quality Technology Program
FAR	False Alarm Rate
FIR	Finite Impulse Response (a class of digital filter)
ft	Foot
FWHH	Full Width at Half Height
FUDS	Formerly Used Defense Sites
GapGeo	Gap Geophysics Australia Pty Ltd
GPS	Global Positioning System
G-tek	Geophysical Technology Ltd., antecedent of Gap Geophysics Aust. P/L
ha	Hectare
HASP	Health and Safety Plan
HE	High Explosive
HERO	Hazard of Electromagnetic Radiation to Ordnance
HHPC	Hand-held personal computer
Hz	Hertz
KVA	Kilovolt Ampere
LP	Laboratory Prototype
m	Meter
mm	Millimeter
ms	Millisecond
MEC	Munitions and Explosives of Concern
MPTX	Medium-Powered Transmitter developed for UXO detection
nT	nanotesla
pps	Pulse per Second
P_d	Probability of Detection
P_{fp}	Probability of False Positive
QC	Quality Control

ROC	Receiver Operator Characteristic
RTK DGPS	Real-Time Kinematic Differential Global Positioning System
RTS	Robotic Total Station
SAM	Sub-Audio Magnetics
SAM UXO	UXO detection method based on the SAM principles, providing both TMI and TFEMI
SERDP	Strategic Environmental Research and Development Program
SHERP	Safety, Health and Emergency Response Plan
SNR	Signal-to-Noise Ratio
sps	Samples per Second
TFEMI	Total Field Electromagnetic Induction
TMI	Total Magnetic Intensity
TM-6	Magnetometer system developed for SAM applications
Tx	Transmitter
UXO	Unexploded Ordnance
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Centre
V	Volt
YPG	Yuma Proving Ground, Arizona

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Executive Summary

This report summarizes work undertaken over the period 2003 – 2010 that has involved several phases of hardware and software development, and its associated testing and performance evaluation.

Following acceptance of an idea that had been demonstrated to the stage of proof of concept, the initial funding saw the development of a fast sampling magnetometer referred to as the TM-6. The idea for a new UXO detection methodology based on Sub-Audio Magnetics (SAM) had originally been developed for the minerals exploration industry in Australia, and its proven potential for this application led to successful granting of funds from various US Govt. agencies.

Initial trials highlighted the worth of developing a purpose-designed geophysical transmitter referred to as the MPTX. After additional funding and development, further trials were conducted to evaluate this new detection methodology centered about the new transmitter and receiver technologies, at Aberdeen and Yuma Proving Grounds, as part of the Standardized UXO Technology Demonstration Site Program.

Two unique attributes of the SAM UXO Detection System are the use of very large loops for the transmitter (40 m x 40 m or 110 m x 110 m), and a single pass receiver that simultaneously measures both TMI and TFEMI, which results in two datasets that are perfectly co-located since both are derived from the same sensor.

The demonstrations have shown there has been a significant improvement in data quality and detection capability through the use of the dedicated purpose-designed transmitter. The demonstration sites have a range of ordnance dominated by medium to small items that have proven to be challenging targets however there has been enough opportunity to highlight the real strength of the system, namely its ability to excel in the detection of large deep ordnance items.

The development program has concentrated on producing high quality hardware, firmware and pre-processing software, and the remaining task is to finalize software to be used for discrimination and classification. This will be an on-going task beyond the scope of this project, and the data that has been obtained is of sufficiently high quality that it is more than adequate to ensure this remaining task that is a necessary part of any commercial system will also be realized.

1. Introduction

1.1. Background

The environmental problem that has been addressed in this work relates to the decontamination of land either formerly or presently under the control of the US Department of Defense (DoD). Relevant programs include Base Realignment and Closure (BRAC) and Formerly Used Defense Sites (FUDS). There are a large number of sites with a known decontamination problem, and based on 2003 figures these include 1700 FUDS and 25 BRAC sites and active installations.

The land could be contaminated with unexploded ordnance (UXO), exploded ordnance debris, buried obsolete munitions and other refuse, all of which have been emplaced during military activities such as warfare (battlefields), training (weapons ranges), munitions manufacturing or waste products from everyday activities at military installations that is buried in landfills. Generally, the problem arises when the land is designated for a new land use that involves a change of ownership (and responsibility) to another government agency or to the civilian sector for such uses as recreation and housing. Given the potential threat to the general public, of some of these buried hazardous materials, there will obviously be some land that needs to be decontaminated to a very high standard.

The process of decontaminating such land comes at a very high cost. One part of the process is the actual detection and mapping of buried materials of interest. Another part of the process involves digging-up and removal of this material from the site being decontaminated. In the last 20 years, geophysical instruments and methods have become an important part of the process. The technology being demonstrated here has the potential to reduce the cost of the geophysical detection and mapping, reduce the risk of missing targets, reduce the number of detected targets required to be investigated through digging, and in particular detect larger, deeper items that may be undetectable by other technologies.

The two most widely used and accepted geophysical sensor technologies applied to the detection of buried materials of interest are magnetic and electromagnetic (EM). They each have their own advantages and disadvantages depending upon the targets expected and the geological and terrain conditions. EM detectors are generally more labor intensive and slower to use than magnetometers. Magnetometers generally have a better detection depth and a reasonable depth estimation capability but can be adversely affected by magnetic geology, do not respond to non-ferrous metals and have limited target classification capability. In many situations, the desired detection performance can only be achieved by acquiring data from both sensor technologies.

Sub-Audio Magnetics (SAM) is a new technology in which an optically pumped, total field magnetometer is used to simultaneously measure the total magnetic intensity (TMI) and the total field electromagnetic induction (TFEMI). When this technology is applied to UXO detection, the methodology is referred to as SAM UXO. The SAM UXO detection system is able to acquire both magnetic and electromagnetic sensor data in a single pass of the survey area with the ease and efficiency usually associated with a magnetic-only survey.

The sampling requirements of a magnetometer that is capable of acquiring SAM data are more stringent than those commercially available and therefore a high-sampling magnetometer was developed for this project in 2003. The work was undertaken by Geophysical Technology Limited (G-tek) (note: this company name was changed to Gap Geophysics Australia or GapGeo in November 2005) with financial assistance from the US Army Corps of Engineers Engineer

Research and Development Center (ERDC). Upon completion of the new magnetometer (referred to as the TM-6), the theoretical detection capabilities of the SAM UXO system were field tested in an Environmental Security Technology Certification Program (ESTCP) funded project conducted at a number of different sites.

Compared to conventional practices and alternatives, the potential benefits from the utilization of this technology are (i) reduced survey costs, (ii) lower risk of missing buried ordnance items, particularly those buried deeper than the detection limit of existing EM systems and (iii) a reduced false alarm rate through having a more complete data set that provides sufficient information to effectively discriminate between ordnance and non-ordnance targets.

This final report describes the objectives, technology, demonstration design and performance assessment parameters for demonstrations conducted at the Aberdeen Proving Ground (APG) in June 2004 (to be referred to as AGP1) and June 2007 (to be referred to as APG2), and at the Yuma Proving Ground (YPG) in June 2008. These two locations are the prime sites of the Standardized UXO Technology Demonstration Site Program.

The Standardized UXO Technology Demonstration Site Program is a multi-agency program spearheaded by the U.S. Army Environmental Center (USAEC). The U.S. Army Aberdeen Test Center (ATC) and ERDC provide programmatic support. The program is being funded and supported by ESTCP, the Strategic Environmental Research and Development Program (SERDP), and the U.S. Army Environmental Quality Technology (EQT) program.

As stated on the program's web-site, "UXO characterization technologies can be affected by variations in site terrain, geology, natural or man-made materials, vegetative cover, and weather conditions encountered. The establishment of standardized UXO technology demonstration sites will allow users and developers to define the range of applicability of specific UXO technologies, gather data on sensor and system performance, compare results, and document realistic cost and performance information".

1.2. Objectives of the Demonstrations

The primary objective of the demonstrations at APG and YPG was to validate the SAM UXO detection technology in order to provide benchmark information with respect to its detection and discrimination capability. They were important trials that provided basic data that has been used to enable a realistic comparison between this and other contemporary detection systems. Given that the system will acquire the two data sets simultaneously in one data stream, it is important to prove they can be adequately separated to provide two data sets of at least equal quality to those obtained with separate passes and alternative hardware.

Two trials were conducted at APG, the first (APG1 in 2004) using an off-the-shelf transmitter and the second (APG2 in 2007) using a new purpose-built transmitter (referred to as the MPTX), aided by additional funding from the government during the course of this contract. An important secondary objective was to compare the results obtained with this new equipment with the original dataset in order to highlight the derived benefit from the newly improved hardware.

Another important objective was to begin the process of technology transfer by involving new people in the fieldwork aspect of the project, and to conduct the work in a manner similar to a commercial application (in particular the survey of the Open Fields) in order to obtain reliable data on survey coverage rates, and assess the operational reliability of the new hardware.

The two Standardized UXO Technology Demonstration Sites represent highly contrasting environments in terms of climate, vegetation and soils. APG is located approximately 30 miles northeast of Baltimore, MD at the northern end of the Chesapeake Bay, encompassing 17 acres of upland and lowland flats, woods and wetlands. YPG is located adjacent to the Colorado River in the Sonoran Desert, near Yuma, AZ. At both sites, a range of scenarios are available to test different operational criteria under controlled conditions. Both have the same range of ordnance types. These are a mix of carefully selected examples found in typical ordnance clearance projects. They include projectiles (20 mm to 155 mm), sub-munitions, mortars and rockets. The specific ordnance types are described in more detail in Section 3.3.

The test scenarios include a Calibration Grid with truth data supplied, a blind test grid where specific locations to be surveyed are marked and located on a regular grid. The main objective being to simply determine the presence or absence of ordnance at each location, and several other areas including a large reasonably flat open field, wooded (APG) or desert vegetation (YPG) and moguls (rough undulating terrain). Many ordnance items have been buried randomly throughout the areas. The locations, depth and type are not disclosed to participants, who are expected to be able to provide basic data about any detected ordnance items. More details on these specific test scenarios are provided in chapter 4.

Of particular interest at the APG2 and YPG trials was a determination of whether the new MPTX transmitter had improved the systems capability to acquire data with a higher signal-to-noise ratio (SNR) than that demonstrated at the APG1 trial. Associated with this was achievement of an acceptably high Probability of Detection (P_d), low Background Alarm Rate (BAR) score and good location accuracy, since these metrics are of particular interest in meeting accepted regulatory standards.

The APG1 trial highlighted the fact that there was difficulty detecting the smaller sized ordnance items and that the SNR of all items in general provided a handicap to obtaining good inversion results in the many instances. A performance metric such as the SNR of a comparable target response (i.e. same or similar item at the same depth as before) is the best way of indicating a fundamental improvement in the new detection system. The scored measure of P_d (especially in the Open Field) would indicate that this improvement can be translated to actual field practice under survey conditions, given that this metric is measuring the system's ability to detect all of the emplaced items. Finally, the BAR would indicate that the system is providing data of sufficiently high SNR that targets are able to be adequately resolved above the noise or clutter limits it is possible to extract information able to assist in the discrimination task.

Advantages of this new technology that will hopefully be proven in these demonstrations include:

- obtaining two high quality data sets with a single pass using field techniques and acquisition rates that are at least equal of other methods;
- providing a cost-effective alternative to other methods;
- measuring the magnetic field at a very high sampling rate and with a low inherent system noise level that allows removal of unwanted effects from the data such as the 60 Hz power line mains and other similar disturbances;

- an ability to detect a wide range of ordnance sizes to their required depth of interest, and especially in the case of large deep items, to depths greater than other methods;
- an ability to collect high quality data to the required standard under adverse terrain, climatic and geological conditions.

1.3. Regulatory Drivers

The DoD is faced with significant costs for environmental restoration and compliance with environmental regulations. Federal regulations (e.g. CERCLA), DoD directives related to programs such as the Environmental Technology Program and DERP-FUDS encourage the development of innovative technology that has the potential to reduce the clean-up cost and ensure the decontamination is completely effective. Advancements in UXO detection and discrimination technologies are necessary to support the operation, restoration, and transfer of the DoD's ranges. The technology being demonstrated falls into this category.

This project is primarily motivated by the desire to create a more efficient UXO detection sensor technology that will deliver a high probability of detection and low false alarm rate and which is suitable for application in all geological and terrain conditions. In particular, this project and demonstration addresses the requirement to increase detection performance through the simultaneous acquisition of the two major types of sensor data, providing for great flexibility in deriving an optimal discrimination capability. Ultimately, it is hoped that the application of this technology will in fact lead to reduced clean-up costs as well as effective decontamination.

1.4. Stakeholder/End-User Issues

Stakeholders and End-Users are interested in knowing their contaminated land has been completely decontaminated. To some extent, they are relying on the detailed and informed scrutiny of regulators and the professionalism of contractors to do the job to the highest possible standard, which, in many respects, will always be limited by the capability of the available state-of-the-art technology. The Stakeholders and End-Users may even choose to stay remote from such details as the actual technologies being employed to decontaminate the land of interest to them. However, if they do choose to show an interest, and find that the SAM UXO system played a role, the results of this demonstration will be readily available to them so they can determine for themselves the suitability of this technology.

The publicly available final report of this demonstration will document details of the technology itself, the effort undertaken in its development and trials, data acquisition efficiency, detection performance (probability of detection and false alarm rate) and suitability of the technology for use in a range of terrain conditions including some that may be considered adverse. They will find that the demonstrations aimed to define the performance and limitations of the SAM UXO system so that its future application could be specified with knowledge that it is an appropriate and defensible technology for the task.

The experience gained from this demonstration and the subsequent reporting will provide end-users with an understanding of the technical, logistical, and financial impact of the SAM UXO system in the environments experienced at these sites, which can most likely be translated to a similar performance at other sites.

2. Technology

2.1 Technology Description

2.1.1 Basic Principles of the SAM UXO Detection Method

In geophysical terminology, the TFEMI component of the SAM UXO system can be described as a large transmitter loop with a roving receiver. In its present configuration, the large loop can be either 40 m x 40 m or 110 m x 110 m, although in practice any size up to 150 m x 150 m is feasible for ordnance applications. The 40 m loop is probably the largest that should be used for detecting smaller sized targets, say < 40 mm diameter. A so-called roving receiver is one that is moved about inside a large loop, and in this case covering the survey area in a systematic manner as a series of parallel straight line traverses. Figure 1 illustrates the basic field layout. The SAM receiver is a specialized, purpose-designed magnetometer (the TM-6) that measures the spatially varying earth magnetic field (TMI) as per normal. The SAM receiver is also capable of simultaneously measuring the time-varying induction field (TFEMI) created by the large wire loop which is connected to a specialized high powered transmitter referred to as the MPTX.

The basic principle being employed is analogous to frequency modulation (the widely used technique in radio-wave transmission and communications) in the sense that the earth's magnetic field is acting like a carrier-wave and is being modulated by the TFEMI information which in the frequency spectrum is quite distinct from the TMI information. The demodulation process, which aims to separate out these two different signals, is undertaken in software after the data has been recorded and later geo-referenced in the pre-processing stage. In this case though, both the modulating (MPTX primary field) and modulated (earth field) signals are magnetic fields rather than the electric fields normally used in communications.

Conventional EM methods use a coil to detect the time rate of change of the induction field as a time varying voltage (referred to as the dB/dt field in mathematical terms). However, the TM-6 magnetometer directly measures the time-varying secondary magnetic field (referred to as the B-field) that may represent a target response to excitation from the original primary field transmitted via the wire loop. The target response is typically a power law/exponential decay that has a characteristic similar to the conventional signals measured by the conventional EM instruments such as the Geonics EM-63 and Zonge nanoTEM. The actual differences between the dB/dt and B-field signals are such that there are many advantages in measuring the B-field response in the specific case of ordnance detection. The most important of these are the fact that any decaying B-field will span a lower range of amplitude values (less dynamic range), and significant information about the targets is present in the late-time portion, which has an inherently higher gain in the case of the B-field. Both of these factors are of great significance to any receiver design aiming to maximize the SNR of a target response.

Because the representation of the secondary magnetic field, that the TM-6 measures, is quite different, we always use the term 'TFEMI' throughout this document to reinforce the fact that we are measuring something quite different to the conventional detectors. We also use the term TFEMI to emphasize the fact that we are measuring the total field and not the component fields that the other instruments are measuring.

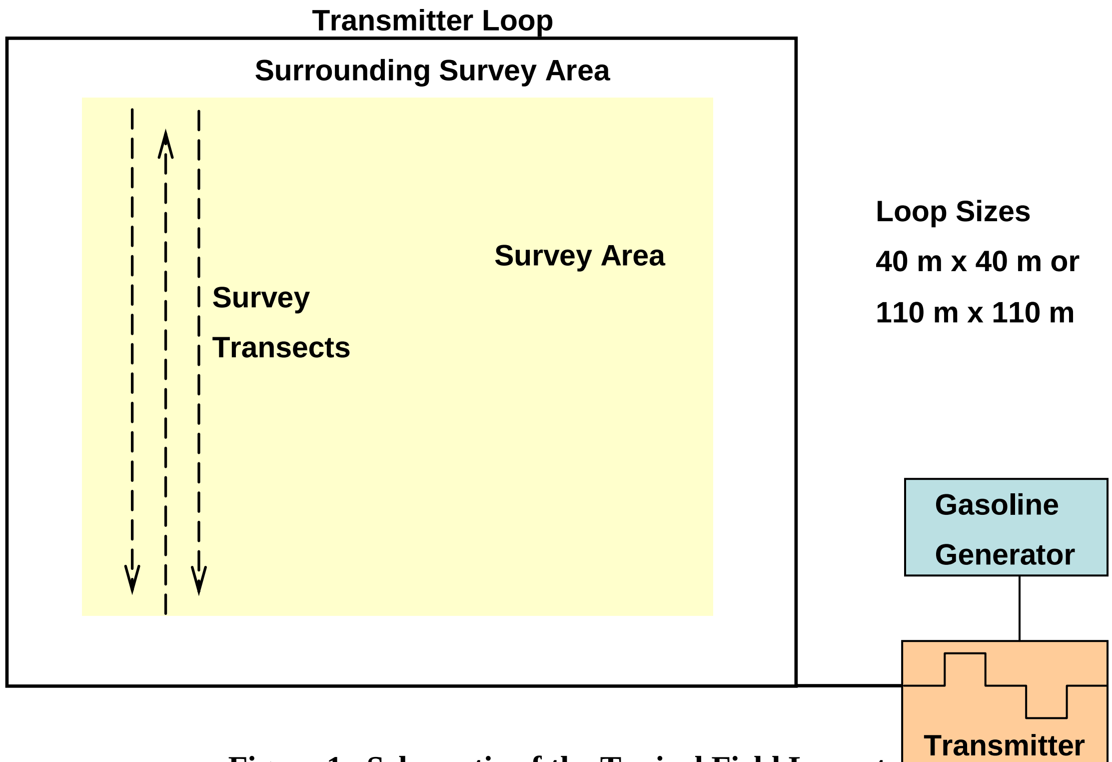


Figure 1 Schematic of the Typical Field Layout

Close-up of the TM-6 magnetometer and the hand-held computer. The backpack also carries the battery power supply, speaker, GPS receiver, radio modem and radio antenna.

Figure 2 TM-6 Backpack

Figure 3 Quad Sensor Array

One of the two data collection methods with two operators traversing inside the loop, one carrying an array of four magnetometer sensors, the other carrying the TM-6 magnetometer (in a backpack) with the handheld user-interface computer in his hand.

Figure 4 Quad Sensor Trolley

The second data collection method replaces the handheld sensor array with a three-wheeled trolley (non-metal) which is the preferred approach if the ground conditions are suitable.

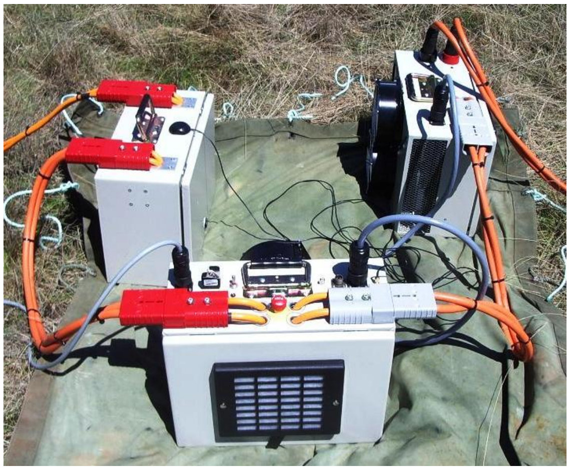
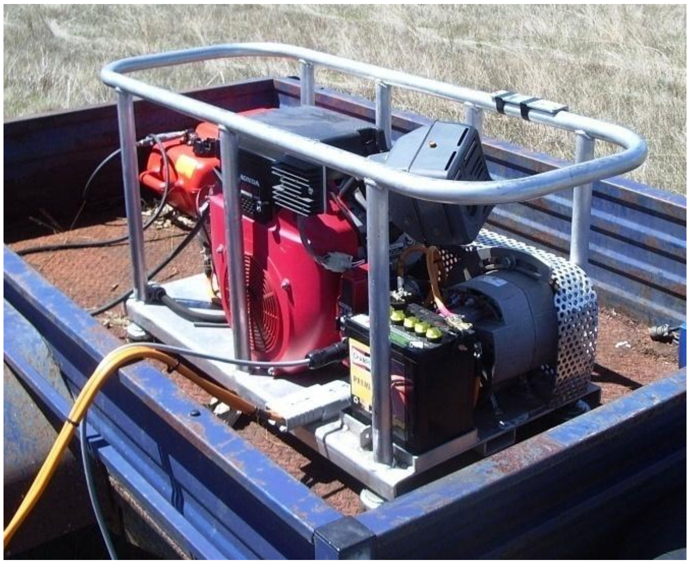


Figure 5 The MPTX Transmitter

The MPTX transmitter is composed of three separate modules, connected with heavy (high current) cable. Note the large cooling fans on two of the modules.



The generator is a gasoline powered engine driving two truck alternators, and is mounted on a trailer, cart or pick-up.

Figure 6   Electrical Generator

The MPTX transmitter generates a bipolar waveform typically with a 50% duty cycle that energizes the ground in the vicinity of the loop with a vertical magnetic field, changing the direction of this induced field at the rate of about 30 times per second (if for example the transmitter frequency is set to 15 Hz). A bipolar waveform is one that causes the current to flow through the wire loop in alternating directions each cycle, illustrated in Figure 7 as the positive and negative parts of the square wave. A 50 % duty cycle means the current is only switched on for 50 % of the time. Therefore the induced field will only be present 50 % of the time (referred to as the 'on-time'). The other 50 % of the time has no induced field (the 'off-time') and that is when the secondary field responses from targets in the ground are measured.

The above description can be applied to any time domain EM system, however the SAM UXO system is unique. Both the induced field in the on-time and any secondary fields present during the off-time are measured by a magnetometer that cannot separate them from their combination with the normal earth spatial magnetic field (i.e. the earth field has been modulated). Separation of the components is only possible in processing because they are measured by a magnetometer that is capable of properly sampling the higher frequency modulating waveform related to the EM induction, as depicted in Figure 8(A). Note that Figure 7 represents a time scale of 0.1 seconds whereas Figure 8(A) extends over a 12 second period.

The other parts of Figure 8 show how the two parameters (TMI and TFEMI) can be easily separated (or demodulated).

- **(A)** The raw SAM data showing the TMI anomaly (with a baseline at about 55000 nT and a peak of 58500 nT at about 19 secs on the time scale) which can be clearly seen with the square wave TFEMI component superimposed on top of it.
- **(B)** The raw data is high-pass filtered to produce the waveform depicted in (B) now with a baseline of zero nT, and with the positive and negative peaks of the square wave ranging from 4000 nT to -4000 nT. In this case the time scale has been reduced down to 2 seconds, spanning the 18 to 20 second portion of (A).

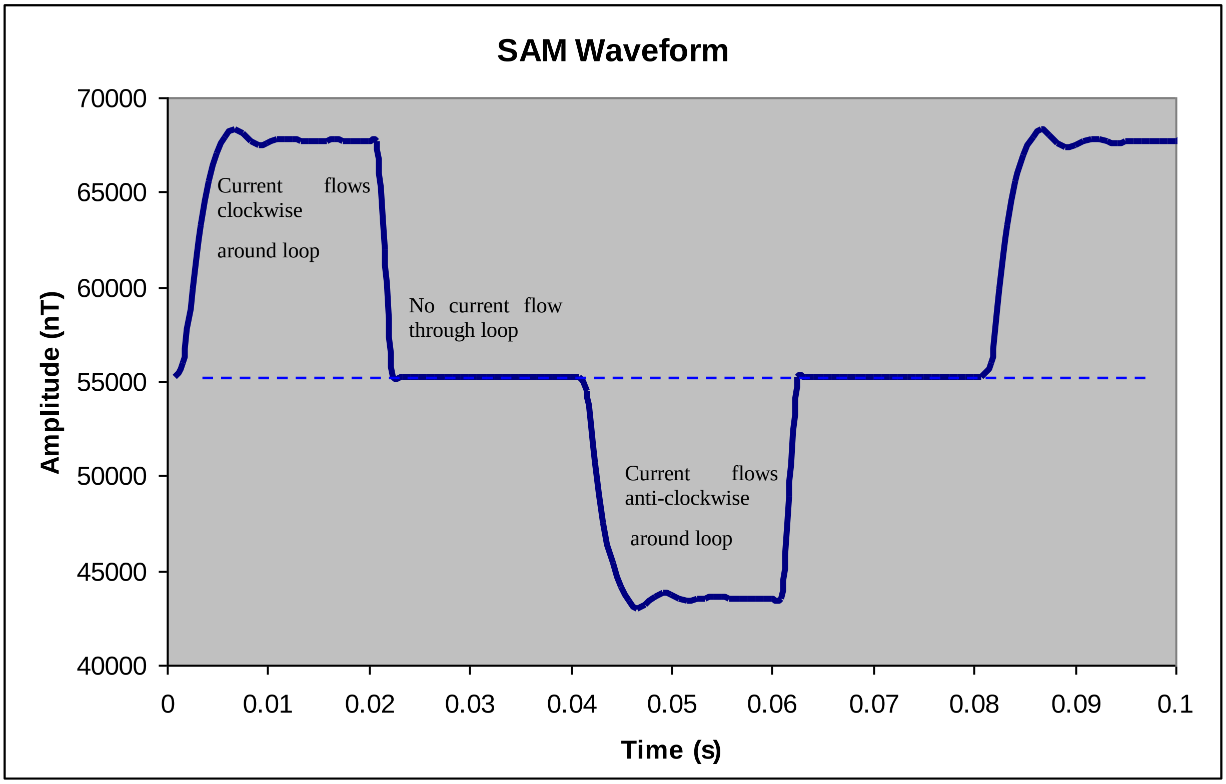
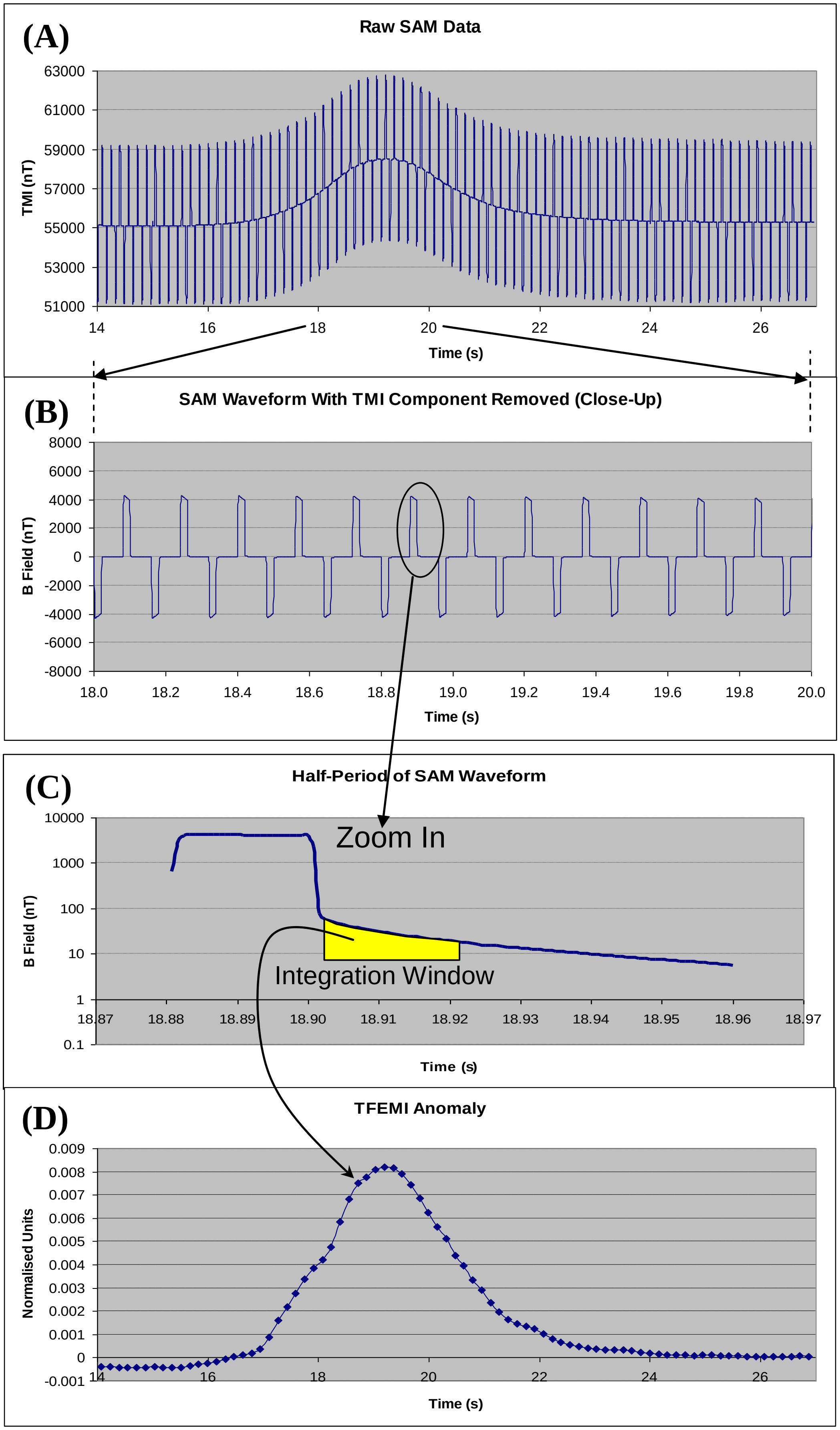


Figure 7 Typical SAM Waveform

(C) One of the positive halves of the square wave (with a 25 % duty cycle) has been expanded on a log scale to highlight the decay of the secondary field representing the target response. When the transmitter is shut-off very quickly, the flat on-time at 4000 nT ramps down over an interval typically between 50 – 100 µs and the anomalous response starts to decay from a peak of about 80 nT. A portion of the decay is selected and averaged, then divided by the primary field value to produce the normalized value which is then represented by a single point on the curve in Figure 8(D).

(D) The TFEMI anomaly is a dipole, with a slight low on the south side, extending over the 12 second period. In practice, each point on the anomaly curve is typically the resultant from the stacking or averaging of 16 half-periods. Unlike output from say the EM-61 which represents a single vertical component, the TFEMI anomaly is the total field, with a contribution from all three components. As such, it is a result that is independent of sensor orientation, which is an important advantage in rugged terrain.

(E) The TMI anomaly is obtained by simply low-pass filtering the raw waveform and it is apparent that the TMI and TFEMI anomalies are very similar, in this case, apart from the scale of their amplitudes.


(A)
Raw SAM Data
TMI (nT)
Time (s)
(B)
SAM Waveform With TMI Component Removed (Close-Up)
B Field (nT)
Time (s)
(C)
Half-Period of SAM Waveform
Zoom In
Integration Window
B Field (nT)
Time (s)
(D)
TFEMI Anomaly
Normalised Units
Time (s)

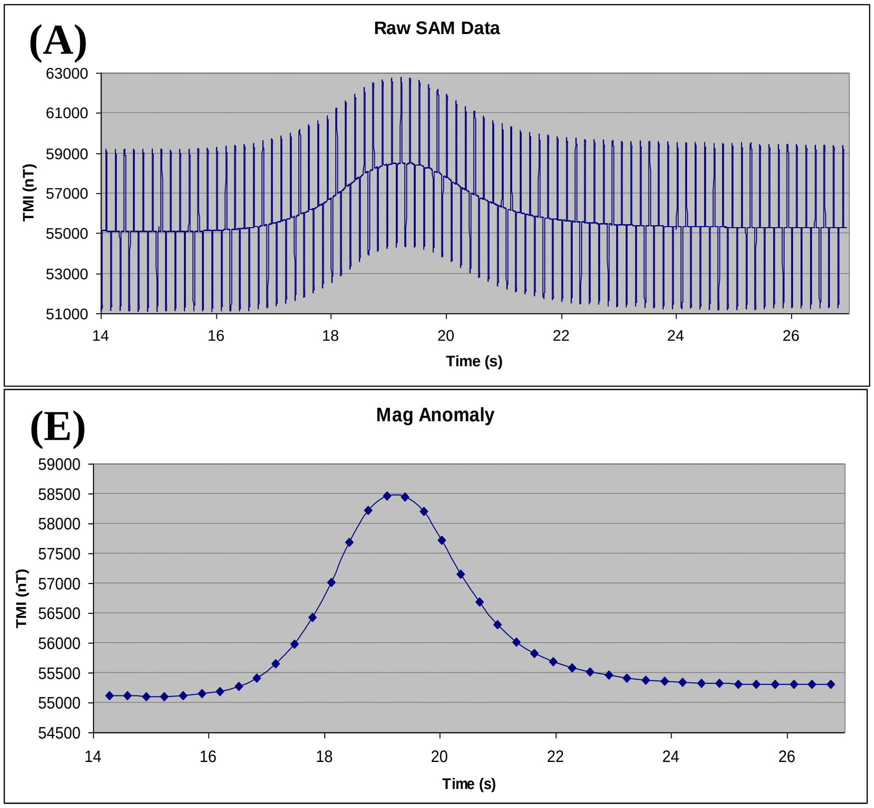


Figure 8 SAM Data Processing Sequence

2.1.2 SAM UXO System Components

Magnetometer Sensors

The usual configuration of the SAM UXO system uses four Geometrics G-822AS cesium vapor sensors, positioned in a line at right angles to the survey direction and spaced 0.375 m apart, resulting in a 1.5 m swath width. To date these sensors have been found to be quite suitable for the UXO detection application, although there are two features of the sensors that require careful management and adoption of certain practices in field operations. These two features relate to its operating range and operating zones. According to the manufacturer's specification, these sensors can measure magnetic fields within the range 20,000 to 100,000 nT. Furthermore, the measured magnetic field vector must fall within a zone that makes an angle greater than 6° from the sensor's equator, and 6° away from its long axis (or poles). In middle latitudes such as Australia and the USA, this usually means the sensor must be orientated vertically for normal surveying. If either of these conditions is exceeded, the magnetometer output is not intelligible (referred to as sensor drop-out).

In normal magnetic field measurement applications, values outside this range would be rarely found, however in the case of the SAM UXO system it is an issue that has to be managed. The MPTX transmitter generates a magnetic field that is added to the earth field as a vector. Problems with the data relating to these two sensor features generally only occur at the start and end of lines, where the sensor is closest to the transmitter loop and the combined earth and induced fields can exceed these limits. This problem is solved by ensuring the transmitter loop is positioned on the ground well away from the survey area. In most situations a buffer zone of about 5 m can be maintained, and this has been found to be adequate in practice.

Magnetometer Electronics Module

The magnetometer referred to as the TM-6 was developed and built by G-tek/GapGeo with support from ERDC and EQT. Its main features include:

1. Inputs the Larmor signal from up to four magnetic sensors simultaneously.
2. Derives magnetic field measurements from each sensor at sampling rates of 1200, 2400, 4800 or 9600 samples per second (sps) using frequency-counting principles.
3. Measurements are acquired at equal time intervals that are synchronized to GPS time.
4. The RMS noise levels for each sample rate are 0.02, 0.04, 0.12, 0.58 nT for 1200, 2400, 4800 and 9600 sps respectively.
5. Inputs and logs position and time information including the 1 pulse per second (pps) strobe from the DGPS receiver.
6. Time-stamps are applied to all inputs with a 6 decimal precision (1 µs), synchronized to GPS time.
7. Magnetometer, DGPS receiver, radio receiver and batteries to power a quad-sensor array for typically 2 hours are carried in a back-pack of total weight approximately 8 kg (Figure 2).
8. Has a graphical user-interface implemented on a Hand-Held PC (HHPC).

Magnetometer User Interface

The TM-6 magnetometer user-interface is based around Windows Mobile (Ver. 5 and 6) and earlier operating systems such as Pocket PC 2003, which can be run on hand-held personal computers (HHPC's) such as the HP Ipaq or the TDS Nomad. The program provides the means to completely configure the TM-6 hardware by setting all of the required logging options and providing for the input of survey information that is to be permanently stored in data file headers. It also provides a means of navigation using the DGPS to locate the operator position and path along pre-defined tracks, although this feature is not used with UXO applications.

Data Positioning / Differential GPS

The TM-6 magnetometer system has been designed to interface with a variety of positioning methods although the main one is DGPS. There is a requirement when using the magnetometer for SAM applications that access must be available to GPS time at least once every 30 minutes in order to maintain precise clock synchronization. If tree coverage disrupts the satellite signals to the extent that DGPS is not practical for positioning, it still needs to be exposed to the satellites occasionally to maintain the time synchronization. In such situations where DGPS cannot be used for positioning, a cotton thread based odometer system provides a good alternative. Newer technologies such as the robotic total station (RTS) have also been successfully trialed at the APG wooded area.

An Ashtech Z-Xtreme RTK DGPS system was used at APG2 and a Novatel OEM4 system at YPG. The DGPS position point (based on the location of the antenna) was on the centerline of the array but offset back from the line of sensors as shown in Figure 4 to minimize magnetic and electromagnetic interference. The absolute error in sensor data positioning relating to heading, pitch and roll could have been as much as ±30 cm appearing as systematic stretches rather than random jumps. As the sensor array is rigid and the relative position of each of the four sensors in the array is fixed, sample interval distance error within the array perpendicular to the direction of survey is non-existent. Sample interval distance error along the line relates to the rate at which the absolute error is changing and is estimated to be no more than 5% of the along-line sample interval, or just a few mm.

Sensor Frame

Figure 3 illustrates the sensor frame with two operators where the second operator carries the instrument pack containing the TM-6, the DGPS and batteries, and standing far enough back so as to be undetectable by the sensors. The four sensors are mounted on a hand-held, non-metallic frame in a balanced manner such that minimal effort is required to keep them in their correct position relative to the traverse line. The elevation of the sensors above ground and the separation between sensors are adjustable to meet the required survey specification. The weight of a quad-sensor array is typically 10 kg.

The sensor frame is ideal for use in undulating to rough terrain, or if the operator is required to maneuver around obstacles. At all times, the operator aims to keep the frame as level as possible to minimize position error due to heading, pitch and roll motion.

Sensor Trolley

The sensor trolley (illustrated in Figure 4) is constructed wholly from non-metallic components and is intended for use in flat to gently undulating terrain with few or no obstacles. One advantage of the trolley is that it allows the operator to concentrate more on maintaining a straight line traverse since less effort is required to try to keep the sensor frame level. Without a trolley, it is quite difficult to keep the frame parallel to the ground at all times. The sensor motion with the trolley is somewhat different to that of the frame. The wheels are rigidly attached to the trolley so undulations in the ground will be transferred. However, it is currently the view that these will be less than when the frame is hand carried.

Batteries

Two types of batteries are generally used with the SAM UXO system, lead acid gel cells (also known as sealed lead acid or SLA) and lithium ion. The lead acid battery pack consists of 5 x 6 V 4.5 amp-hr batteries, weighing 4 kg. The Li-Ion pack consists of 2 x 15 V 7.5 amp-hr cells, weighing 1.5 kg. Although there is an obvious capacity and weight advantage with the lithium batteries, they are much more expensive and are classified as hazardous goods and this restricts their transport to road freight.

Transmitter Loop

In the present system configuration, two loop sizes are being used, 40 m x 40 m and 110 m x 110 m. Both are linked to the transmitter with a 20 m feeder cable. Each loop is made up of 4 equal lengths, with special ‘quick-release’ connectors at each corner. In practice it has been found to be quite easy to move the loops to the next grid by moving them one side at a time. On average, crews will spend 40% of their time moving the loops and 60 % of their time surveying the area within each loop setup.

The two transmitter loop options consist of multi-stranded copper wire with specifications summarized in Table 1:

Table 1 Summary of Loop Properties

Loop Size (m)	40 x 40	110 x 110
Wire Outside Diameter (mm)	13	14
Wire Area (mm^2)	35	50
Wire Resistance μΩ/m @ 20 °C	536	379
Wire Resistance μΩ /m @ 60 °C	620	439
Total Loop Resistance (mΩ) @ 20 °C	86	167
Total Loop Resistance (mΩ) @ 60 °C	99	193
Wire Weight gm/m	430	600
Loop Weight / Cut Length (kg)	17.2	66
Loop Inductance (μH)	250	700

MPTX Transmitter (Current Source)

The new MPTX transmitter provides a constant current that energizes the survey area with the primary magnetic field. As illustrated in Figure 7, the transmitted waveform is a bipolar square-wave that can be set to either 25 % or 50 % duty cycle. The frequencies can be selected from 6.25, 12.5 and 25 Hz (Australia) or 7.5, 15 and 30 Hz (USA). The combination of frequency and duty cycle determine the on-time, off-time and maximum possible current. These frequencies have been selected because they are all sub-multiples of the mains power-line frequencies, and this simplifies the task of removing this source of interference from the data through averaging techniques. The onset of each waveform period is synchronized to GPS time, to match the time intervals in the magnetometer and the time-stamping of the data record.

The transmitter options are selected in the User-Interface and the choice for a given survey will depend on survey objectives, site specific conditions and location. Table 2 summarizes two of the options that might be considered for surveys in the USA, to highlight the compromises involved in the selection.

Table 2 Example of Transmitter Options

Frequency (Hz)	Duty Cycle (%)	On-Time (ms)	Off-Time (ms)	Current (A)	Primary Field (nT)
7.5	25	16.7	50.0	400	11137
15	50	16.7	16.7	300	8352

The main compromise is between primary field strength (and therefore target SNR) and spatial sampling frequency. The lower transmitter frequency allows a choice of a lower duty cycle while still maintaining sufficient on-time, which in turn allows a higher current resulting in the higher primary field. However the lower transmitter frequency also means fewer data points per meter, for the same survey speed. One method of maintaining the same spatial frequency would be to halve the number of half-period stacks in the case of the lower transmitter frequency.

The MPTX needs to be located 20 m from the corner of the loop, and it is usually positioned on the field in a location that only requires it to be moved after surveying two adjacent loop positions.

Figure 5 illustrates the MPTX transmitter, comprising three modules:

1. Controller (control circuits, computer, data logger, GPS receiver and on/off switches)
2. Transmitter (power transistors and constant current devices)
3. Capacitors (large capacitors that allow the generator to be under constant load by absorbing power during the off-time)

The MPTX can be operated in three different modes, described as follows:

1. Constant Current: adjustable in 10 amp steps from 10 to 400 amps, providing a flat current during the on-time once the exponential rise has finished. In this mode the current is extremely stable, with a variation between successive pulses significantly less than 1 in 200 (<<0.5%).
2. Controlled Current: the alternator output is adjusted to maintain a consistent current at the point just at the end of the on-time, before the current turn-off. The current during the on-time will have a slow fall after the initial exponential rise, and will be less stable than the constant current mode.
3. Constant Voltage: the alternator output is adjusted to maintain a constant voltage at the MPTX output terminals. This mode will be useful when driving higher resistance loops or when requiring the maximum possible current.

The MPTX is controlled by microcontrollers and the only manual switches are power on/off to the computer-based control circuit and a large safety switch for emergency shut-down of the system. A number of sensors are incorporated into the controller to provide an independent measurement of important system parameters such as loop resistance, voltage, current and temperature. These measurements are continuously analyzed by an on-board computer, checking for over-temperature, over-voltage, over-current, unregulated current, low alternator output, high loop resistance, high headroom error, output resistance change and GPS dropout. Any of these conditions being met will lead to an automatic system shutdown.

The unit also includes a data logger using a Secure Digital (SD) memory card to record data on a continuous basis. This provides a complete record of the variation in all of the important measured parameters and the actual output current. A simple command protocol is used to allow communications between the MPTX and the user-interface running on a HHPC.

Transmitter User Interface

The MPTX transmitter is controlled by software running under Windows Mobile 6. All configuration options are set in the graphical user interface and transmitted to the controller module. Figure 9 illustrates the three main screens used to both control the instrument and provide the operator with required information. The HHPC communicates with the controller module by direct serial cable link or Bluetooth so the MPTX can be controlled remotely (usually by the TM-6 operator working inside the grid). Information is fed back to the HHPC to keep the operator informed of such parameters as loop resistance, temperature inside the cases, output voltage and current. This information is updated once per second, and it is possible to view a graphic plot of the waveform shape, to check that the actual transmitted waveform has the desired characteristics. This data is measured using independent current sensors which are the last stage in the transmitter output.

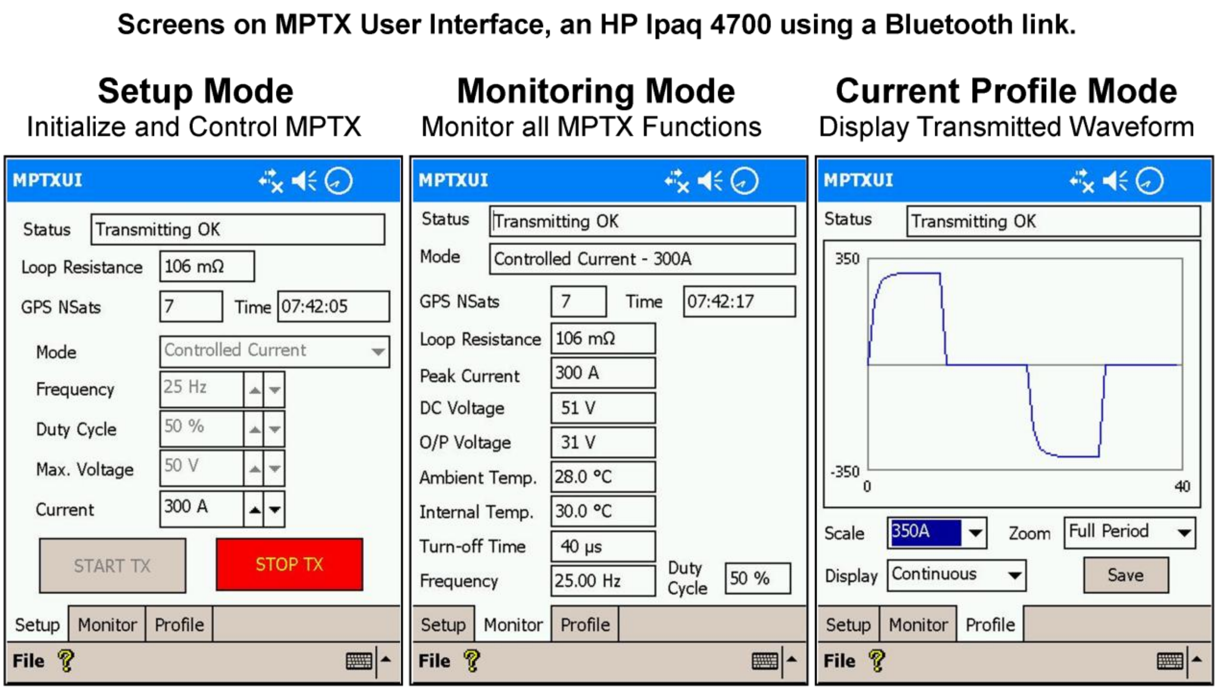


Figure 9 MPTX Graphical User Interface

Generator

The electrical generator (illustrated in Figure 6) is comprised off a Honda GX670 twin cylinder gasoline powered engine that drives two Leece-Neville truck alternators, capable of producing a total output power of about 9500 W. Voltage rectifiers are located inside the alternator casings to convert the alternating current to direct current which is then delivered to the MPTX transmitter via a short low-resistance cable.

The generator had been thoroughly tested prior to deployment to the USA. After shakedown trials it was decided that better performance was achievable by changing the belt drive system.

Further tests confirmed this. The new belt system reduced vibration and cleared away some occasional vibration related, system glitches known to have caused system shutdowns.

Cable Reels

Cables are transported between sites on specially-built cable reels. The reels are also used at the beginning of the survey to lay the cables out at their first position. Once the survey has commenced, the cables are hand-dragged to each new grid position. At the end of the survey, they are rolled back onto their reels.

The total weight of the complete cable set, including reels, is approximately 500 kg. This includes the 40 m x 40 m loop, the 110 m x 110 m loop and the 20 m feeder cable. Both loop sizes consist of four reels each, with 40 m and 110 m of cable on each reel respectively.

Transmitter/Generator Trailer

The MPTX transmitter and generator were mounted on a small trailer and moved around the demonstration sites using a small ATV vehicle such as a Polaris Ranger.

2.1.3 Survey Procedure

1. Setup the DGPS base station at the nearest surveyed monument.
2. Prepare the survey site by surveying in pin flags at grid corners (30 m x 30 m) using the TM-6 in a special navigation mode where all pin flag locations are pre-loaded and easily relocated using the navigation software.
3. At the first grid to be surveyed, lay out non-metallic survey chains (measuring tapes) along the grid ends (usually the northern and southern boundaries) to mark out two lines defining the start and finish points of each individual traverse. Position visual markers (orange plastic cones) on the survey chains to mark the start and end of the first traverse line, usually the westernmost edge.
4. Lay out the wire loop as a square, ensuring the sides are straight and the wire is at least 5 m away from the boundary of the grid survey area, all the way around. Connect all four wire segments and the loop feeder.
5. Position the trailer with generator and transmitter at a point about 20 m off the grid, halfway between the current grid and the next grid.
6. Set up the transmitter with connecting cables between the three modules, the loop feeder, and the generator. Set up GPS antenna and ensure that the MPTX user-interface (HHPC) is handy.
7. Prepare the TM-6 and sensors for survey and temporarily position the sensors, placing them on the ground at the start of the first line (effectively the local origin of the grid).
8. Check generator fluid levels and start engine, keeping throttle at the idle point.
9. Power up the transmitter controller (with no power going into the wire loop at this point).
10. Turn on the HHPC, start the MPTXUi program, select BlueTooth for the data link.
11. Check loop resistance on the user-interface and program the transmitter with the required configuration.

12. Adjust engine throttle to full power and connect power to the loop (software switch on the user-interface), check for error messages on the user-interface and wait for power to reach full operating level.
13. With the equipment still on the ground, check that the magnetometer is functioning correctly.
14. With the sensors stationary at the local origin, record two minutes of data (QC check).
15. The two operators would now pick up TM-6 and sensors and begin traversing the grid.
16. Grid is surveyed as a series of parallel straight line traverses, spaced 1.5 m apart, starting at point zero on the polychain and finishing at point 30.0 m. At the completion of each line the sighters are moved to a new position on the chain marking the next line. Each grid will contain 21 surveyed lines, and the last line of each grid will correspond to the first line of the next, to provide redundancy and assist with 'grid stitching' (joining grids into a single map).
17. After grid has been completed, switch off power to the loop, return engine throttle to idle, exit the MPTXUi program and turn off the HHPC, switch off the power to the Controller and turn off the generator.
18. Survey the location of the loop laid out on the ground surrounding the survey area that has just been completed, using the TM-6 and sensor array with the DGPS.
19. Position the TM-6 at the next survey grid and move the 4 loop segments to new positions surrounding this next grid.
20. Start the next grid as per the previous grid.
21. At completion of days work, turn off DGPS base station, shut down all other systems, leave loops in place on ground or in position ready for next grid on following day, repackage equipment and store away for overnight break, put all batteries on charge, back up data onto additional storage media, complete any necessary paperwork, and depart survey site.

2.1.4 Quality Control

Quality control measures fall into 4 categories:

1. Undertake certain field procedures prior to actual surveys, providing real-time indicators as well as data for later analysis.
2. Have constant monitoring of important system parameters and automatic recording of quality indicators.
3. Embed detailed survey information into the data record for later review.
4. Provide for alarms built into operating system software to sound audible warnings to operators to minimize time wasted collecting bad data if the system is not functioning correctly.

Daily Checks

1. Power on and equipment warm-up, check magnetic sensor signal levels and background noise, GPS signal quality and other system checks such as TM-6 timing calibration, PPS polarity, transmitter loop polarity, GPS time and date and other configuration parameters.
2. Personnel test for presence of any metal in clothing.
3. Vibration test of cables and connections while checking system function.
4. Check measurement of DGPS antenna position relative to sensors, and sensor alignment
5. Check that the sensors are connected to their correct cables using the TM-6. An audio tone should sound as a small target is placed near each sensor.
6. Positional accuracy check. Move sensor array (with DGPS antenna) over a known position and check that the reported location matches the written record.
7. Perform 'Clover Leaf' (forward/reverse lines in a cross) over a known target at a known position using same location each day.
8. Static background noise test - record data with sensor stationary for 2 minutes at same location each day.

Checks at Every Survey Grid

1. Once the transmitter is running and with the sensors stationary on the ground at the local origin of the grid (the start of the first line), collect two minutes of data prior to the commencement of the grid survey.
2. The first and last line of each grid will be surveyed twice and are therefore able to be used as a 'repeat line' test, where later the data is checked to make sure the profiles are the same. That is, in the case of adjacent grids, the last line that is surveyed on one grid will correspond to the first line being surveyed next.

Start of Project Checks

1. DGPS positioning test – check the location of an alternative monument using DGPS and compare measured coordinates with published coordinates.
2. Static background noise test - record data with sensor stationary for 10 minutes at several locations across the site. Compare the results in terms of RMS noise as well as their amplitude spectral densities.
3. Azimuthal test – check the sensors for magnetic field dropout by changing their orientation off the vertical.
4. 6 line test – a single line is measured out about 30 m with a target placed half-way along the line. Forward and reverse lines are repeated at different speeds, and with/without the target present.
5. Octant test - check for heading error by traversing across a target on the ground in the pattern of a cross (×) and plus (+). i.e. 8 lines total, 4 different lines covered twice in -reversed directions. The target is placed at the centre of the pattern.

2.1.5 Data Storage, Processing and Management

The TM-6 has an in-built CompactFlash card reader, and typically uses a high quality (industrial grade with high temperature rating) 1 GB CompactFlash card as the main data storage media. This allows rapid transfer of data to a laptop or office PC, and provides the high capacity needed by the SAM UXO system. If data is collected with a sample rate of 4800 samples per second on a 30 m x 30 m grid, each data file will be about 55 MB. The system has been in use now for more than 5 years and has proven to be extremely reliable.

Data is stored in a proprietary binary format, and software has been developed to convert this to conventional formats after certain pre-processing steps have been performed. The main data processing steps are summarized as follows:

1. Pre-processing - MagPI
   - editing of raw profile data to remove dropouts, spikes and other noise,
   - editing of headers to correct for errors or adding extra survey related information,
   - preliminary viewing of data for QC purposes,
   - removing bad lines from the file if they were repeated,
   - setting up the processing sequence – choosing filter coefficients, stacking parameters (number of stacks and stack overlap), integration and normalization windows,
   - filtering and stacking to produce separate TMI and TFEMI data sets,
   - producing TFEMI profile data by integrating decays, followed by normalization with the primary field strength measured over a small nominated window at the end of the on-time, then re-scaling to give the data a ‘sensible’ number range,
   - producing final TMI profiles with additional down-sampling and low-pass filtering,
   - geo-referencing to assign position coordinates to every processed data point through interpolation of the GPS position data and merging based on the accurate time-stamps,
   - formatting and output of data sets in XYZ format ready for input to Geosoft,
   - Final QC of profiles, selected decays and track plots.
2. Processing – Geosoft
   - viewing profiles of processed data checking anomalies,
   - filtering of lines to remove spikes, DC offsets etc.,
   - gridding the XYZ data to produce a GRD file and then imaging the gridded data as a color map.
3. Processing – MagSys
   - input the GRD file produced by GeoSoft,
   - automatic detection of anomalies based on a nominated threshold level, selecting targets whose amplitude exceeds the set threshold,

- estimation of TMI induced magnetic dipole and XYZ position of target,
- estimation of other anomaly parameters (FWHH, peak amplitude, RMS noise level)

4. Processing – UXOLab
   - estimation of TFEMI induced dipole moment

5. Processing – MagPI/Matlab
   - extraction of anomaly profiles and decays corresponding to peak amplitudes into a single database file (Excel compatible)
   - modeling of TFEMI decay as a sum of two exponentials
6. Interpretation – Excel
   - consolidation of data and derived target parameters from previous steps into a single excel spreadsheet 'database',
   - statistical analysis of data, leading to discrimination,
   - presentation of results for submission as spreadsheets.

2.1.6 Key Design Criteria

The original idea of the SAM system came about through G-Tek/GapGeo's involvement in minerals exploration in Australia. Many years of research went into this early development, including trials that proved the idea of SAM TFEMI being useful for UXO detection. Although these early trials demonstrated the feasibility, the technology at that time was inadequate for commercial application. Sufficient experience was gained to be able to develop a good functional specification of a new SAM UXO detection system, which lead to the development of the TM-6. Subsequent experience with that instrument as described in this report then lead to the development of the purpose-built MPTX. Key design criteria for these two developments are outlined as follow:

MPTX Transmitter

- large area, low resistance and low inductance loop,
- high current and low voltage (keep external voltage < 80 V for safety reasons),
- bipolar waveform essential for separation of TMI and TFEMI components,
- waveform synchronized to GPS time,
- very fast current turn-off to ensure good high frequency content in driving pulse,
- stable controlled current output (less than 0.5% variation),
- easily programmable waveform configuration allowing a range of duty cycles and frequencies (providing a range of on-time/off-time options)
- ability to run all day in all weather conditions,
- time-domain only (no 100% duty cycle option),

- reasonably portable (utility vehicle),
- generator constructed with off-the shelf and readily available components (engine and alternators),
- full software control of hardware (minimal switches on control panel),
- high level of system monitoring (voltage, current, temperature, loop resistance) and safety measures (automated shut-down etc),
- continuous recording of measured parameters.

TM-6 Magnetometer

- high sampling frequency,
- low quantization noise,
- capable of sampling up to 4 magnetic sensors simultaneously,
- accurate time stamping of data synchronized to GPS time,
- large field data storage capability with easy transfer to office PC,
- easily accommodate logging of other devices through serial input,
- graphical user interface,
- audible warning tones sound if error conditions, such as reduced DGPS quality, occur (related to reduced satellite coverage),
- audio linked to magnetic sensor input to provide tonal variation with signal amplitude change,
- navigation (e.g. for establishing grids or navigating to dig locations),
- positioning systems to include GPS, cotton odometer and RTS,
- able to be carried in a backpack,
- capable of operation in ambient temperature extremes.

2.1.7 Chronological Summary of the Development

A chronological summary of the development is summarized in Table 3.

Table 3 Chronological Summary of the Development

Date	Location	Task
Jan - Apr 2003	Armidale, NSW, Australia	Design and build TM-6 prototypes,
May – Jun 2003	Armidale, NSW, Australia	Test TM-6 in lab for compliance with functional and design specifications
Jul 4 - 7 2003	Newholme, Armidale, NSW, Australia	First field trial at seeded site with TM-6 and Zonge GGT-10 transmitter
Jul 8 - 11 2003	Woodland Hill, Armidale, NSW, Australia	Further testing of TM-6/GGT-10 using test stand and large range of ordnance under carefully controlled conditions
Jul 14 - 30 2003	Limestone Hills, Helena, MT	First US trial of TM-6/GGT-10 at a live site
Aug 5 - 7 2003	McKinley Range, Huntsville, AL	Trial at a seeded site
Nov 18 - 21 2003	Woodland Hill	Trial of TM-6 to compare GGT-10 with alternative system (PosTEM) to test design principles of a future MPTX
Apr 28 - May 8 2004	Waikoloa, HI	Trial of TM-6/GGT-10 at live and seeded sites
May 24 - Jun 5 2004	Aberdeen Proving Ground, MD	1st Trial of TM-6/GGT-10 at Standardized UXO Technology Demonstration Site
Nov - Apr 2005	Adelaide, SA, Australia	Final development of specification, design, construction and assembly, preliminary testing of MPTX laboratory prototype (LP)
May 16 – 30 2005	Adelaide	Full scale bench testing of laboratory prototype
Jul 1 - 5 2005	Newholme	First field trial of MPTX LP at seeded site
Aug - Dec 2005	Brisbane, Qld, Australia	Temporary suspension of project due to company restructuring
Apr 27 - 29 2006	Newholme	New start to project, continuation of MPTX field trial at seeded site with engineering prototype (EP) following further development of hardware/software
May - Sep 2006	Adelaide	Further enhancements to MPTX EP to meet modified specification
Sep 4 - 8 2006	Newholme	Major shake-down test of TM-6/MPTX EP
Nov 12 – 16 2006	Newholme	Trial of system with alternative larger loop, larger targets and broader scale sampling
Jan 29 – 30 2007	Sydney, NSW, Australia	Trial at new seeded site – equipment failure shortened trial.

Feb 15 – 17 2007	Adelaide	Repairs to equipment
March 13 – 19 2007	Armidale	Further modifications and enhancements of system. Full test of system following modifications.
April 2007	Armidale	Final trial of system and full test prior to shipment to USA
June 2007	Aberdeen Proving Ground, MD	1st Trial of TM-6/MPTX at Standardized UXO Technology Demonstration Site
June 2008	Yuma Proving Ground, AZ	2nd Trial of TM-6/MPTX at Standardized UXO Technology Demonstration Site

2.1.8 Potential Applications of the Technology

The following points summarize the potential applications of the technology:

- theoretically the system can be applied to any application currently utilizing time-domain EM induction,
- it is particularly suited to applications in rugged terrain due to the portable nature of the receiver and flexibility with the layout of the large-sized transmitter loop,
- it can be applied to environments with a high level of magnetic geological noise because the two measurements are geo-referenced to the highest possible degree which allows easy recognition of geological false alarms,
- the method is particularly suited to detecting large deep ordnance targets such as those found in aerial bombing ranges,
- the TM-6 can be used just for magnetic surveys alone, and is particularly suited for use in environments with high level of interference from power lines and other infrastructure,
- is particularly suited for helicopter or aircraft surveys because the portable, fast-sampling TM-6 magnetometer permits high spatial sampling frequency even if the instrument is moving fast across the ground, interference from helicopter sources can be easily filtered out and the TM-6 magnetometer has been designed to accept multiple inputs such as laser altimeters and fluxgate magnetometers to determine heading errors etc.

2.2 Technology Development

Introduction

The technology has been tested at a number of different sites, most of them seeded, some live and all together representing a wide range of terrain and geological conditions. Repeated surveys at seeded sites have provided an opportunity to compare different instrument configurations and, in particular, measure improvements due to changes in hardware. The most significant hardware change that has occurred over the course of the project was the development of the purpose-built MPTX transmitter. The two final demonstrations (APG2 and YPG) provided the best opportunity to highlight the success of that development.

Aberdeen Proving Ground May/June 04

The APG1 demonstration was conducted using the TM-6 with the Zonge GGT-10 transmitter, energizing a 38 m x 38 m loop with 8 turns, running a current of 13 amps and producing a primary field strength of about 3000 nT at the centre of the square.

At the start of the demonstration, data was collected over the Calibration Grid with the 8-turn loop surrounding the whole area. Many passes were made trialing a range of operating parameters. These results were analyzed and resulted in the selection of what was considered to be the optimal set of operating parameters that were fixed for the rest of the surveying. Consequently, the transmitter frequency was set to 15 Hz with a 50 % duty cycle and the TM-6 was used with a sampling frequency of 1200 samples per second.

The Blind Grid was surveyed with two adjacent loops. The rest of this site, including the open field, the wooded area (with RTS and cotton odometer navigation) and the moguls, was split up into a pattern of 30 m x 30 m grids, each being covered with a single pass using the same instrument parameters mentioned above.

All of the grids were covered as a series of parallel straight line traverses, with a line spacing of 1.5 m, a sensor height of 0.3 m and sensor separation of 0.375 m (these survey parameters were repeated at the all later trials at APG2 and YPG).

The work was considered to be a success from an operational point of view, testing the methodology, field survey techniques, team work and data processing/interpretation. However, when scored by ATC, the results were generally disappointing. This was attributed to the poor SNR, linked to an under-performing transmitter. At previous trials, using the same transmitter, an output current of 18 amps was achieved. At this trial, the system output level was 13 amps which greatly reduced the primary field strength (as seen in the transmitter comparison in Figure 11). The significance of this lower current output was not fully appreciated at the time.

Figure 10 is presented as an example of a commonly used method of succinctly illustrating detection capability, plotting detected targets according to their buried depth and diameter, but with no reference to their amplitude. In this case, the results summarize the trial over the Blind Grid. The symbols simply indicate whether the items were detected or not, The 11 x Diameter line indicates a standard that is expected to be met for detection equipment, as specified by the USACE.

To some extent, the results were also influenced by the experience of the interpreter. For example, Figure 10 and Table 4 show, after a review and with the knowledge of the truth data, the detection performance in the Blind Grid would have been much better if different selection criteria had been applied. The analysis, summarized in Table 4, categorizes targets not previously considered as hits. The targets indicated by a diamond, in the figure were found to have a distinguishable anomaly that with the benefit of hindsight, should have been included in the list of hits. Some of these were found to be influenced by anomalies from adjacent grids, some were off the mark by a greater radius than what was considered applicable at the time and the others had a low SNR that was thought to be noise. The majority of the missed points with no discernable anomaly were either below the diagonal line or at the smaller diameter end of the scale in Figure 10.

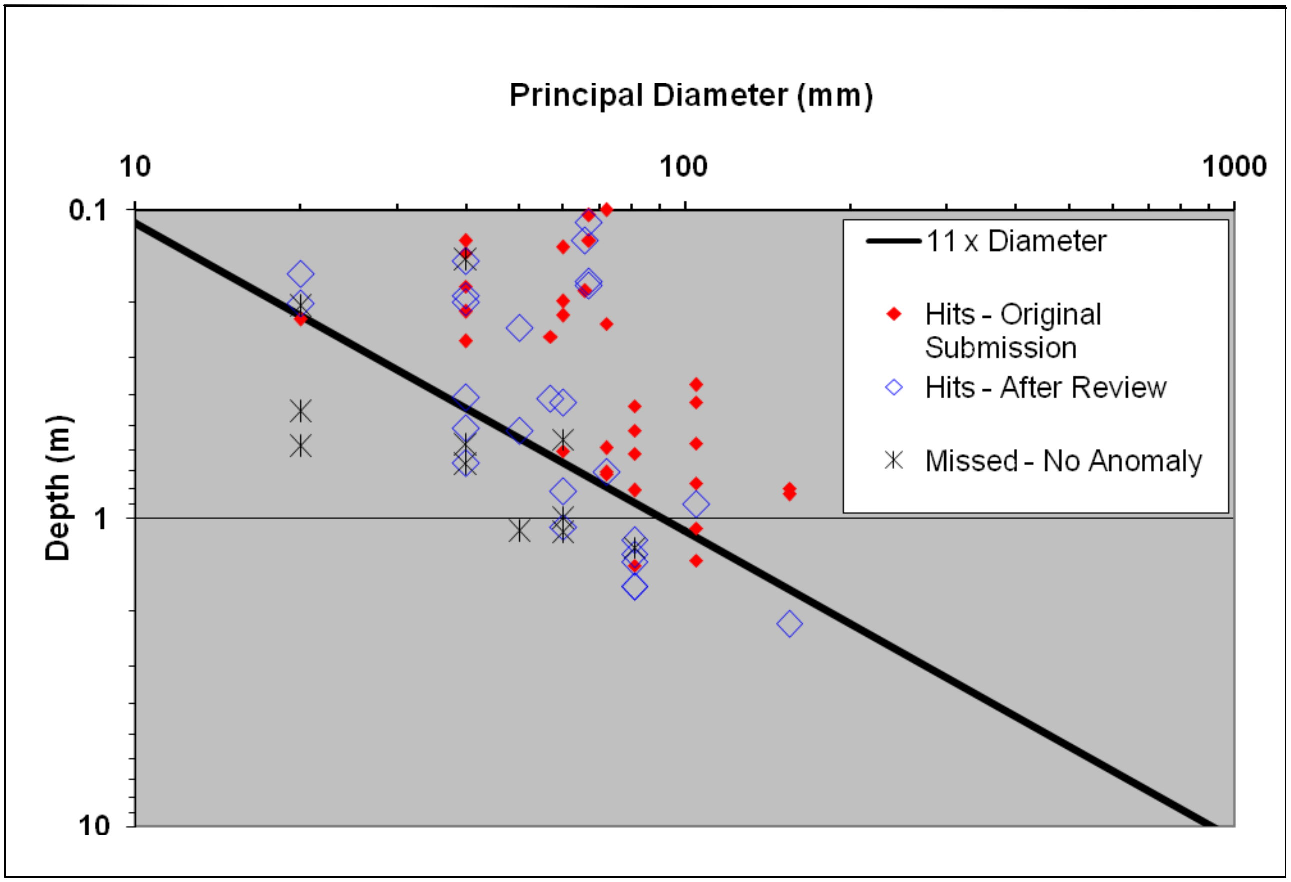


Figure 10 Achievable Detection Depths - APG Blind Grid

Table 4 Summary of APG Blind Grid Results after Review

	Total	Hits	Misses			
			No Anomaly Discernable	Overlap from Adjacent	Off Mark	Low SNR
Ordnance	84	37	12	9	10	16
Clutter	95	67	7	9	4	8
Total	179	104	19	18	14	24

After consideration of the anomalies missed due to being off the mark or having a low SNR, a target figure of $P_d = 0.8$ was considered attainable in the next demonstrations (from Table 4, $P_d = 0.8 = (104+14+24)/179$), especially given that the new MPTX would improve all target SNR's and the rapid transmitter shut-off and subsequent very high dI/dt excitation would also improve detection of the smaller items.

Despite the poor result, the data was considered to be extremely valuable because it provided us with truth data of both ordnance and clutter, which would greatly help the future statistical analysis, once the new data sets had been obtained.

Newholme July 05

Results from this trial were presented at the October 2005 IPR, the 2005 Partners Conference and a specially prepared report submitted to ESTCP on the Newholme work.

The first field trial of the MPTX, in its laboratory prototype form, proved to be extremely encouraging. The system performed at its expected level right from the beginning. The 1 ha Newholme grid was covered in two passes:

(i) nine 33 m x 33 m grids, 4800 samples per second, 12.5 Hz transmitter frequency, 50% duty cycle,

(ii) one 110 m x 110 m grid, 4800 samples per second, 12.5 Hz transmitter frequency, 50% duty cycle.

Figure 11 provides a good indication of the difference between the GGT-10 previously used at Newholme (2003) and APG1 (2004) and the new MPTX used at the first Newholme trial in 2005. The comparison illustrates the different primary field strengths as measured at the centre of the loops. The figure also indicates the loop sizes and number of turns in each case (numbers in brackets). The MPTX (40 x 40 m x 1 turn) example indicates what was used at the final two trials at APG2 and YPG, and the primary field was almost three times more than what had been achieved previously at APG1. Table 5 summarizes some of the current levels and primary field strengths that were attained during the Newholme trial for various configurations.

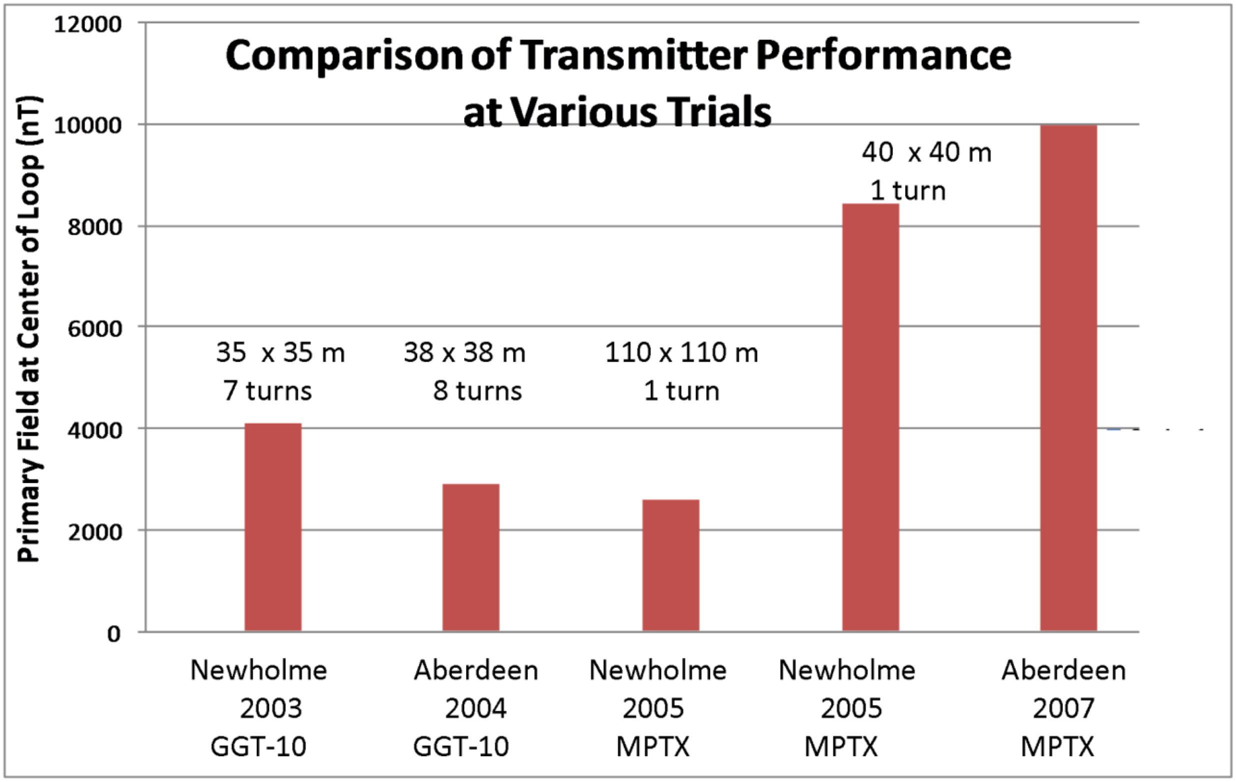


Figure 11 Primary Field Comparisons - Different Loops and Transmitters

Table 5 MPTX Performance in Newholme Trial

Status of Constant Current Drive	Loop Size (m)	Duty Cycle (%)	Theoretical Current (A)	Maximum Current Tested (A)	Minimum Primary Field (nT)
On (Mode 1)	40 x 40	25	400	400	11313
On (Mode 1)	40 x 40	50	320	300	8485
Off (Mode 2)	40 x 40	25	500	500	14142
Off (Mode 2)	40 x 40	50	360	350	9899
Off (Mode 2)	110 x 110	50	270	250	2571

The *Theoretical Current* figures in Table 5 assume standard temperature and pressure (STP) or 25° C at sea level. The *Maximum Current Tested* figures are slightly lower, because the trial was conducted at a location with an altitude of 1020 m above sea level, in cooler winter air approximately 20° C, both of which acted to reduce engine power. The stated *Minimum Primary Field* values represent the measured field strength at the centre of the grids. The maximum performance is presently limited by the available horsepower from the generator rather than the transmitter itself. A future option might be to use a larger engine if a performance increase was required.

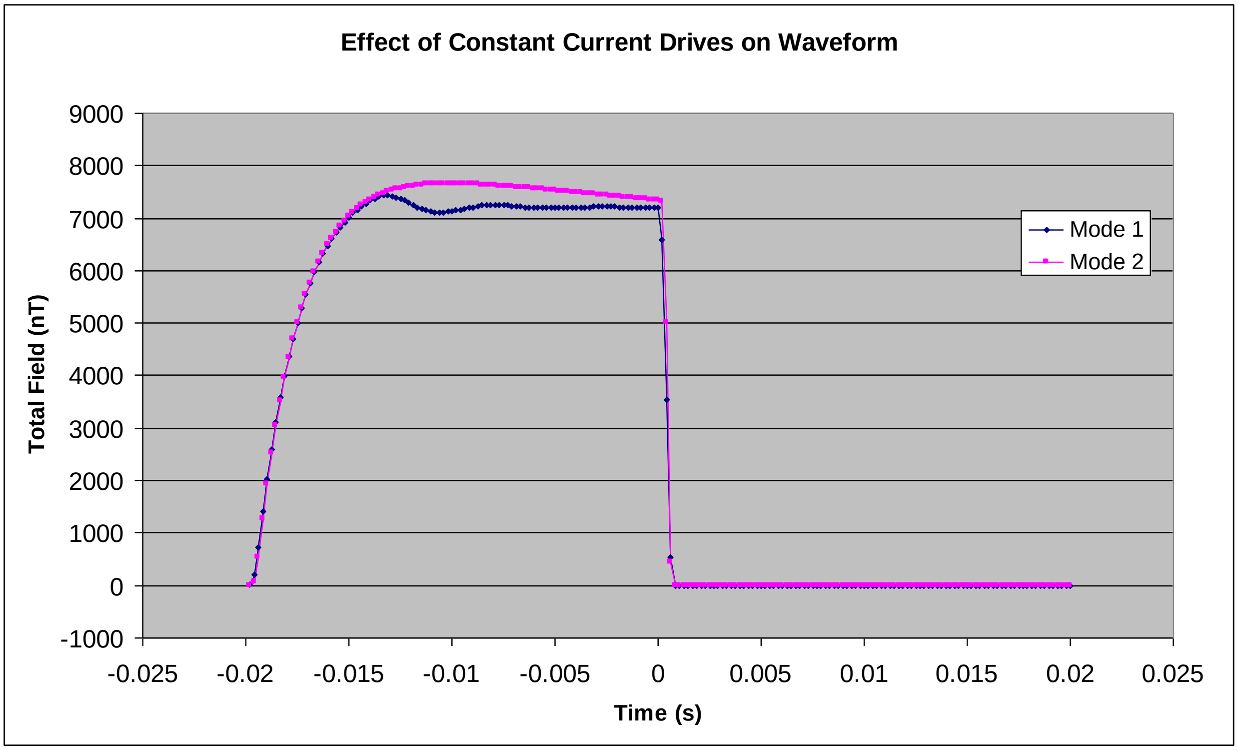


Figure 12 Illustrations of MPTX Current Modes

Figure 12 is an example of the transmitted waveform with the results of the two modes of operation superimposed together. The waveform represents a transmitter frequency of 12.5 Hz and 50% duty cycle, sampled at 4800 samples per second (on-time and off-time are both 20 ms). Mode 1 has the constant current drive switched on. Mode 2 has the constant current drive set to maximum, resulting in no influence on the output current level. The constant current device flattens the current waveform, and the difference in the two waveforms represents the energy that needs to be dissipated as heat, hence Mode 1 runs much hotter. The rapid turn-off or ramp down of the current is due to the low inductance/low resistance of the single turn loops. This provides a significant benefit by producing a great deal of high frequency energy that has lead to an improved capability to detect smaller ordnance items.

Figure 13 is similar to Figure 10 but is based on the detection of ordnance items at the Newholme test site. The items referred to as *Previously Undetected* indicate those not able to be detected by the Zonge GGT-10 in the previous 2003 survey. The most significant point to observe in this figure is the fact that all items detected with the 40 m loop were also detected with the 110 m loop. This result takes on more significance when one considers the difference in the primary field strengths as illustrated in Figure 11. That is, the MPTX has detected some of the smaller items missed by the GGT-10, even though the primary field was significantly lower because of the larger loop. It should be noted that if a given survey objective is to find larger sized ordnance items, it might be appropriate to use the 110 m loop, in which case there would be a significant improvement in productivity and lower survey cost.

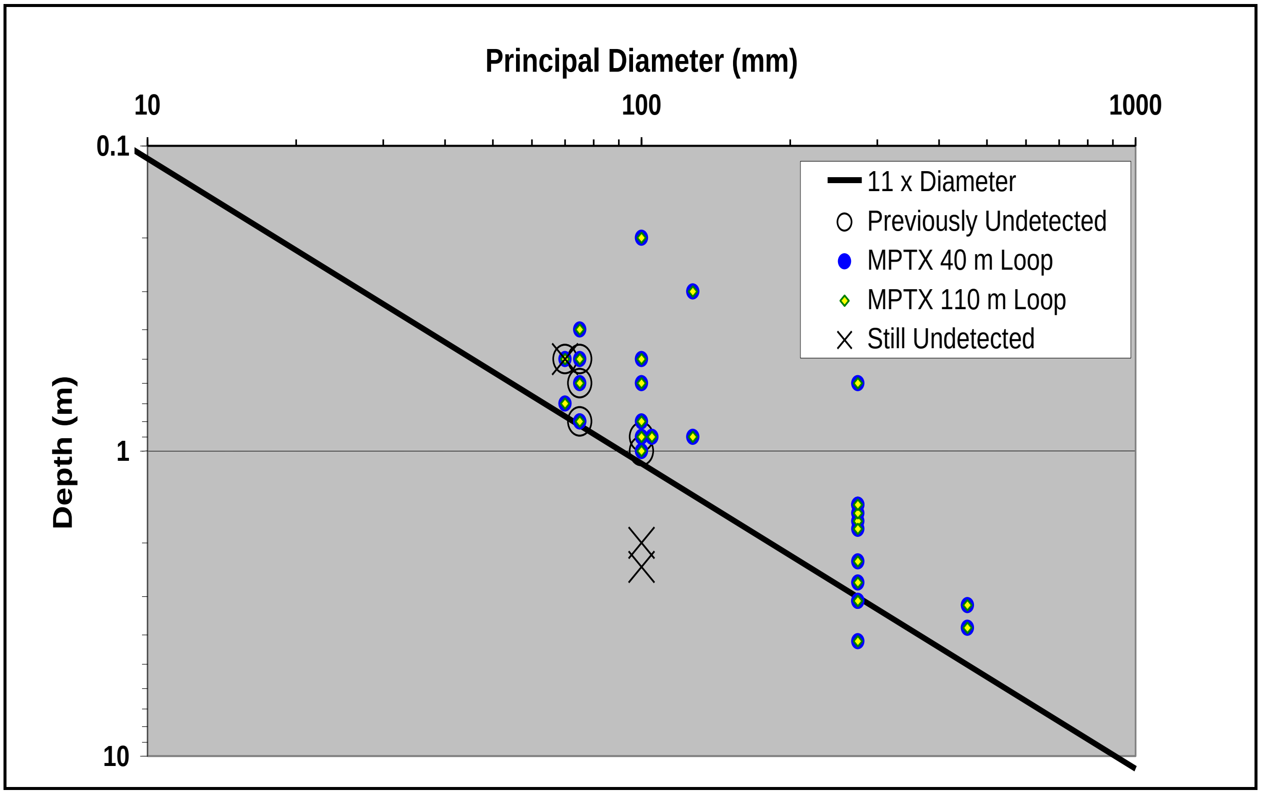


Figure 13 Achievable Detection Depths - Newholme

Figures 14 and 15 are a transmitter comparison of target decays corresponding to the peak anomaly amplitude for a 500 lb bomb at 3.1 m depth and a 105 mm projectile at 1.0 m depth respectively. These depths place both of the items close to their required detection depths according to the 11 x Diameter rule. In both cases they have been normalized against their respective primary field strengths, in order to illustrate the fact that there are still differences in the responses with the two different transmitters, even after the effect of the obvious SNR difference has been removed through normalization. In both cases the sampling frequency was 4800 sps, The GGT-10 decays lose the first 4 points compared to 3 points with the MPTX due to the frequency counter smearing the response during the ramp-down transition from the on-time to the off-time (the MPTX ramp is about 5 times faster than that of the GGT-10). It is also apparent that the MPTX curves are a lot less noisy than the GGT-10 curves.

The smaller ordnance item – a 105 mm projectile (Figure 15) - has been highlighted further in Figure 16 which shows the profiles from the two transmitters based on the integration of a windowed sample of the decay curves. Although there is a significant difference between the two profiles, one could still say that this target was easily detected with the weaker GGT-10 transmitter. However there is a significant difference between the qualities of the decays (Figure 15), which is of great importance in the detailed analysis required for discrimination. This result supports the observation that the effect of the higher transmitter power and more rapid ramp-down will have more significance to smaller items than the larger bombs. That is, we could substantially reduce the primary field (using the GGT-10 or the MPTX with a 110 m loop) and still adequately detect the larger ordnance items, whereas the quality of the smaller items response falls off more sharply.

In practice, the most important advantage of the MPTX will be the fact that the primary field can be set much higher than with any other available transmitter, thereby providing the best possible SNR for any sized ordnance item.

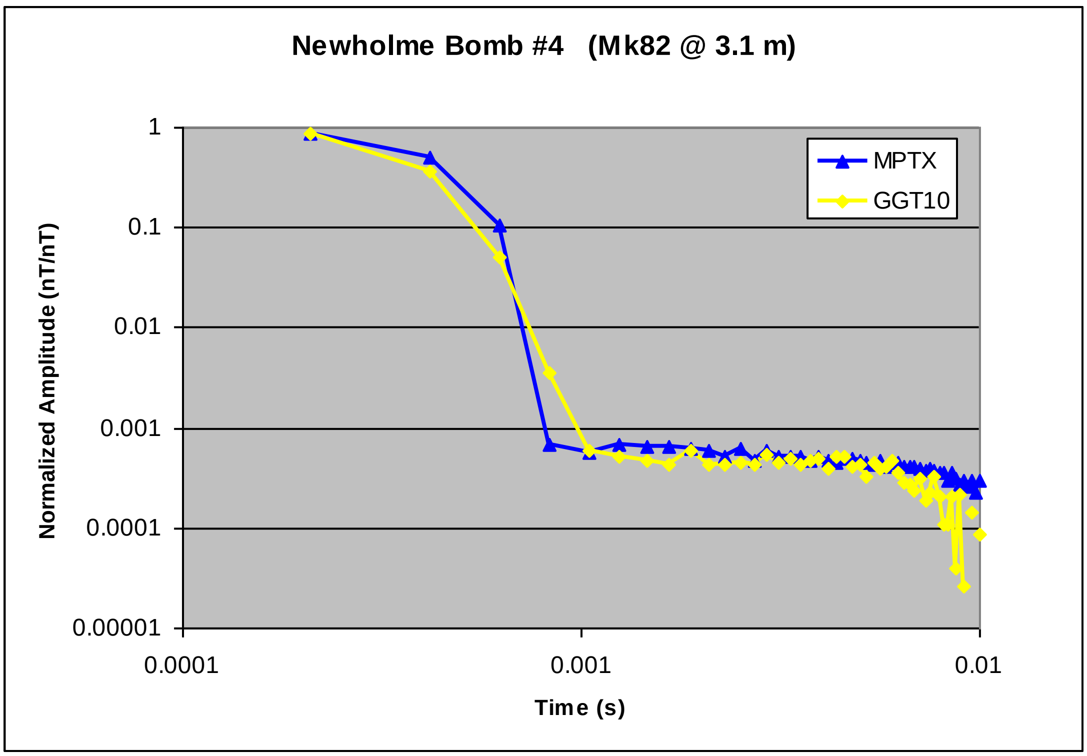


Figure 14 Transmitter Comparisons – Decay from Large Target

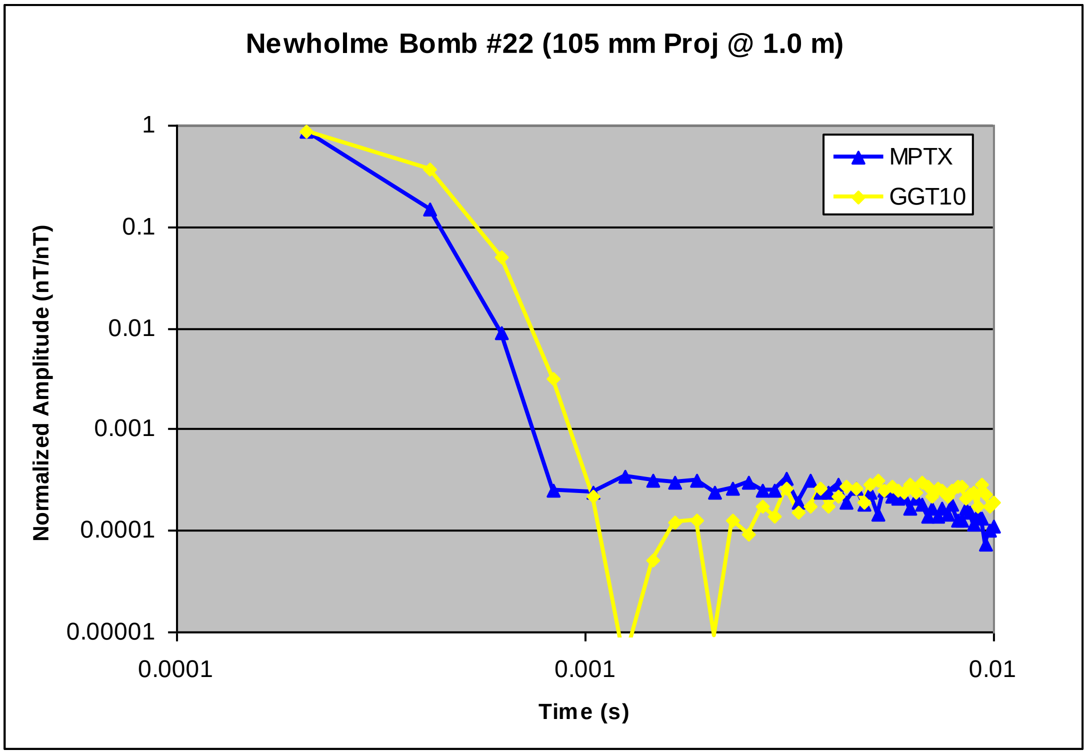


Figure 15 Transmitter Comparisons – Decay from Medium Target

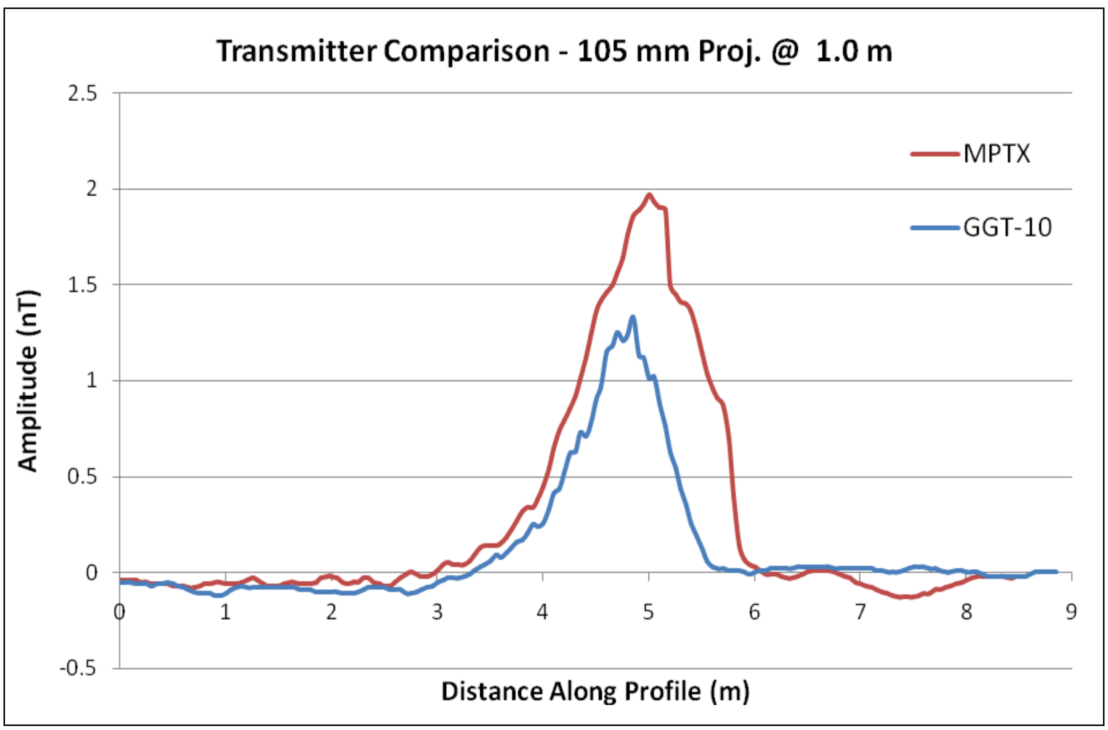


Figure 16 Transmitter Comparisons – Profile across 105 mm Projectile

Newholme April/September 06

Preliminary results from these trials were reported at the May 2006 IPR, and further results were reported in a poster at the Partners Conference in November 2006,

At the first trial of the MPTX in its new engineering prototype form in April 2006, one important survey parameter was changed, namely the size of the surveyed grid within the 40 m loop. Again the area was covered in two passes, described as follows:

(i) 25 m x 25 m grids, 1200 sps, 12.5 Hz, 50% dc,

(ii) 100 m x 100 m grid, 1200 sps, 6.25 Hz, 25% dc.

A small traverse was also undertaken over 3 selected targets with a number of passes at various settings, in order to obtain direct comparisons between 1200 – 9600 sps and with transmitter frequency / duty cycle of 12.5 Hz / 50 % and 6.25 Hz / 25 %.

Apart from testing the MPTX operation, these 2006 surveys were also intended to complement the previous 2005 Newholme survey. Data sets were acquired with a different combination of instrument parameters, in order to help determine the optimal combination for the given site conditions, assisting in the process of determining the optimal settings for the future demonstrations at APG2 and YPG.

The two main variable groups, selected through menu options in their user interfaces are:

(i) Selection of receiver (TM-6 magnetometer) sampling interval. 1200 sps produces the lowest noise, especially at late-time where one is most interested in capturing the weakest part of the target decay. The trade-off is a later starting point in the early-time data. A faster rate such as 4800 sps provides samples earlier in time, and even though the data is noisier at late time, there is enough of it that an additional averaging step to down sample it to a 1200 sps equivalent may be a reasonable compromise.

(ii) Selection of the transmitter frequency / duty cycle and power level. A lower frequency and duty cycle results in a longer off-time and higher primary field strength, but it reduces the number of data points available for spatial stacking, potentially resulting in a longer spatial sampling interval. The off-time needs to be long enough to collect enough of the late-time decay to properly capture the most significant portion of the target response. The higher primary field strength might make it possible to reduce the number of stacks, thereby maintaining the spatial sampling interval to an acceptable value.

The reduction in grid size was found to be necessary in order to minimize the problem of responses from targets outside the grid being superimposed on those of interest within the grid, causing a masking or false anomaly effect. The change from 33 m grids to 25 m grids provided an increase in the distance between the grid edge and the loop of 4 m from 3.5 m to 7.5 m. This problem mainly related to the large shallow 500 lb bombs at Newholme, and the change to the smaller grid did eliminate the problem. However, at the upcoming demonstrations the grid size of 30 m (same as the previous survey) will be used because no problems of this nature were encountered at the previous trial, mainly due to the generally smaller mix of items.

The 2006 surveys were conducted in two parts because the first version of the engineering prototype trialed in April was found to have a significant over-heating problem. The September trial fully tested the final version of the engineering prototype, as depicted in Figure 5. The change from two to three separate cases fitted with larger fans and heat sinks solved the over-heating problem.

The analysis of the data set collected at this trial provided an additional opportunity to compare the performance of the new MPTX against the GGT-10, trialed at the Newholme site in 2003. Figures 11 to 16 already provide various comparisons, however it is useful to provide another example (presented here as Figure 17) using Signal/Noise Ratio (SNR) as the method of comparison rather than amplitude. This figure is based on the tabulation of the SNR of all targets detected at Newholme by the GGT10 (29 out of 35) and MPTX (35 out of 35), and expresses the difference as the variation in the probability of detection as a threshold is applied to the SNR's. That is, as the SNR acceptance threshold is increased, fewer items will stay above the threshold and the P_d will decrease. If the Newholme site had included clutter items, this graph would resemble a ROC curve. It is apparent that the MPTX is producing results that generally have a higher SNR, but the two curves converge as the SNR increases because both transmitters were performing well with their detection of the larger shallower targets with the high SNR.

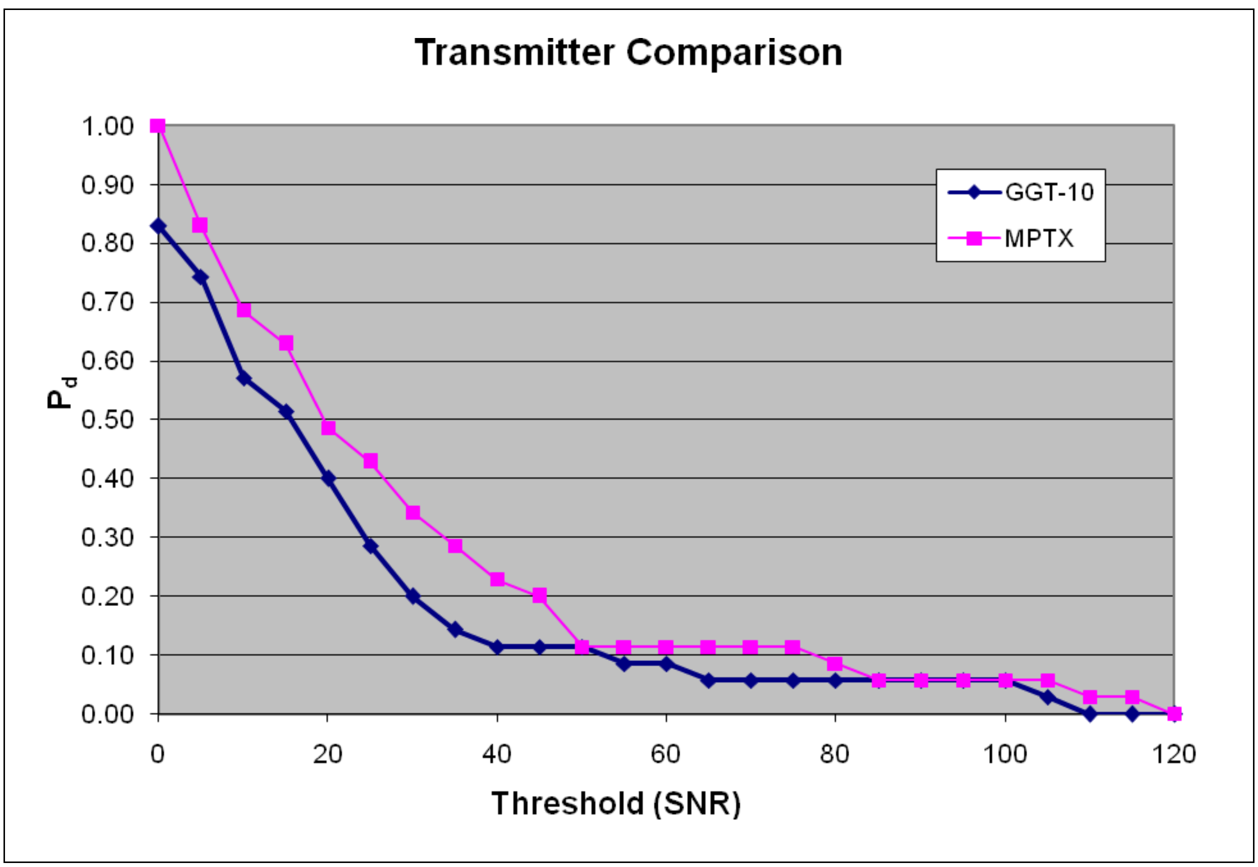


Figure 17 Transmitter Comparison – Newholme - Probability of Detection

On the question of determining the optimal set of instrument parameters for the future trials, the selection of the sampling frequency of 4800 sps over 1200 sps had proven to be the easier of the two variable groups mentioned previously. Figures 18 and 19 are presented to highlight the most significant points influencing that decision.

Figure 18 illustrates the transformed response which is derived by dividing the decay data by a trial decay with a nominated amplitude and time constant, so that when the late-time portion appears horizontal, the selected trial time constant is a good estimate of the time constant of the late-time exponential decay. Moving to the left (earlier in time), the point where the decay moves upwards off the horizontal indicates the transition between exponential decay and the more complicated power law decay that dominates early time. In this example that point is seen to be at about 5 ms.

This result is significant because it shows data collected at 1200 sps (yellow curve) does not sufficiently sample the early time portion of the decay, although it does a very good job of sampling the late-time exponential portion. The key point to note is that the 4800 sps curve is good enough to provide a reasonable estimate of the dominant time-constant in the exponential late-time part of the decay, while at the same time providing much more resolution of the early-time decay. Analysis of other target responses have shown that the 4800 sps data from the Newholme trials is better suited to providing an estimate of the zero time amplitude (inductive limit) because it has more data points to be applied to the decay curve modeling.

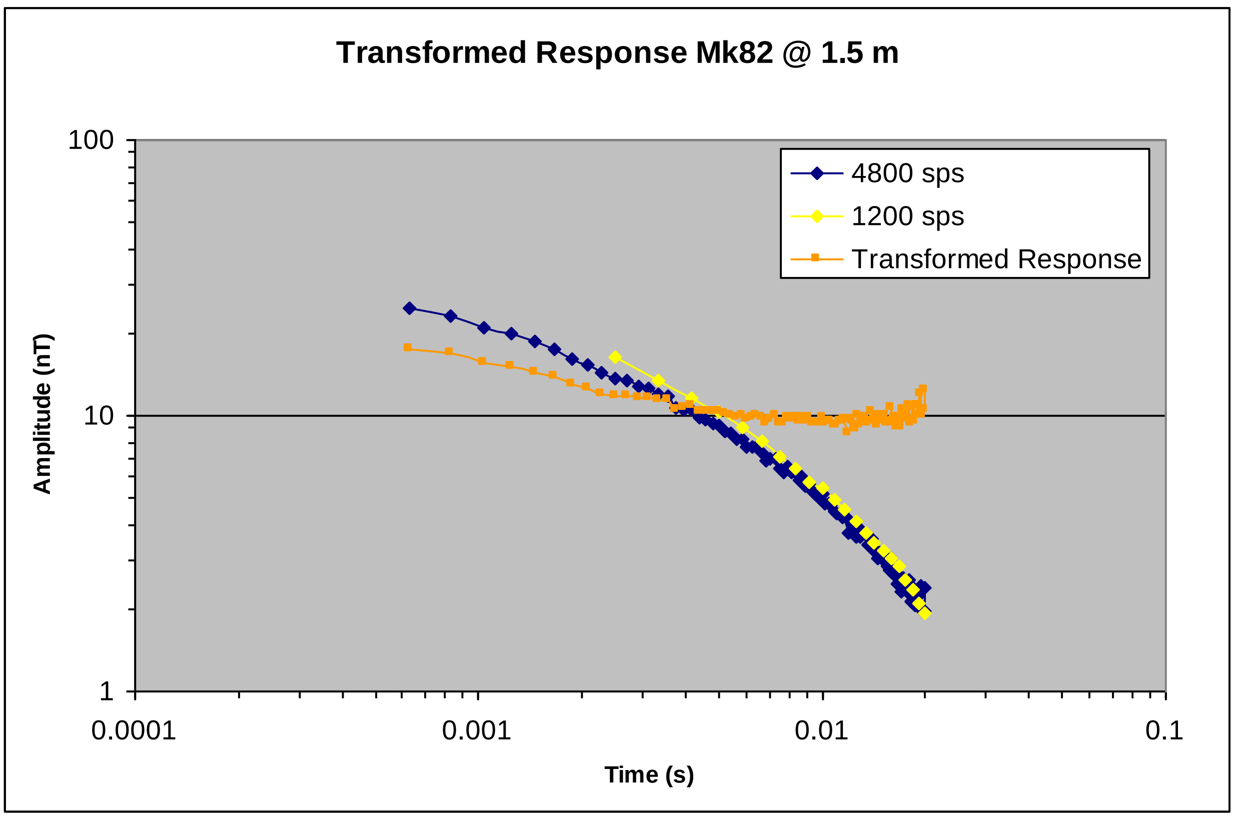


Figure 18 Sampling Frequency Comparisons – Transformed Response

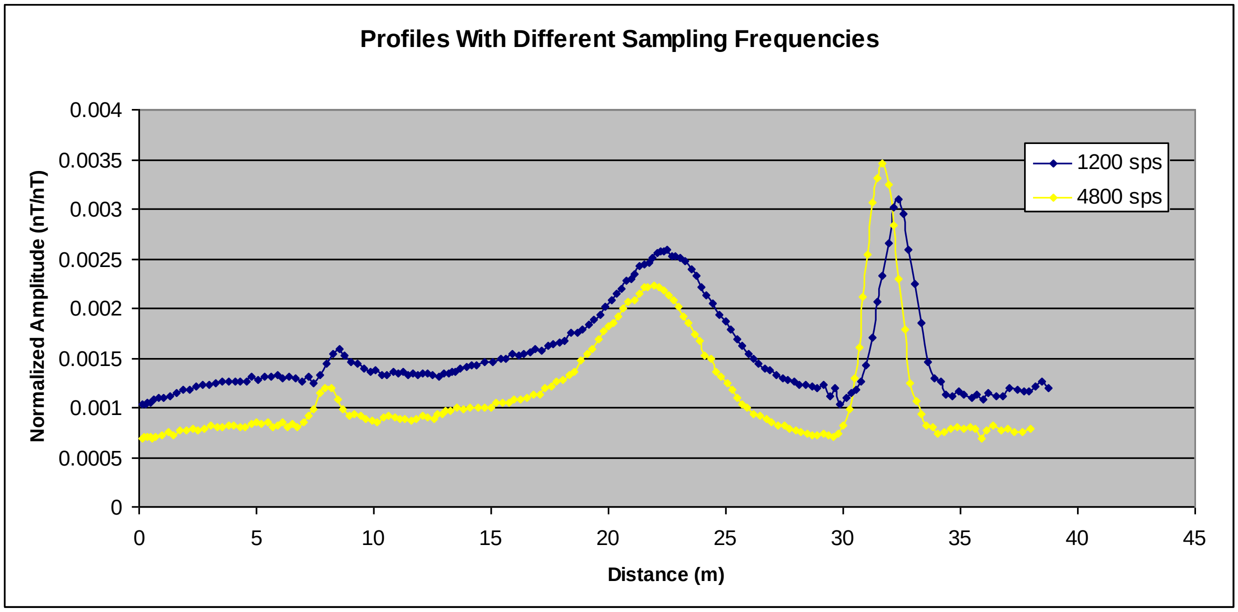


Figure 19 Sampling Frequency Comparisons – Profiles

In figure 19, two profiles are being compared, and the figure clearly illustrates there is no real difference between the two options, in terms of the apparent SNR of the three targets sampled along the profile. Profile data such as this is used to generate a grid file and color image which is then used to select anomalies of interest by automatically detecting any peak above the nominated threshold. The interpretation of the Newholme data sets has shown there is no difference in the overall result between a 1200 sps and 4800 sps data set. Therefore the obvious choice is to use 4800 sps in further demonstrations because of the added advantages to be gained from the extra early time decay information.

The second of the two main variable groups mentioned previously is the selection of the transmitter frequency / duty cycle and power level. This combination has proven to be more difficult. It has been determined that the most prudent approach for any new demonstration was to repeat the process undertaken at the start of the APG1 demonstration. This involved taking advantage of the Calibration Grid to help determine the optimal set of instrument parameters that will maximize SNR's. Thus takes into account the site specific conditions and takes full advantage of the flexibility offered by the SAM UXO detection system. In practice, this may only require two separate passes, trialing 15 Hz / 50 % duty cycle and 7.5 Hz / 25 % duty cycle, as illustrated in Figure 20, which is using the Australian equivalents based on the different power mains frequency (50 Hz in Australia, 60 Hz in USA).

The most important trade-off is between:

(i) lower primary field strength shorter off-time, higher spatial resolution, and

(ii) higher primary field strength, longer off-time and potentially lower spatial resolution.

Figure 20 illustrates that this trade-off can produce a very similar result. In this case, the spatial resolution of the two profiles is almost equal because the 6.25 Hz data has been stacked at half the number of the 12.5 Hz data. Note the Y-axis has been drawn with a log scale.

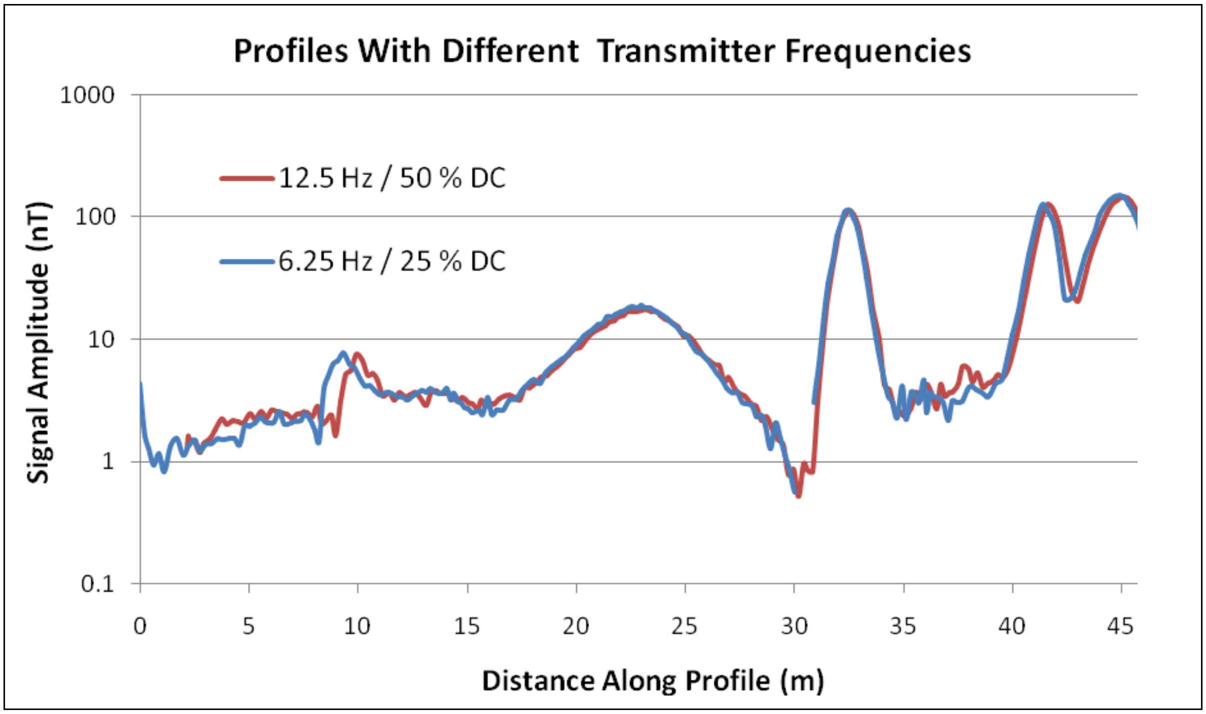


Figure 20 Transmitter Frequency Comparisons – Profiles

In Figure 20, the average spatial sampling interval for both profiles is identical at 0.22 m. The primary field at the centre of the loops was 7929 nT (12.5 Hz) and 11887 nT (6.25 Hz). The 12.5 Hz profile was formed with 16 half-period stacks and 50 % overlap, while the 6.25 Hz profile used 8 stacks and 50 % overlap. There are 5 anomalies in the profile correspond to the following targets (left to right):

(i) @ 10 m on x-axis, BDU33 @ 0.6 m depth below ground,

(ii) @ 22 m on x-axis, Mk 82 @ 4.2 m,

(iii) @ 32 m on the x-axis, Low Drag Fin from Mk 82 @ 0.7 m,

(iv) @ 41 m on the x-axis ,Mk 82 Fin @ 0.6 m,

(v) @ 45 m on the x-axis, Mk 82 @ 1.5 m.

The choice of transmitter frequency is difficult because there are arguments that favor both options. For example, a higher primary field (using the 6.25 Hz / 25 % DC combination) will also provide a higher dI/dt and therefore has the potential to generate more high frequency components in the excitation, which is important to the smaller sized targets. However, the faster transmitter frequency will always result in a higher spatial resolution which in itself is also quite important for the detection of weak responses. Irrespective of the potential for generating higher frequencies, or to produce the higher spatial resolution, it may be that the most significant factor in detection of small items is simply to obtain the highest possible primary field strength, without consideration of any other factors. To do this, one would choose the lower transmitter frequency and duty cycle.

Part of the consideration of the site specific conditions, in the context of setting system parameters, relates to the actual range of ordnance buried at the site, in addition to environmental factors such as soil, terrain etc. Figure 21 is included to illustrate the range of ordnance items found at Newholme, the APG Calibration Grid and the APG1 Blind Grid (in 2004).

The Newholme trials highlighted the capability of the SAM UXO system to detect the larger deeper items. Figure 21 clearly shows that the majority of the buried items at Newholme are larger than 100 mm diameter. The figure also illustrates that most of the items buried in the APG Blind Grid were less than 100 mm diameter. This remained as the configuration for the later APG2 trial in 2007, which is being reported here. One can conclude that the results from the Newholme trial were not necessarily a good indicator of likely performance at APG/YPG, because of the significant differences in the samples of ordnance sizes and depths. The good performance of the system in detection of large deep items is discussed in more detail in Section 7.2 – 2. Target Detection Depths, where more results are provided from experiments aimed at determining maximum possible detection depths of the large items.

There is a strong argument in support of using trials at each specific site to help determine the choice of transmitter parameters, given the significance of having to allow for the different mix of ordnance at different sites.

The APG2 (2007) and YPG (2008) demonstrations took on great importance in providing detailed information on the SAM UXO system's detection capability for items and depths that are shallower and smaller than those at the Newholme site. Together, the data from these different sites provided plenty of high quality data to fully characterizing the system performance.

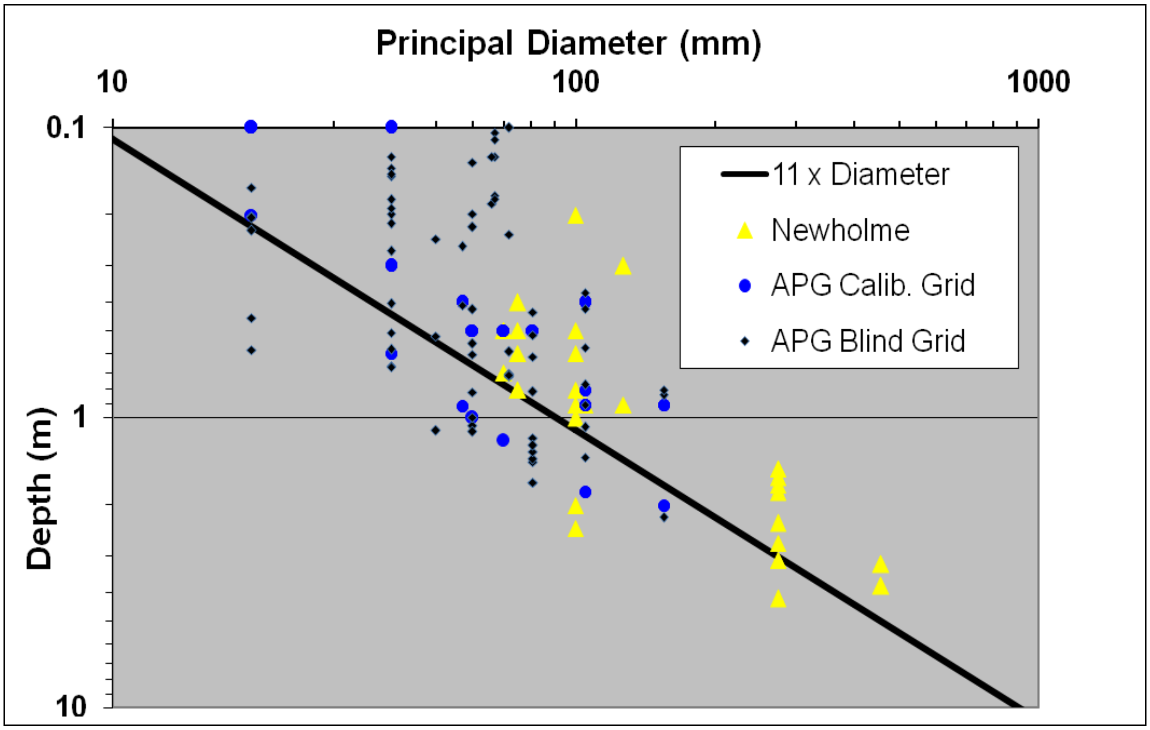


Figure 21 Ordnance Sizes Present at APG and Newholme

Adelaide/Armidale February/March 07

During a demonstration of the MPTX, in late January, a component failure was experienced, due to an unknown cause. After replacement of the failed component, the system was exhaustively tested and monitored at the level of individual components. During this monitoring process a second failure was observed, resulting in the cause being established and remedied. During this process some additional minor faults were found and remedied, resulting in system performance, that in some respects, now exceeds the original specification. This mainly relates to the stability of the current during the on-time, while operating with the constant current devices. Other mechanical changes were also undertaken, again resulting in a better overall performance. The changes to the MPTX at this time relate more to long-term reliability and would not have affected the quality of the results obtained at the previous April and September trials on the Newholme grid.

Prior to freighting to the USA, the system was tested a final time at Newholme on at least three 25 m x 25 m grids just as a final check of performance.

Summary

Apart from the changes to the MPTX and generator, the rest of the system as described in Section 2.1.2, and the field methodology described in Section 2.1.3 remained unchanged during all of the trials at Newholme since July 2005. After the April 2006 trial, the MPTX layout was changed from two modules to three, in order to remedy over-heating. The three module configuration has been well tested since then (including the September 2006 trial) without any over-heating problems. A component failure in January 2007 led to a thorough design review and component testing, resulting in one problem being diagnosed and remedied. Final changes were made to the MPTX and Generator in March 2007 that can described as 'fine-tuning'.

Illustrations have been presented that show how a profile view across selected anomalies is a useful and relevant method of comparing target responses resulting from different system configurations. The relevance of this type of comparison relates to its use to derive anomaly SNR's, as well as forming the basis of anomaly detection when converted to a map. The fundamental processing procedures undertaken to produce profiles and maps from the raw data have also remained unchanged since the time of the first APG demonstration in June 2004. However, there has been a significant improvement in the way in which these procedures are implemented, resulting in greater efficiency and less time being required to perform the tasks. One development that has proven to be quite valuable is the use of graphical aids during this pre-processing stage to check on data quality and fix problems such as, a sensor drop-out.

All of the main hardware parameter options were trialed at the Newholme site and the figures presented have been chosen to highlight the main issues involved in the selection of the hardware parameters. The choice of sampling frequency was quite certain, but the transmitter frequency and duty cycle were less certain, because of the compromises involved and the need to obtain more site specific information. Our view is that the final selection of hardware parameters must be based on trials and results of the various options on Calibration Grids at the specific sites, prior to the full demonstration.

2.3 Advantages and Limitations of the Technology

Advantages of the SAM UXO System

- A single pass of the survey area provides two data sets (TMI and TFEMI).
- The two data sets are perfectly co-located due to the use of the one sensor.
- The sensors are easily carried and maneuvered around obstacles.
- The system is suitable for application in rugged terrain.
- A wide swath width ensures a good survey coverage rate.
- It is very well suited to the detection of large deep ordnance items. It is also believed that this system has no equal in this regard.
- The use of a single-turn loop ensures low inductance and therefore allows a very fast current switch-off.
- The fast switch-off and is combined with very the high current which results in an extremely high rate of change of current with time (dI/dt), which ensures good induction at early time.

Limitations of the SAM UXO System

- It is not suited to detecting small ordnance items (smaller than 35 mm projectiles). An objective of the APG2 and YPG surveys was to determine the detection limit of the new MPTX, which was predicted to be better than the GGT-10 transmitter used at APG1.
- It is not suitable for use in low latitudes near the equator, due to the low angle of the earth’s magnetic field. This background field is being modulated by the induced primary field with much less amplitude than at higher latitudes, resulting in an attenuated target response.
- It requires the use of a small petrol generator that would be running for about 60 % of the time, and this might be considered too noisy in some locations. If this proves to be a severe limitation in certain locations, there is always the possibility of housing the generator in a sound-proof container.
- This system has a bulky transmitter to complement the highly portable receiver. The petrol generator and transmitter modules will sit on a small trailer which needs to be moved across the survey area as the loops are moved to each new location. The disadvantage of the bulky transmitter is outweighed by fact that it only needs to be man-handled once per grid.
- The field procedures require the large transmitter loop to be moved around the survey site as each grid has been surveyed, and this requires the overall survey area to be pegged or flagged at 30 m intervals to assist in the rapid layout of the loop in its correct position.
- The ground response increases with ground conductivity and loop size, however in our experience to date, this has not been a problem. Even in the case where we trialed the system with a loop 400 m x 200 m in an area with higher than average conductivity.
- Because the basic receiver is a magnetometer, this imposes constraints on the operators and survey aids such as sensor frames/trolleys in that they cannot be magnetic. Generally the TM-6 is far enough away from the sensor so there are no real limits due to the magnetic properties of the instrument.

Alternative Technologies

The Geometrics 858 and the Scintrex SM-5 NavMag are two magnetometers that can be compared with the TM-6 in terms of magnetic measurements, although the TM-6 can use the same sensors as either of these instruments. The key differences are that the TM-6 can be deployed with 4 sensors whereas the others are limited to two maximum, and the sampling rate of the TM-6 is as much as three orders of magnitude greater. The high sampling rate of the TM-6 provides an opportunity to fully filter out any interference from man-made sources such as power lines or engines that might otherwise diminish the quality of data taken.

Three off-the-shelf, time-domain, electromagnetic induction instruments used in ordnance applications are the Geonics EM-61, EM-63 and the Zonge nanoTEM. These are all small loop systems that can excite targets from different directions as they pass overhead. They will provide data that may result in a better estimate of target orientation than the SAM UXO system. However, this is probably the only area where they have an advantage. These systems are also known to have a problem detecting smaller items, and interestingly one of their solutions is common to the SAM UXO system as well, namely to increase the transmitter power.

The SAM UXO system is the only true B-field system. Theoretically, it has a better chance of acquiring good quality late-time data. The dynamic range or spread of data amplitudes from the inductive limit to the noise floor is much less with a B-field system. There is a better chance of being able to estimate the inductive limit of a target, which we hope to prove can be of benefit in the discrimination process.

Lastly, the SAM UXO system can be run at much lower frequencies than the alternatives. Therefore it is more capable of generating fundamental excitation modes relating to the largest dimensions of the targets that the others cannot generate. This is especially the case for the larger ordnance items.

3. Performance Objectives

Table 6 summarizes the qualitative and quantitative performance objectives that are the primary performance criteria used to evaluate the performance and cost of the SAM UXO detection system. Meeting these performance objectives is considered to be the best indicator of a successful demonstration and validation of the technology.

Table 6 Summary of Performance Objectives and Results

Qualitative Performance Objectives				
Performance Objectives	**Metric**	**Data Required**	**Success Criteria**	**Results**
1. Ease of Use	Vote of Confidence	Feedback from operators, operators opinions	Operator acceptance	Deemed easy to operate
2. Environmental Factors Affecting Performance	Subjective judgment on effect of environ. factors	Observations and notes in daily log, sample decays of background	General observations	No adverse effects encountered, but Yuma heat slowed operations at times
3. Reliability	Survey time lost due to system malfunction or equipment breakage	Observation and notes of downtime in daily log	Little or no loss of time through breakdown and repair time	Achieved an adequate level of reliability
4. Versatility	Subjective judgment	Observations and notes in daily log	Expect it to perform well in variety of conditions	Good versatility
5. Maintenance	Subjective judgment	Observations and notes in daily log	Requires minimal maintenance - batteries and fuel only	Only needed to perform required daily maintenance
6. System Function	Subjective judgment	Observations and notes in daily log	Does it meet system specifications	Yes, system specifications were met
7. Site Coverage	Judgment of area able to be fully covered in survey	DGPS track data of sensor and maps of acquired data	Is 100% coverage able to be achieved over the site	Yes sites were fully covered
8. Readiness for commercial application	Subjective judgment	Information resulting from consideration of other performance objectives	Good performance in all criteria when considered on an equal basis.	System ready for commercial application in all aspects except target discrimination and classification

Quantitative Performance Objectives

Performance Objectives	**Metric**	**Data Required**	**Success Criteria**	**Results**
1. Target Signal/Noise Ratio	Signal/Noise Ratio	Signal amplitudes and background noise levels for selected known items	> 1.5 is regarded as clearly detectable	Many targets detected with SNR in range 1.1 – 1.4. Targets above 1.3 are very clear
2. Target Detection Depths	Whether or not items are detectable beyond 11 x diameter.	Burial depth of items	Can it detect items to a depth of 11 x diam.	Projectiles 37 mm or greater were detected to the 11 x Diameter depth. Some smaller items were detected but not all. i.e. can't guarantee 100% detection of smaller items.
3. TFEMI Decay Quality	Fit of the late time portion of decay to an exponential	Results from analysis of selected decays	$R^2 > 0.9$ (associated with a model fit)	For target SNR range of 1.03 to 4.87, R^2 ranged from 0.981 to 0.998.
4. Probability of detection of ordnance (P_{do}) and Probability of detection of clutter (P_{dc})	# of ordnance detections / # emplaced ordnance items # of clutter detections / # emplaced clutter items	Results provided by ATC for Blind Grid (BG) and Open Field (OF)	$P_d > 0.95$	APG BG $P_{do} = 0.60$ APG BG $P_{dc} = 0.75$ YPG BG $P_{do} = 0.75$ YPG BG $P_{dc} = 1.00$ APG OF $P_{do} = 0.30$ APG OF $P_{dc} = 0.35$
5. Probability of background alarm (P_{ba}) and background alarm rate (BAR)	# of background alarms / # empty grid locations # of background alarms / arbitrary constant	Results provided by ATC	BAR < 0.05	APG BG P_{ba}=0.05 YPG BG P_{ba}=0.05 APG OF BAR = 0.05
6. Location Accuracy	Mean location error and standard deviation	Published location of items. Estimated location from geophysical data.	Mean Error < 0.25 m Std Dev /< 0.25 m	Mean Error = 0.09 m Std Dev = 0.2 m Satisfactory result

7. Survey Rate	Number of acres of data collected per day	Accurate log of field work time and area covered by survey	2 acres / day	APG1 = 4 acres / day APG2 = 2.2 acres / day YPG = 2.0 acres / day
8. Processing Time	Time required to process 1 days worth of data	Log of processing time required for one days data	Aim for a ratio of 1:1	Ratio of 1 day processing for 1 day data collection achievable for Response Stage but not Discrimination Stage
9. System Function	Checklist of system function	Results of analysis of system function tests from selected grids	Meet system specification	System does meet specification

3.1 Qualitative Criteria

1. Ease of Use:

The SAM UXO system is a tool for performing the task of detecting buried ordnance and the 'ease of use criterion' simply refers to the ease with which operators are able to go about the task of surveying the ground with the equipment and producing the required data. It is mainly referring to the physical aspects of the work, as well as the human interaction with the system as the operators are controlling it and using it correctly.

For any new geophysical survey system, it is important to be able to establish that the system can be easily man-handled during the normal course of operational activities in a manner that does not compromise operator health and safety factors. The conduction of the trials has provided sufficient operational experience to determine the optimal number of operators and their required skill levels, in order to achieve an optimal level of productivity, taking into account labor cost factors and operator workload. New personnel were exposed to the equipment and field methodology at both the APG and YPG trials, and required minimal training in order to become familiar with the TM-6 and MPTX software user interfaces.

During the trial surveys, the operators were constantly being asked their opinions about all operational aspects of the work. Their operational competence during the initial stages of the survey when everything was new to them was observed, especially with respect to operational procedures that would have an impact on data quality. Throughout the course of the surveys, their health, fitness and enthusiasm was constantly monitored, and discussed as a group in the evenings.

The most obvious metric for this criterion was a vote of confidence from the crew, and this was achieved. One important factor that led to this conclusion was the fact that the number of operators available was sufficient for the task, and the workload was maintained at a suitable rate to take account of the climate and required physical effort – especially in the mid-summer heat of Yuma Arizona (daily temperatures > 100° F).

More details on aspects of the design of the system that have lead to the vote of confidence are given in Section 7.1. It should be noted that, of the seven different personnel involved in the APG and YPG trials, all of whom were surveyed for opinions, only one of them was involved in the design of the system, and would therefore have a natural bias in this criterion.

2. Environmental Factors Affecting Performance:

The trial locations at APG2 and YPG provided significantly different environmental conditions with respect to climate, vegetation, soil conditions, terrain and geology. Therefore, they provided the perfect opportunity to determine if environmental factors affect system performance, given that similar work was undertaken at both sites. In particular, there was an expectation prior to the surveys that extreme wet weather might have been a significant factor at APG2 (from prior experience) and similarly the extreme heat might have been a significant factor at YPG (also from prior experience). Environmental factors are being considered in terms of their impact on field operations, data quality, and system function.

The trials over the Calibration and Blind Grids provided the best opportunity to assess if these factors contributed to any significant difference in performance, given that the target types and burial depths were similar at both locations. If it is assumed that instrument factors were similar, any observed differences might be attributed to the environmental factors. While this criterion is essentially looking at qualitative factors, it is also useful to consider a quantitative measure, namely the depth detection performance at the Calibration and Blind Grids at both sites, to see if there is any indication of an environmental influence.

Inspection of figures 33 and 34, comparing depth detection of items at APG2 and YPG does show some detection differences at the two sites, especially with some of the smaller items (BLU-26, 40 mm M385 and Mk118). However, these differences are deemed to be the result of different instrument factors (lower sensor height and slightly higher primary field), and not environmental factors, because the difference in the background response is not great enough to have a masking effect at APG2, compared with YPG.

Given that the metrics used to assess this criterion were mainly subjective, the main source of data were the daily logs of activities being kept by both ATC (temperature, rainfall, soil moisture etc.) and GapGeo (MPTX parameters during operations), as well as the derived TFEMI background responses corresponding to no targets. Some aspects of this criterion that have a quantitative component are referred to in other following sections (e.g. ordnance detection depths).

a) Field Operations

One significant environmental factor requiring special mention was the high daily temperature encountered at the YPG, and the impact this had on operational procedures. One important point to mention was that it determined the daily timetable of activity whereby work was started at dawn and finished in the early afternoon, with a modest survey area coverage target each day. This provided a means of performing the task at the hottest time of the year at this site, in a manner that was sustainable to the operators. Similarly at APG2 there was always the potential that wet weather and summer storms might impact on the work schedule, but fortunately stoppages due to rain and lightning etc. were minimal

b) Data Quality

Previous trials in Hawaii and Montana showed that geology can have a significant impact on performance, even to the extent that the method cannot be used effectively at some locations with extreme magnetic soils. Soil magnetic properties at APG and YPG have been found to be insufficient to influence the ability of the system to detect the targets. Soil electrical properties and geology are also known to influence the method through the relationship between ground conductivity and loop size.

The ground electrical properties influence the background response by masking early time signal if the loop is too large and conductivity too high, through an effect referred to as the half-space response. This is a bulk effect at the scale of the loop itself, and is therefore mostly related to the geology underlying the soil, unless the soil cover has a depth at a similar scale to the loop size. This masking effect would be most noticeable with items being detected at a low SNR. However, the modeling and actual collected data from both APG and YPG show that this ground response had no influence on the system's ability to detect ordnance.

c) System Function

The most significant environmental factor affecting performance was the high summer temperature at Yuma, which did influence the system function, but not to the extent that it prevented a successful outcome. Because the MPTX is air-cooled, using fans blowing across heat-sinks, it is less efficient when the air itself is very hot (greater than 100 °F). The system has heat sensors that provide an indication of internal system temperature and can cause the system to shut down automatically when a certain level is exceeded. Through careful monitoring of this temperature, the system was shut off manually on the few occasions when it became a problem. In general this had a negligible effect on productivity as it would usually occur close to the end of the working day, or at a scheduled break. The natural operational cycle of grid survey and loop movement meant that the system was being shut down on a regular basis, which usually provided the required time to allow the system to cool down, except when air temperature was at its greatest at the end of the working day.

The internal system temperature is related to the ambient air temperature but it is more significantly influenced by the operator's choice of duty cycle, transmitter frequency and nominated output current. Because of the need to produce the highest possible current, this meant it would have not been possible to use 50% duty cycle due to the potential for over-heating the system. However the choice of 25% for all of the work for other reasons meant this never became an issue.

3. Reliability:

A statement about the reliability of the system is considered to be an important performance criterion because it has implications to the running costs associated with the negative effect of lost time due to system malfunction. There is a significant cost associated with just having personnel deployed in the field and therefore any time not spent working is important. The system, as deployed, is an engineering prototype. Therefore, a detailed record and account of its reliability has relevance to the next phase of the project that will involve development of production models of the system.

Daily logs of activities by both ATC and GapGeo catalogued the downtime and subsequent unplanned maintenance tasks required during the demonstration. As well as highlighting the lost time, an important related factor is the knowledge of how quickly and easily any faults and breakdowns were able to be remedied (repairability).

In general the system proved to be very reliable. At YPG there was no loss of survey time due to equipment failure. At APG2, there was 2 hrs 10 mins of lost time over the 13 days of surveying. Details of the specific incidents at APG2 are summarized as follows:

- A single incident while surveying (engine running) one of the grids saw a connector on the main loop start to 'smoke' and enough heat was generated at the cable connection to melt the insulation. This connection was then repaired following a simple procedure with the appropriate tool. It occurred because that connection had been poorly coupled by the operator, and the high current load meeting this high resistance connection resulted in the failure. The connections occur at the 4 corners of the 40 x 40 m loop and use a special fitting where a twisting action is used to connect the ends. After that incident operators were more careful when coupling connectors, and there was no subsequent recurrence, even at the much hotter YPG.
- The sensor trolley was constructed completely of non-metal parts and one weakness encountered at APG2 was the wheel axles which broke on a number of occasions and required replacement. After the first few times, spares were always carried in the field to minimize the down-time. Replacement of an axle was very quick so there was no significant loss of work time. There was no opportunity during the APG2 survey period to source a better material. A much stronger high density plastic material was used on the trolley at YPG and did not fail during the YPG trial.

Painstaking attention to detail has gone into the design of the MPTX transmitter, as well as the TM-6 receiver, and firmware. Both systems incorporate sophisticated error and fault detection, instrumentation to monitor certain functions and conditions, and real-time operator help in the user–interface when a failure does occur.

4. Versatility:

Versatility has been put forward as a performance objective because the system is unique, the first of its kind and has been specifically designed for the ordnance detection problem. Therefore it is of great interest to determine that the design is one that will allow it to be deployed to virtually every possible location with a UXO problem. Apart from the two sites at APG and YPG, the development program has seen it deployed at a number of different sites that have provided the required information to allow us to make a clear statement about its versatility.

This criterion is defined in terms of the types of terrain to which it can be deployed as well as the ability to configure it for different UXO problems. Some of the terrain types and UXO problems to which it can be applied are not represented by the two APG and YPG demonstrations, but they are being discussed because they have been part of the development program at other sites. As discussed in a previous section, the two test sites have quite different environments and the same system configuration was used at both sites. The fact that it was used at these different locations with no change to the configuration is indicative of its versatility. This suggests that the system can be easily adapted to meet the requirements of virtually any situation.

The key to versatility in design, for UXO problems, is the high current transmitter which permits a wide range of options for loop size and design primary field. The basic goal is to have as much mass of copper wire on the ground as possible since this determines the amount of the electrical current that is possible, which in turn determines the primary field strength for a given area or magnetic dipole moment, which has a direct linear relationship with SNR and detection capability. With the MPTX, this is achieved through the use of thick cable (35 mm^2 and 50 mm^2) with very low electrical resistance.

For detection of ordnance items at AGP2 and YPG (excluding the sub-munitions and 20 mm projectiles) the required primary field strength with a 40 m x 40 m loop is of the order of 10000 nT. With the MPTX using 35 mm^2 wire, this can be achieved using a single turn loop which has a correspondingly low inductance. In order for any other commercially available system to generate a field of that strength, the loop size would be much less, and would require many more turns of a higher resistance wire because of their electrical current limitations. This results in a much higher inductance. This is undesirable because it degrades early-time performance, reducing the ability to detect smaller items.

Even though we have chosen 40 m x 40 m and 110 m x 110 m as the standard loop sizes, the system can be configured with any sized loop. When referring to the loop size and required primary field for a particular UXO problem, the starting point is to consider the size and depth of ordnance items requiring detection. In the case of APG2 and YPG, the range of sizes is very large (20 mm to 155 mm projectiles) so a compromise configuration was required. For instance, as shown in the Newholme trials, large deep items can be detected using a 110 m loop with a corresponding gain in survey efficiency. If only items of 76 mm or less were required to be detected, loops smaller than 40 m x 40 m would be used in order to boost the primary field even higher than the usual target level of 10000 nT level, resulting in much higher SNR than that demonstrated here. The former example is discussed in more detail in Section 7.2. Unfortunately, the latter example has not been demonstrated other than by indirect means where one can look at the significant improvement in detection of smaller items between APG1 and AGP2 because a higher primary field was being used (refer to Figures 11 and 33).

Having discussed the versatility of the MPTX in terms of loop size and design current/primary field, which relates to the transmitter, it is appropriate to next discuss the receiver – the quad sensor magnetometer – which also has great versatility in how it can be deployed. At APG1 the receiver was configured as a man-carried quad sensor array (refer to Figure 3), whereas for APG2 and YPG it was configured with a quad sensor on a wheeled trolley (refer to Figures 4 and 26). Both arrangements have their advantages, and clearly the wheeled trolley is ideal for use at locations such as the APG and YPG Open Fields. The wheeled trolley has no hope of being used at other locations such as that illustrated in Figure 32, where the system was successfully trialed. The well known Limestone Hills in Montana represents a good example of terrain as rugged and steep as which one would expect to find anywhere else, and would require deployment of the man-carried sensor array.

It should be noted that on the most extreme terrains, there is also the option of using the receiver as a dual sensor, if the site required the operators to be carrying a lighter load, so as to allow more flexibility with negotiating a rugged hill-side. Another point to note is that, if the MPTX is ever deployed in environments similar to Limestone Hills, there is a transmitter operating mode where we can change the wire configuration allowing the use of a longer feeder cable. This would reduce the number of transmitter/generator moves required which is the tactic employed at steep sites where it may be difficult to position them at the grid corners. That is, one would leave the heavy generator at one location say at the top of the hill, while the loop is moved over the hill side as required. This approach was successfully demonstrated at the trials in 2003, prior to the development of the MPTX.

5. Maintenance:

The SAM UXO system is one that incorporates a mixture of mechanical, electrical and electronic components that are generally being run on a continuous basis during the working day, for many consecutive days. The system requires a minimal amount of maintenance in order to achieve reliable operations in this manner. There are some tasks that are required to be performed on a daily basis that can be classified as maintenance, namely the refueling of the motor as required and overnight charging of various batteries. Other tasks are undertaken on a weekly basis such as tightening nylon nuts/bolts on the sensor trolley and cleaning the engine air filter. The numerous system checks such as instrument cable connections, transmitter support mountings on the trailer, engine oil, loop cable insulation and fuel lines should also be considered as maintenance.

If, in the long term, the maintenance activities are able to be restricted to those listed, then it will be noted that this performance objective has been successfully met. During the course of the surveys at APG and YPG, particular attention was given to these activities in order to determine that the maintenance plan was adequate to ensure long term reliable operations. As mentioned in Section 3 Reliability, there were a few mishaps at APG2 relating to poor choice of components and one error by an operator. Despite these minor incidents, the performance objective is considered to have been successfully met because the continuous level of stated maintenance during the conduct of the two trials was found to be sufficient. Performance matched the experience prior to those surveys, and in the period since. Other factors that have been considered as supporting this conclusion are the fact that the total time spent on maintenance is quite low, are not complex and require a minimal level of skill.

6. System Function:

There are a number of factors that can be assessed as qualitative criteria relating to system function that have been included as performance criteria. They are considered as crucial factors in the overall system operations. Therefore, their correct functioning will provide feedback for the overall design process. Failures in these factors could potentially lead to design modifications. In the case of a lack of failure, we can assume the current design is adequate and this performance objective has been met.

These factors are listed as follows:

- There were no ‘bugs’ encountered in the system firmware or processing software during the trial period.
- The MPTX can be run all day without overheating (not counting the odd occasion at the hottest part of the day in Yuma in what can be considered very extreme conditions).
- The various commonly monitored MPTX parameters, such as current, voltage and resistance, all followed levels that match the design specification.

- The Bluetooth wireless link between the hand-held computer running the user interface and MPTX controller works satisfactorily when the operator is on the survey grid 30- 40 meters away from the MPTX.
- There were no logistical problems associated with moving the generator and MPTX continuously across the site, grid by grid,
- There were no timing problems with the GPS synchronization between the MPTX and TM-6, ensuring the stacking of waveforms to produce the required output was free of error.
- The time stamping of input data based on a sophisticated scheme supported by the GPS 1 second pulse was adequate in ensuring there were no errors in geo-referencing, typically seen as herring-bone patterns in anomalies, or other data mismatches.
- The TM-6 is able to handle the computational overhead associated with sampling four sensors at 4800 samples per second and logging DGPS position information through a serial port.
- There were very few sensor dropouts present in the data record.
- There was no loss of data on any day due to hardware or software failure.

The satisfactory operation of the system, especially with respect to the above listed factors can justify the conclusion that this performance objective is being met.

7. Site Coverage:

If a survey specification calls for 100% coverage of an area, it is expected that the whole area is scanned by the sensor in a manner that ensures all areas of ground fall within the sphere of influence of that sensor. Reasons for less than 100% coverage might include the presence of obstacles such as vegetation or structures (e.g. power poles, fences) poor operator technique with respect to maintaining straight lines during traverses, or bad data that went unnoticed during the initial QC check, resulting in ‘holes’ in the overall coverage.

At both APG2 and YPG the rectangle shaped Calibration Grids were able to be covered with a single loop setup. The Blind Grids in both cases were slightly larger and required two adjacent loops to complete the 100% coverage. Both open fields were irregular polygons and because our survey technique is based on squares, full coverage of those areas was more difficult.

- The survey methodology is based on setting out a 40 m wire loop but will only survey a 30 m area within that loop since the sensor / receiver becomes saturated too close to the wire (the magnetometer sensor ceases to function if the signal level is too high or if the vector moves into the dead zone). Therefore it is always important that we were able to deploy the loop outside the area defined. Operating close to fences or roads becomes problematic and this did cause some slight difficulties in some areas at APG, but not enough to prevent acquisition of the required data. YPG presented no problems in this regard.
- The 3-wheeled trolley was adopted as a technique to ensure systematic uniform coverage of the ground, combined with aids that included a sighter at the halfway point of every traverse (to help the operator maintain a straight line), and short traverse lines, all of which ensure the surveyed 30 m x 30 m block is fully covered.

- The whole site is covered as a series of grids, with overlap between adjacent grids – common boundaries and lines that start and end before and after the boundary respectively.
- The sensor spacing and height are important considerations, which are chosen according to the spatial sampling requirements of the smallest items known to be present in the ground.

8. Readiness for Commercial Application:

As a performance objective, the readiness for commercial applications is a statement that summarizes the outcome of the assessment of all of the other qualitative and quantitative criteria. The trials have been undertaken as the final part of a long research and development program, and the ultimate goal of that process has been to develop a commercially viable system.

The system is considered to be ready for commercial application with one qualification. All aspects of the hardware, firmware and preprocessing software are complete and well tested. The only remaining area where more work is required is with the detailed data processing and interpretation required for discrimination and classification. Recent progress in this area has indicated that this too is close to completion. The remaining task of testing the YPG open field data is on-going, beyond the scope of this report, but will eventually be reported to the public domain by other means. This isn't thought to be an impediment to commercial application, because we have successfully completed several commercial applications since YPG. The present level of data interpretation has proven to be satisfactory.

3.2 Quantitative Criteria

1. Target Signal/Noise Ratio:

Signal/Noise Ratio (SNR) is widely accepted as the best method of comparing the strengths of responses that are being compared in scenarios such as that being discussed here (APG2/YPG), where a new system is being trialed at two locations, and we are interested in determining if it represents an improvement over previously tested older technology (APG1). It is also common practice to quote the detection limit in terms of the SNR, and a value of SNR = 2 is often used in many disciplines. In practice, with SAM UXO, it has been found that clear detection of targets with much lower SNR's have been possible because the typical TFEMI dipole target has a response with a low spatial frequency characteristic that means it will clearly stand out amongst a background of much higher spatial frequency noise.

Results obtained from the Calibration Grids have been used to calculate the SNR's of weak anomalies. Of particular interest were a number of different ordnance items representing a range of target depths and sizes that were not detected at APG1, but were detected at APG2 and YPG. Some of these targets were detected with SNR's of the order of 1.1 to 1.4, and this result agrees with previous trials at Newholme, as illustrated in Figure 17, where the MPTX is seen to have a clear detection advantage over the GGT-10, as the SNR approaches the detection limit. These results exceeded the expectation that SNR's of between 1.5 and 2.0 might have been appropriate to use based on work in other similar disciplines.

2. Target Detection Depths:

One the most widely asked questions of any ordnance detection system would be "how deep can it detect this type of ordnance"? Therefore it is quite reasonable that detection depth should be used as a performance criterion, especially because it is one of the variables along with orientation that has been used in the design of the Standardized UXO Technology Demonstration Site Program, where a range of ordnance types have been buried at the two locations, with identical depth/orientation combinations.

Figure 21 is a plot of ordnance depth and size, which is a common approach to summarizing detection depth. In this case, the figure is simply indicating the range of depths at which different sized ordnance items are buried at APG's Calibration Grid, an early configuration of the APG Blind Grid (as surveyed at APG1) and the Newholme Grid. The Blind Grid data was able to be plotted because that truth data subsequently became public information. Figure 10 is the same type of plot illustrating the actual depth detection achieved at the APG1 survey on the Blind Grid. Figure 39 is the same plot showing actual depth detection achieved at the APG2 and YPG Calibration Grid. In all three figures, lines or symbols indicate the depth corresponding to Depth = 11 x Diameter, which is recognized as a *de facto* standard that indicates the required depth detection for different sizes of projectiles.

In looking at Figure 39, the reasonable conclusion to draw is that all but one projectile with a size of 37 mm or greater was detected at least to the 11 x Diameter depth. The smaller items (20 mm projectile, sub-munitions and grenades) were detected with mixed success. That is, identical items at the same depths were detected in some cases but not all. A number of the larger projectiles were buried at depths well beyond the 11 x Diameter depth, but none of these were detected. Larger Mk 82 bombs at Newholme have been shown to be detectable beyond their 11 x Diameter depth (Figure 13).

It is important to qualify these results with a statement about the primary field used for their detection. That is, as has been shown with larger items (Newholme bombs), as well as the comparison of results from APG1 and APG2, increasing the primary field can bring items into the detection range. If a survey required detection of smaller items in the future, the target primary field of 10000 nT which is suitable for projectiles would need to be increased for the smaller sub-munitions and grenades.

3. EM Decay Quality:

The quality of the EM decay is a performance criterion that is mainly of interest to discrimination rather than actual detection of an item *per se*, as in the case of data submitted to ATC for the Response Stage analysis. Figures 14, 15, 46 and 47 illustrate the merits of using the EM decay as a means of comparing the response of the same item to different transmitters, because that difference is so apparent in a qualitative sense. For discrimination, there are a number of characteristic parameters that can be extracted from the decay, including derivation of magnetic moments through inversion. Some convenient measure of the quality of the decay could therefore provide an indicator of the likely success of the various analysis techniques.

This performance criteria aims to quantify what is generally quite apparent visually when the late time portion of the decay from typical ordnance items is observed on a semi-log scale where the well known exponential decay is seen as straight line. If an exponential model is fitted to the late time target response, one could use the correlation coefficient as an indicator of how well the data fits the given model, especially as one considers a fit that extends down close to the noise floor. In this way, the metric for measuring EM decay quality can be the relationship between the correlation coefficient and the signal/noise ratio, as observed in Figure 43.

All of the items in the Calibration Grid at APG2 were analyzed in the manner described (i.e. fit an exponential model to the late time decay) with the result that for a range of signal / noise ratios of 1.03 to 4.87, the correlation coefficients (R^2) ranged from 0.981 to 0.998. This result is one that is considered to be quite encouraging for future discrimination work, and the performance success criterion is considered as being met with a result that is quite satisfactory.

4. Probability of Detection:

The probability of detection of ordnance (P_{do}) or clutter (P_{dc}) provides a measure of the system's ability to detect all of the emplaced ordnance or clutter items in the seeded sites. They are probably the single most important criteria of interest to many of the people interested in the Standardized UXO Technology Demonstration Site Program. A perfect score of 1.0 indicates the system has detected all emplaced items, which is always the goal of any ordnance detection/clearance task.

This metric is obviously useful for comparing different systems that are trialed over the same seeded sites, but to some extent is influenced by subjective factors that relate to the need for the data processor to nominate a detection threshold, so that the detection task can be automated. It is also related to software processing factors that relate to how well the processing can suppress noise and enhance signal, and hardware factors (primary field strength, receiver sensitivity).

Three seeded sites at both APG2 and YPG were surveyed. At one of the three (Calibration Grid) the truth data was available at the time of the surveying, therefore a probability of detection does not apply in that case. For the Blind Grids, a finite set of possible target locations are laid out on a regular grid, and an unknown number of ordnance and clutter items are buried at these known locations. The probability of detection, in this case, is calculated as the ratio of the reported number of ordnance or clutter items to the actual known number. The truth data for this total known number of ordnance or clutter items is typically not revealed for a period of the order of years after the sites were configured. On the Open Field, the ordnance and clutter items are buried at random locations, and the probability of detection is calculated the same way as with the Blind Grid, based on list of possible ordnance items submitted to ATC for scoring. The results from the ATC scoring are provide in a report sent to us, and is also publically available.

The data presented in Table 6 (provided by ATC), groups all ordnance sizes together, and the result is less than satisfactory, since the performance success criteria were not met. However, when the items are considered on the basis of size, and grouped into three size categories as illustrated in Section 7.2 Table 12, a better indication of performance is revealed. It is only for the smaller ordnance items (less than 37 mm proj.) that the result is unsatisfactory. Clearly the SAM UXO system is not suited to detecting these small items. In contrast to this result, detection of the medium to large ordnance and clutter items can be considered satisfactory because they come much closer to achieving the success criteria.

5. Background Alarms:

The background alarm rate (BAR) is a metric that provides an indication of the number of nominated ordnance or clutter detections that do not correspond to any items emplaced by ATC. As such one has to presume they represent noise. As a performance criterion, it has relevance because false targets represent wasted effort at the time of anomaly investigation. Therefore, it is desirable that they are kept to a minimum. It is a criterion that is linked to the probability of detection (P_d) because in order to maximize P_d, the interpreter might be tempted to include responses whose amplitude is within the known noise, simply because they have a similar spatial appearance to known targets. Background alarms would usually be anomalies of this nature with very low amplitude. This metric needs to be considered alongside the P_d because a high P_d and a high background alarm rate indicates that many of the items in the seeded site represent items close to the detection limit of the system. The ideal result is a high P_d and a low background alarm rate, indicating most targets are probably being detected with a good SNR.

BAR is calculated as the ratio of the number of reported detections that do not correspond to known emplaced items to the known number of actual emplaced items (i.e. known to ATC but not to us).

The data for BAR listed in Table 6 represent a result that one should consider as borderline to satisfactorily meeting the success criteria. One reason for this result is the fact that many of the smaller items are being detected with a signal/noise ratio close to the detection limit, of the order of 1.1 to 1.3, and it is therefore not surprising that some of the detections do in fact represent a geological clutter or noise response.

6. Location Accuracy:

Location accuracy is another performance criterion that has implications for the required effort at the time of anomaly investigation. If the quoted location of an ordnance item is accurate, the investigators should be able to relocate the target easily with a minimum of effort, particularly with respect to the required amount of digging. Factors influencing location accuracy include the type of DGPS system being used, whether it is being operated correctly, how the position information is merged with the sensor data, and how a usually broad anomaly that is usually dipole shaped is assigned a point location.

This criterion refers to the positional difference between the actual item's true location (part of ATC's Truth Database) and the predicted location supplied with the detection results. The result for the Open Field was provided to us by ATC in their published reports of our trials, For the APG2 Open Field, the mean of the location errors of the items = 0.085 m, with a standard deviation of 0.2 m, which is considered satisfactory. Given that UXO technicians would use the predicted locations to relocate the items using DGPS to navigate to that location and then use a metal detector to pinpoint the item, an error less than 0.25m has to be considered as satisfactory from a practical point of view. This is less than the size of a typical metal detector coil that might be used for that task.

7. Survey Rate:

The survey rate is a measure of the rate of coverage of the survey area, usually quoted in units of acres per day. It has implications for the cost of surveying, and can potentially determine the viability of the system. The data for survey rate has been accumulated from a number of sources that include ATC and GapGeo operator logs, as well as time data embedded in the sensor data and transmitter digital log.

The two major activities that are carried out throughout the day are:

1. Laying out the wire loop as a 40 m x 40 m square and setting up the transmitter.
2. Surveying a grid measuring 30 m x 30 m inside the wire loop with the magnetometer.

The efficiency with which both of these activities are carried out has an equal impact on the overall survey rate. One key factor is being able to survey ground as a sequence of adjacent blocks, since this allows for the minimal transfer of the wire loop each time. Data based on performance at APG1, APG2 and YPG is considered indicative but not definitive, because this field work had multiple objectives and was subjected to constraints that influenced the work rate, some of which would not normally be present in a commercial environment. For example the high summer temperature encountered at Yuma lead to a work rate that was lower than normal in order to avoid having to work at the hottest part of the day. For this reason, a fairly modest survey target was set for each day's activities. Another factor that determined overall work rate at APG2 was that time spent setting up the loops, on occasions, was far greater than normal due to being forced to move back and forth between opposite ends of the range to fit in with other range activities.

8. Processing Time:

The time required to process and interpret the data is a factor that influences the cost of the method since it involves the labor of highly skilled personnel. In the commercial environment it is important to turn around data in a timely manner and one way this can be achieved is with appropriate software tools. One guideline based on experience with other methods is 1 day of processing for every day of data collection or a ratio of 1:1.

A lot of effort has gone into streamlining the pre-processing software that converts the raw sensor data into geo-referenced response data with a suitable format for input to the mapping and interpretation packages. Automatic procedures can then be used to pick anomalies of interest that are then subjected to detailed analysis.

9. System Function:

As previously discussed, there are a number of qualitative factors to consider as indicators of performance through consideration of system function. There are a number of quantitative criteria relating to system function that are being included as performance criteria because they are considered as crucial factors in the overall system operation. These are listed as follows:

- the output current level is extremely stable between successive on-times,
- a consistent primary field can be maintained within grids (during time taken to survey one grid) and between grids,
- there is minimal noise from EM interference in the processed data because we are able to filter out any that is present, especially mains power,
- expect the system to function according to its specification as it has done in previous pre-demonstration trials.

4. Site Description

4.1 Site Selection

The Standardized UXO Technology Demonstration Sites at APG and YPG have been used as the main test sites for this development project. They were specifically established by the Govt. to provide a place where UXO detection and discrimination technologies can be tested in a controlled environment. GapGeo recognizes the importance of testing with a standardized approach where the same protocols must be followed by all demonstrators, thereby providing the best opportunity to evaluate the relative performance of emerging technologies such as SAM UXO and compare this with the existing systems. The baseline data set obtained from a first trial of a new system is also useful for evaluating performance improvements as that system goes through its development cycle, with repeated visits to the sites.

It was apparent from GapGeo's involvement in previous APG/YPG trials with other technologies that these demonstration sites contain a variety of terrain and contamination scenarios where a great deal of attention to detail has been applied to setting them up. This includes documenting the emplaced items accurately, providing a good mix of target types and sizes, depths and orientations, as well as using realistic examples of clutter. The sites were well prepared for the task, including detailed characterization of the environment (geology, soils and geophysical properties) as well as on-going monitoring of variables such as rainfall and soil moisture. They are generally regarded as being quite representative of realistic conditions likely to be encountered by detection systems in commercial applications.

The infrastructure in place at each site and the involvement of site personnel ensures demonstrations can be undertaken with high efficiency and minimal effort in logistical tasks (e.g. overnight battery charging and secure storage of equipment), access to detailed information about site characteristics and access to actual ordnance items for testing purposes.

There was value in trialing the system at the two different demonstration sites because they represented quite different climates, geology and soil types but similar scenarios in terms of ordnance types, depths and orientations, therefore providing an opportunity to assess the relative influence of the environmental factors in overall performance.

The APG site was visited on two occasions, firstly in June 2004 using an off-the-shelf transmitter, followed by another in June 2007 with the new purpose-built-transmitter. The YPG site was visited a year later in June 2008, again using the new transmitter. The two visits to APG provided an opportunity to highlight the extent to which the system performance had been improved with the development of the new transmitter.

The different scenarios at each site are referred to as the Calibration Grid, the Blind Grid, the Open Field, Moguls and Wooded Area. During the first APG visit, all scenarios were sampled, including three different positioning technologies (DGPS, RTS and Cotton Odometer). Due to logistical and time constraints, only the Calibration Grid, Blind Grid and Open Field were trialed at the 2nd APG visit and at YPG.

The three main scenarios, trialed at APG2 and YPG, had differing value to the overall objectives, as discussed next.

(i) Calibration Grid

Surveying the Calibration Grid provided a chance to obtain good quality target responses for which the full truth information was available at the time of the survey (i.e. target type, size, weight, depth and orientation). Incorporation of the information into a library of target responses has provided a valuable data set for future development of statistics–based discrimination algorithms, and training sets to establish key correlations between various derived target response parameters, with respect to their grouping (ordnance or non-ordnance).

The Calibration Grid had a mix of items that included some we already knew were a challenge to detect (the smaller items) and others that were more easily detected (the larger items). It also provided an opportunity to understand the influence of site specific variables such as soil, terrain and climatic factors.

An important use of the data has been to develop depth detection limits for different ordnance items given that the same items have been buried at a range of depths and a relationship between SNR and depth has been derived. The known ability of a system to detect certain items at given depths is often a key criterion used for determining suitability of a system for a particular project.

The Calibration Grid also served an important role in providing an ideal location for testing equipment function at the start of each site visit.

Perhaps the most important work undertaken on the Calibration Grid was a series of repeated passes that trialed different instrument parameters, in order to obtain data that was used to determine optimal survey configurations. Some of these passes were performed for academic reasons, to study the effect of certain variables, in order to gain a better understanding of the system.

(ii) Blind Grid

Because each test location in the Blind Grid was marked, the analysis of the scored results provided an opportunity to gauge system performance that is independent of normal instrument related factors such as positioning method and sensor platform. It also provided a good opportunity to test the accuracy of the methodology being employed to determine XY position of the data prior to handing all results in to ATC.

The true value of the Blind Grid in this development project was realized when the APG truth data was released since it provided a much larger data set than the Calibration Grid alone, for establishing a target response library that also included clutter items. Figure 21 highlights the broader range of ordnance sizes and depths included in the Blind Grid.

To a limited extent one can also use the results to obtain some idea of the likely range of response parameters from the other scenarios, since it is possible to use this data to obtain examples of both maximum and minimum signal levels. This usefulness is dependent on an assumption that the Blind Grid targets are representative of targets in the other scenarios.

(iii) Open Field

The open field was considered to be a good test of what one should expect in a realistic survey. There was sufficient work over enough days to provide a good measure of the average survey productivity, to illustrate the benefit gained from teamwork and momentum, to determine the types of problems likely to cause down-time (e.g. fieldwork limitations imposed by satellite availability or bad weather), and to test the equipment reliability because it is being forced to run for many consecutive days (equipment overheating, cable connections, battery performance). In general, it was well suited to providing the necessary data to properly assess the qualitative performance criteria and document the performance of the entire system in actual range operations.

Compared to the Calibration Grid and Blind Grid, the open field provided the best clutter dataset and therefore the best opportunity to generate data for testing discrimination algorithms, especially with the benefit of the truth data which became available for APG in early 2009.

Because our unique data collection methodology covers the site as a series of independently acquired small grids, one has to assume that there could be difficulties associated with analyzing data from items located on a grid boundary. The analysis of the open field data set provided a good opportunity to investigate if there is a loss in data quality or detection capability through ‘grid stitching’ issues, i.e. how well two adjacent grids can be joined. As it turned out, there were grids collected in the APG and YPG open fields with items located near grid boundaries, and they were adequately resolved.

4.2 Site History

The APG/YPG sites have been in use by different vendors for demonstration and validation of new UXO detection technologies since 2001-2, and are still in constant use today. Military activities at these sites prior to their development as test sites are unknown but likely to have been normal range activities typical of any army proving ground. These activities prior to the creation of the sites in their current form are considered irrelevant since a great deal of effort went into decontaminating the ground which was cleared of all potential false targets prior to emplacement of the seeded items, and at other times since then. Similar instruments to those used by vendors in their demonstrations were used for this preparation work. Periodically the sites are reconfigured so that truth data may become available. This involves digging up emplaced items and burying them somewhere else, fully documenting their new locations, depths and orientations.

From time to time the test sites have been reconfigured and this provides an opportunity for ATC to provide the truth data to researchers. Through this process, truth data has been obtained for the APG 2004 and 2007 surveys, for the Blind Grids and partial open fields. The most recent reconfiguration provided ATC with an opportunity to revise their overall strategy and change the nature of the scenarios as well.

Figures 22 and 23 are maps of the two demonstration areas and the following discussion summarizes the physical attributes of the various scenarios at these sites.

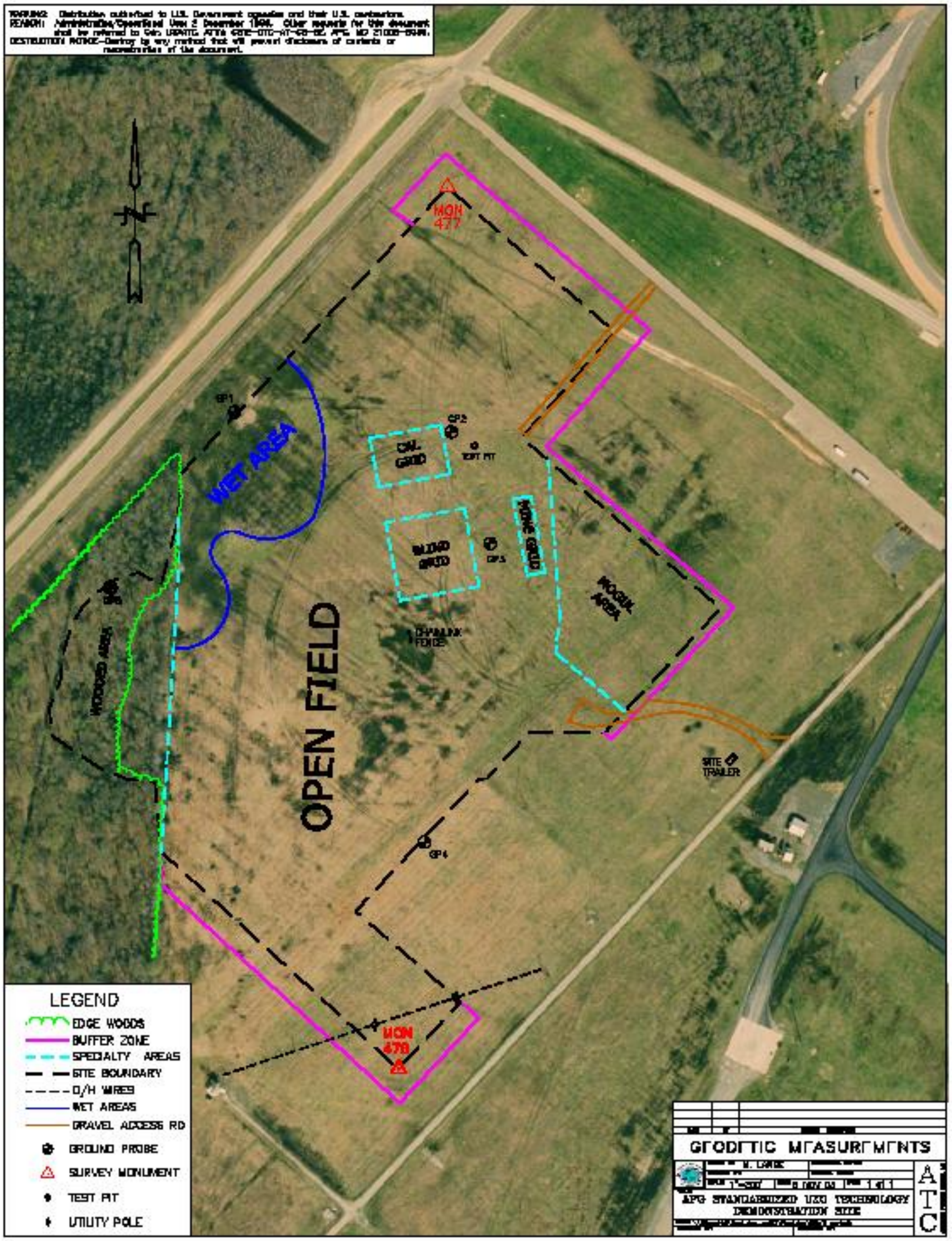


Figure 22 APG UXO Demonstration Area Site Map

Description of Site Scenarios

(i) The APG Calibration Grid (0.3 acres, flat, grass)

Figure 22 is a photo of the APG test site and shows the location of the Calibration Grid at the northern end of the site within the open field survey area, just north of the Blind Grid and to the west of the mogul area. Seventeen lanes contain six identical munitions buried in various orientations and at three different depths. One lane contains four steel spheres buried at a depth of 0.5 to 2 meters. Another lane contains two each (30.48 cm and 60.96 cm diameter) circular steel plates buried at 0.3048 m (1ft) and 0.9144 m (3 ft) respectively. A third lane contains 15 cm and 30 cm diameter copper wire hoops (12, 16, 18 and 20 gauge) buried at 0.3 meters depth. The wire hoop gives a standard signature dominated by a single exponential decay which therefore provides a means to test the instruments accuracy in measuring that known response.

Ordnance items that were generally oblong in shape (aspect ratio not equal to one) were buried in the ground in six orientations and at three different depths. Ordnance that were more rounded in shape (aspect ratio of one) were buried at three different depths. The first and last item in each calibration lane contains a 3.6 kg steel ball (8.9 cm diameter) buried at a depth of 0.15 m to provide a uniform signature that can be easily identified when viewing the data.

(ii) The APG Blind Test Grid (0.48 acres, flat, grass)

The APG blind test grid is located just to the south of the Calibration Grid, close to the centre of the site and is also within the open field area. It consists of a 3000 square meter area that can be expanded to encompass a 4000 square meter area in the future. The blind test grid is made up of the same type of munitions found in the Calibration Grid and open field area. Clutter items may include scrap metal, exploded ordnance debris, wood, rocks, tree roots, etc.

(iii) The APG Open Field (13.68 acres, flat, grass)

The open field forms an irregular shape, with the tree covered area along part of the western boundary and the mogul area along part of the eastern boundary. This test area provides a variety of realistic scenarios essential for evaluating sensor system performance. The scenarios and challenges found in the open field consist of a gravel road, wet areas, dips, ruts and trees. Vegetation height varies from 15 to 25 centimeters. Other challenges on the open field include electrical lines, swales, stone pads/roads, and metallic fencing. All of these features are designed to test the capability of the different types of sensor platforms and hand-carried detectors in dealing with typical cultural features typically found in ranges and areas requiring UXO clearance.

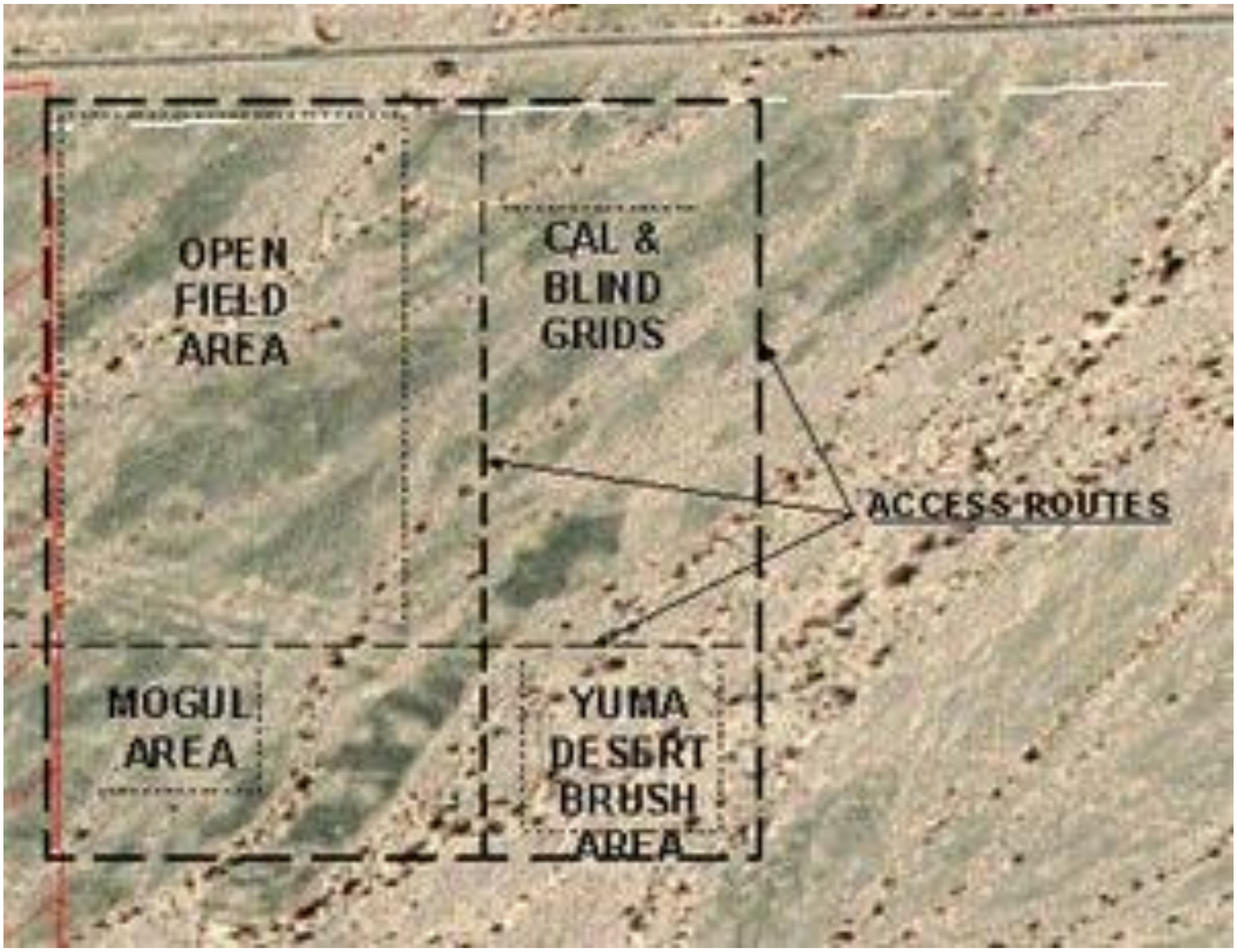


Figure 23   YPG UXO Demonstration Area Site Map

(iv) The YPG Calibration Grid (0.43 acres)

Figure 23 is a photo of the YPG test site and shows the location of the Calibration Grid relative to the other scenarios, in the north-east corner of the block. The layout and configuration of targets in the Calibration Grid at YPG is identical to the Calibration Grid at APG. Therefore it is possible to obtain two data sets that should only have differences reflecting the different physical environments, assuming the operator survey techniques is identical at both sites.

(v) The YPG Blind Test Grid (0.27 acres)

The blind test grid is located adjacent to the Calibration Grid in the north-eastern corner of the YPG test site, east of the open field range and consists of a 1600 square meter area. The blind test grid includes the same type of ordnance found in the Calibration Grid and open field area. Clutter items may include metal debris, rocks, desert vegetation roots, etc.

(vi) The YPG Open Field Area (15.38 acres)

The open field dominates the western half of the YPG test site and is the largest of the test areas, measuring approximately 200 by 350 meters. This area provides the demonstrator with a variety of realistic scenarios essential for evaluating sensor system performance. Challenges include flat open areas, dips, ruts, electrical lines, metallic fencing, desert extreme, stone pads and roadway areas, gullies and desert brush vegetation. There are thousands of surveyed grid cells within the Open Field area. At the center of each grid cell, the demonstrator will find either ordnance, range clutter or nothing. Some parts of this area can be are covered with desert brush type vegetation and overall is used to test the performance of different sensor platforms in a desert environment that is considered to represent severe conditions. The soils in this region may have a horizon of calcium carbonates that tend to cement together in the soil, producing hard layers in the subsurface. Ground temperature can reach up to 160°F by early afternoon. Spring time air temperatures in shaded areas can exceed 110°F.

Present Operations

The APG/YPG sites have been in constant use by a large number of demonstrators and a wide range of different instruments since 2001-2, and this will continue into the foreseeable future. Periodically the sites have been reconfigured so that truth data was able to be published. This involved digging up emplaced items and burying them at new locations within each scenario area, fully documenting their new locations, depths and orientations. The detailed truth data that included target dimensions, photographs, depth and orientation along with instrument responses becomes a valuable resource for researchers, providing for example training data for statistically-based classification schemes. The fact that the clutter targets receive as much attention as the ordnance in the compiled data adds to its value. Therefore the importance of the periodic reconfiguration should not be under-estimated.

Both sites are located on active U.S. Army establishments and therefore access to these sites is under strict control. The sites are the key facilities being used by the Standardized UXO Technology Demonstration Site Program and they are also used for similar activities by other Government sponsored programs. Present activities are centered on the day-to-day conduct of that program and include maintenance tasks such as vegetation control (mowing grass) and keeping the facilities in good order. Both sites have permanent staff involved in administration of the Standardized UXO Technology Demonstration Site Program, including monitoring of environmental conditions, supervising demonstrators, documenting their activities for the official record, scoring their submitted results and producing reports of their achievement.

The APG site includes a number of additional facilities that are available to researchers for specialized studies such as landmine detection and ordnance characterization in air using a non-metallic test tower to support instrumentation above ordnance placed on the ground surface.

4.3 Types of Munitions Present

Table 7 summarizes the 14 ordnance types used at the two demonstration sites.

Table 7 Description of Ordnance at Demonstration Sites

Type	Description	Length (mm)	Width (mm)	Aspect Ratio	Weight (lbs)	L-Large, M-Medium, S-Small,
20 MM	20 MM M55	25	20	1.25	0.25	S
40MM	40 MM MK II	179	40	4.48	1.55	S
40MM	40 MM M385	80	40	2.00	0.55	S
M42	SUBMUNITION	62	40	1.55	0.35	S
BLU-26	SUBMUNITION	66	66	1.00	0.95	S
BDU-28	SUBMUNITION	97	67	1.45	1.70	S
57MM	57MM M86	170	57	2.98	6.00	M
MK118	MK118 ROCKEYE	344	50	6.88	1.35	M
60MM	60 MM M49A3	243	60	4.05	2.90	M
81MM	81MM M374	480	81	5.93	8.75	M
M230	2.75" ROCKET	761	75	10.15	18.20	M
105MM	M456 HEAT RD	640	105	6.10	19.65	L
105MM	105MM M60	426	105	4.06	28.35	L
155MM	155MM M483A1	870	155	5.61	56.45	L

5. Test Design

5.1 Conceptual Experimental Design

The APG/YPG sites have been subjected to a large number of surveys by various vendors using a range of technologies, most of which have been based on either magnetometry or electromagnetic induction. All of the results are publicly available and provide a means of benchmarking the performance of the SAM UXO system against the state-of-the-art. The ATC who are responsible for scoring the submitted results provide detailed reports in a standard format that includes a range of statistical analyses that are designed to provide information that can be used for performance comparisons between the different technologies that have been trialed.

The SAM UXO system itself was initially trialed at APG in May 2004 (APG1), using an off-the-shelf transmitter (the Zonge GGT-10). Two later demonstrations, one at APG in June 2007 (APG2) and the other at YPG in June 2008, used the new purpose-built SAM MPTX transmitter. Therefore, a comparison of the results from the three surveys (e.g. SNR differences for the same items) has provided an indication of the level of improvement that has been achieved, during the conduct of this ESTCP funded development.

The data collected previously was used in a number of different ways, some related to hardware issues and others related to software. The following summary provides an indication of the number of items for which truth data is available:

(i) Calibration Grid: 91 clutter, 82 ordnance

(ii) Open Field: 198 clutter, 129 ordnance

(iii) Blind Grid: 118 clutter, 91 ordnance

(iv) Other Sites: 88 clutter (non-military scrap and exploded ordnance debris

(v) Newholme: 38 ordnance

This data has provided us with a reasonable truth dataset for use as a baseline, and although some of it was collected with a different transmitter, a lot of the data still has sufficient S/N to provide a good characterization of the mix of ordnance items. More importantly it is apparent that the data set also includes a large collection of clutter items, and therefore has great value when used for the testing of new discrimination algorithms, in order to make judgments about which data parameters are the most useful.

In the context of the future use of the MPTX, the objective of obtaining the highest possible quality of data from these demonstrations took on considerable importance, in order to build up a larger truth dataset.

Table 8 summarizes the work undertaken using the SAM UXO detection system at APG2 and YPG and includes the sizes of the areas of each scenario at the two sites, the sensor conveyance methods, the number of 30 m x 30 m grids needed to cover each area, and the number of different passes using different instrument settings.

Table 8 Summary of APG2/YPG Surveying

Location	Scenario	Area (ha)	Area (acres)	Sensor Method	Number of Grids	Number of Passes
APG	Calibration Grid	0.12	0.30	Wheeled Trolley	1	7
	Blind Grid	0.19	0.48	Trolley	2	3
	Open Field	5.54	13.68	Trolley	76	1
YPG	Calibration Grid	0.17	0.43	Wheeled Trolley	1	4
	Blind Grid	0.11	0.27	Trolley	3	2
	Open Field	6.22	15.38	Trolley	78	1

In both the Calibration and Blind Grids, the survey lines that pass directly over the top of the buried ordnance items are known and well marked. Repeated passes with 3 and 4 sensor alternatives were conducted to provide samples of the two extremes of horizontal target/sensor offset. That is, the 3 sensor pass (with the same sensor separation as the 4 sensor arrangement) provided the maximum possible target response because the middle sensor was positioned to pass directly overhead of each target item and with that configuration the outer two sensors provided the minimum possible response. With 4 sensors, the traverse line was positioned in between the middle two sensors, and therefore provided a sample of the maximum likely response in the situation where the ordnance item does not pass directly overhead of an item. The analysis of these results was mainly of academic interest, and was intended to show the range of responses that can occur for given targets, based on the horizontal offset between the target and the sensor traverse line.

In practice, we expected both the 3 and 4 sensor passes to result in the same location for the target anomalies. Derived locations were based on gridded (interpolated) data so it was expected that the interpolated anomaly shape might vary slightly depending on horizontal offset. That is, we would expect both interpolated surfaces from the 3 and 4 sensor passes to be identical, except that the surface from 4 sensor pass should produce an interpolated maximum similar to that actually recorded in the profile. A detailed study of the actual decays was also used to investigate the variation relating horizontal offset between sensor and target. It was considered important to study this under controlled conditions.

At the start of the APG2 trials, a number of passes were conducted on the Calibration Grid with different instrument parameters, and these results were studied prior to the later surveys to ensure the optimal combination was selected for the Blind Grid and Open Field surveys. These are discussed in more detail in a later section.

In addition to the data obtained from the Calibration Grid, additional control data aimed at providing characterization of the 14 ordnance items referred to in Table 7 was obtained from a special trial conducted at the sand-pit facility at APG, located near the Calibration/Blind Grids.

The transmitter and loop was set-up as per normal centered on the pit and the response from the 14 ordnance items buried in the sand at shallow depths was measured.

There is a slight degree of variation in terrain conditions between the two demonstration sites, as discussed in detail in Section 3.3, however the vegetation, soils, geology and climate differences are more pronounced. APG can be described as lush with obvious effects from high rainfall, compared to YPG with is dry and sparse, with very little rainfall.

The mix of ordnance type, depth, density, and distribution pattern will vary between the different scenarios within each site, but are theoretically identical between the two sites. The Calibration and Blind Grids have an ordnance density specifically tailored to the specific purpose for those grids with items laid out in set patterns as described previously, whereas the open field has a more random distribution. Depth distribution in the Calibration Grid also follows set guidelines, but is more random in the Blind Grid and open field. Figure 21 summarizes the size/depth combinations of the ordnance items buried in the Calibration and Blind Grids in 2004, and Figure 39 is a similar figure for the APG2 / YPG Calibration Grid in 2007 and 2008 respectively, (after a site reconfiguration), showing the similarity.

5.2 Site Preparation

The main site preparation activities undertaken prior to the demonstration at APG2 were the routine maintenance activities performed by site personnel such as mowing of the grass. To a large extent groups such as ours arriving at these sites for their demonstrations are very much at the mercy of recent climatic events. This is particularly relevant to APG, where there is the possibility that it may be wet and muddy from rainfall. In general, vendors have to perform their demonstrations in the environment as they find it on arrival, without any specific opportunity to change the site conditions, if they are adverse. YPG with its quite different site conditions and climate required no grass mowing.

On the first day at APG2, the DGPS base station was set up at a local survey monument situated at the northern boundary, overlooking the whole area with an unobstructed line of sight. After the base station had been set-up, accuracy was tested by checking the measured coordinates against the positions provided by ATC for a number of known locations around the site, including another monument located at the southern boundary of the site. A similar procedure was followed at YPG.

When satisfied that our DGPS was running to the required accuracy, we used it to help set out a grid over the whole site, using small pin flags to mark each grid corner and each flag was labeled with its designated reference. Grid corners were 30 m apart, with the north-south line orientated to grid north (based on UTM coordinates) rather than magnetic north.

ATC have a site office adjacent to the APG survey area and this was used for storage of valuable equipment overnight as well as a place to leave batteries on overnight charge. Equipment cases, storage containers and shipping aids (pallets) were also stored in this facility. It was also used as a place to set up a laptop computer so data collected in the morning work session was checked during the lunch break. A similar facility was available at YPG and was used in the same manner.

5.3 System Specification

The two main categories of system operating parameters that are adjustable at any time relate to the transmitter and receiver. Careful choice of these parameters is essential in order to achieve the best possible data quality. Other system components that also influence data quality are the sensors themselves, the positioning system and the sensor platform.

Table 9 summarizes some of the more important transmitter/receiver parameter variations considered for these demonstrations.

Table 9 Summary of System Operation Parameters

Transmitter Frequency (Hz)	Duty Cycle (%)	On-time (ms)	Off-time (ms)	Current (A)	Primary Field (nT)	Number of Stacks / Overlap	Spatial Sampling Interval (m)
7.5	25	16.7	50.0	≈ 400	11150	8 / 50%	0.27
7.5	25	16.7	50.0	≈ 400	11150	16 / 50 %	0.54
15	50	16.7	16.7	≈ 300	8400	16 / 50 %	0.27

(i) Transmitter

Transmitter parameters include current mode, output voltage and current, frequency, duty cycle and loop configuration. The MPTX has three operating modes referred to as:

1. Constant Current – high stability and repeatability,
2. Controlled Current – lesser stability than the constant current device but allows a slightly higher current, and has less heat to dissipate in hot climate
3. Constant Voltage – for alternative loop configurations

In all three cases the transmitted waveform is a bipolar square wave. The shape of the waveform after it is turned on is exponential and depends on the resistance and inductance of the loop. The difference between constant current and controlled current modes is illustrated in Figure 12.

Once the current has reached its maximum level, the constant current device ensures the current levels off to a constant value for the bulk of the on-time, and this is repeatable between successive on-times with less than 0.5 % variation, ensuring a target is excited in an extremely uniform manner as the receiver passes overhead. For this reason the variation in the magnitude of the response can be truly attributed to geometric effects alone. The low inductance of the loop ensured the turn-off and transition to zero current was extremely rapid (of the order of 50 μs), which meant the pulse that excited the targets had significant high frequency components, that are needed to resolve the smaller ordnance items.

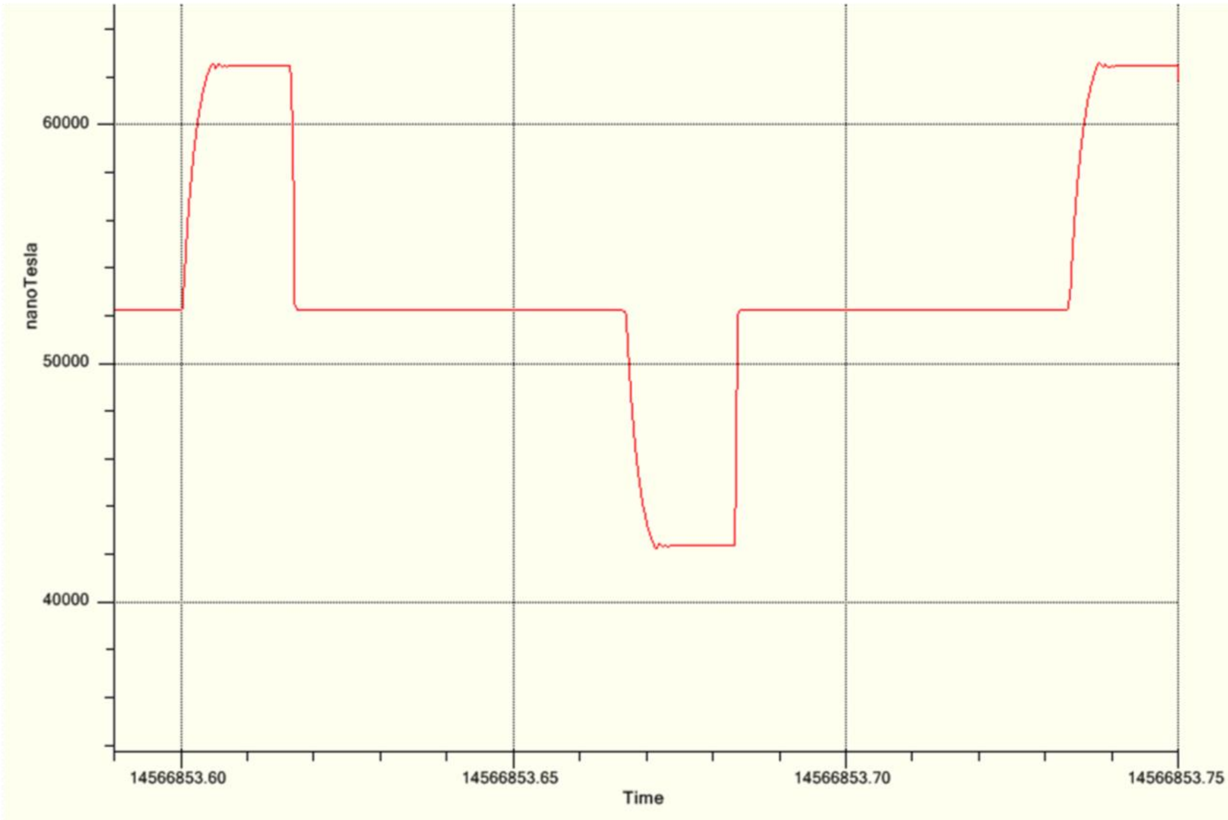


Figure 24 Transmitted Bipolar Waveform

At both the APG2 and YPG demonstrations, the system was used with a 40 m x 40 m square loop, with the MPTX set in Constant Current mode. The actual current was set to a level that was close to the maximum possible for the given combination of parameters and site conditions. As seen in Tables 2, 5 and 9, a higher current is possible with a lower transmitter frequency and duty cycle. The desire to maximize current contributed to the choice of parameters. The level that was finally achieved further depended on site specific conditions such as air temperature and elevation. The user-interface allowed the operator to step the current level up in increments of 10 amps. The normal procedure was to select a current just below the possible maximum for the selected parameters, then step it up until the engine started to labor, then back off again so the final selected level was one that the operator judged as able to be maintained comfortably by the engine and alternators.

The Calibration and Blind Grids were surveyed with a range of passes to obtain comparison data that was used to highlight the influence of the different settings, and which helped to establish the optimal combination of settings for the given site specific conditions at APG and YPG.

The factors that were considered when making these choices were discussed in detail in Section 2.2. For both the APG2 and YPG demonstrations, the optimal combination of parameters was deemed to be transmitter frequency = 7.5 Hz and duty cycle = 25 %. Figure 24 illustrates the bipolar waveform that was being transmitted at both APG2 and YPG for the bulk of the surveying. This waveform frequency/duty cycle combination resulted in an on-time of 16.67 ms and an off-time of 50 ms. The transmitter delivered a current into the single turn loop of about 390 amps, creating a primary field amplitude of the order of 10000 nT.

This combination was chosen because they met the following criteria:

(i) The on-time was sufficiently long enough to ensure the largest items likely to be present were sufficiently energized to produce their characteristic longest possible decay constant.

(ii) The off-time was sufficiently long enough to ensure the target decay from the largest items present was not being truncated before the signal level dropped to a point near the noise floor.

(iii) The lower frequency and longer off-time combination was one that allowed for the highest possible transmitter power and loop current, as this was considered important for detection of smaller items.

(iv) The resultant spatial sampling frequency was adequate to ensure the required level of sampling, to minimize under-sampling of the spatial anomalies from the smaller items.

(v) The high transmitter power being achieved was sufficient to adequately compensate for the SNR improvement normally associated with waveform stacking that another combination might have allowed if a lower power level was considered acceptable.

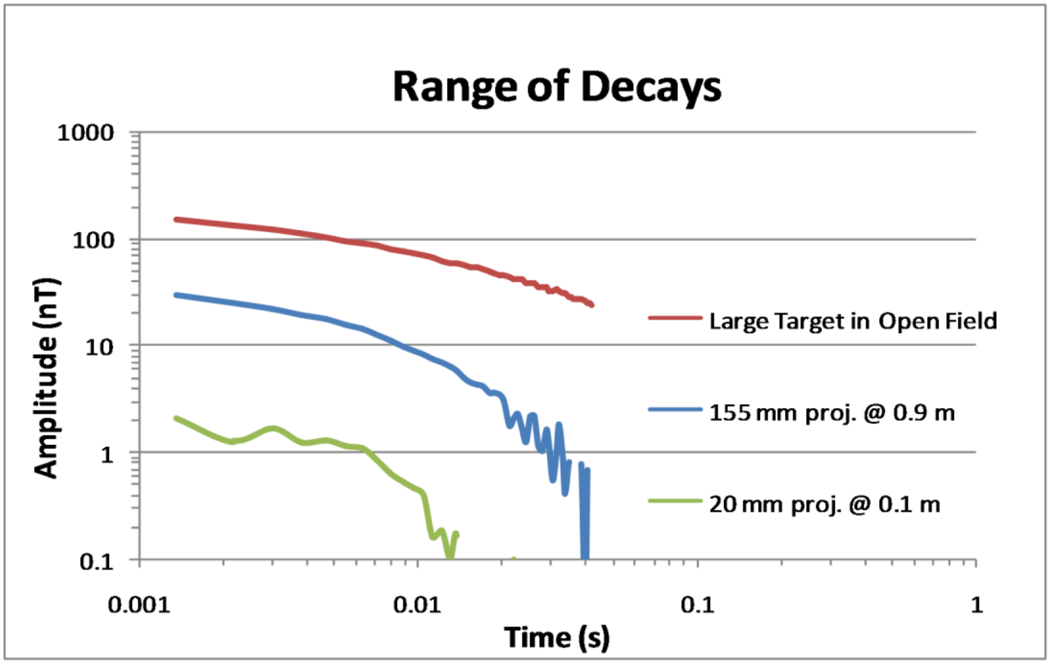


Figure 25 Range of Decays with Different Target Sizes

Figure 25 shows three decays from a small, medium, and large ordnance item, illustrating the variation in responses at APG2; including the likely minimum and maximum decay lengths. The 50 ms off-time is seen to be about right for targets of the size of the 155 mm projectile; however the decay from the larger target (probably a shallow Mk 82 500 lb bomb) is seen to be truncated.

One of the strengths of the SAM UXO system is the fact that these important system parameters can be easily selected and chosen to take account of the site specific conditions encountered at any new location, as well as being balanced against other factors such as survey objectives and ordnance sizes/depths likely to be encountered.

(ii) Receiver (TM-6 magnetometer)

The main selectable parameter relating to the receiver (TM-6 magnetometer) is the sampling frequency, which can be selected as one of 1200, 2400, 4800 or 9600 samples per second. At both the APG2 and YPG demonstrations the sampling frequency was set to 4800 samples per second. The exceptions were the initial trial passes over the Calibration and Blind Grids, where for academic reasons additional data was also collected at 1200 samples per second.

During the time interval between the two surveys in 2007/08, the system firmware was modified so that the data recorded at YPG was stored on disk in a more raw state. Even though it was recorded at 4800 sps, it could be later down-sampled so as to duplicate what it would have been if 1200 sps were selected for the actual survey. This new feature is one that has allowed a much improved flexibility with signal filtering. This was achieved by moving the down-sampling algorithm from the firmware into the pre-processing software.

All data is recorded in the TM-6 magnetometer onto a CompactFlash card in a proprietary binary format. The following list summarizes the data written to the file:

- NMEA GGA strings (1 per second, differential corrections already applied),
- magnetic sensor data or TM-6 frequency counter output (4800 samples per second) from 4 sensors, recorded as pT with 9 significant figures or 0.1 pT resolution,
- survey information, transmitter and receiver parameter settings embedded in the file headers,
- time-stamps with 1 μs resolution, recorded as seconds since midnight New Year's Eve and tagged to every data input, which in this case meant every individual magnetic sensor input and each GGA string.
- System parameters such as battery voltages (5 second intervals).

(Note: magnetic sensor data here refers to the raw data stream from the Cs sensor / frequency counter that includes both TMI and TFEMI components).

(iii) Positioning

All position information was acquired using RTK DGPS systems that provided differentially corrected information at a 1 Hz rate, which was interleaved with the magnetic sensor data in real-time and stored in the data file sequentially. The magnetic data was stored in a binary format while the position information was stored as ASCII.

As illustrated in Figures 27 and 31, the DGPS antenna was located on the sensor platform at a low height so as to minimize errors due to pitch, roll and yaw as the trolley traversed the ground, and in line with the central axis of the trolley. To convert the antenna position to sensor positions, the same offset was applied to all 4 sensors in the along-line direction. This is the normal practice, if it is assumed the trolley followed a straight line path. Across line offset corrections were applied according to the position of the sensors relative to the central axis.

(iv) Magnetometer Sensors

Standard Geometrics G-822AS sensors were used along with the TM-6 magnetometer to provide data with a resolution of 0.1 pT. The noise floor of the sensors has been measured to be about 0.12 nT RMS when the TM-6 magnetometer is set to a sampling frequency of 4800 sps, which is well below the 1 nT noise floor of the data typically being acquired during these trials.

(v) Sensor Platform

For APG2 and YPG, the TM-6 magnetometer was operated with a quad-sensor configuration, and a hand-pushed three-wheeled timber trolley was used for sensor conveyance, illustrated in Figures 27 and 31. This was a departure from the configuration used at APG1, which used the hand-held array illustrated in Figure 3.

5.4 Calibration Activities

The equipment was fully tested at our Newholme facility prior to packing for shipment to the USA in May 2007. This testing simulated the actual survey method, with emphasis placed on running the transmitter for long periods of time, to test its reliability.

After shipping from Australia and prior to deployment to APG and YPG, the equipment was stored in the premises of ARM Inc. in Hershey PA. It was delivered to each site in rented vans by the operators. Assembly and configuration of the system took place at each site office facility adjacent to the survey areas.

Initial shakedown of the system once configured was undertaken at each location on their Calibration Grids. Initial system checks once configured included the following:

- Check all mechanical links and moving parts are secured.
- Check all cable connections on transmitter, generator and loops.
- Check all batteries are fully charged.
- Check fluid levels in the engine and power up the generator.
- Check power delivered to transmitter from alternator.
- Check transmitter control system (Bluetooth link to HHPC).
- Check DGPS fully functioning with differential corrections from Base Station with radio link.
- Check TM-6 magnetometer fully functioning with four sensors.
- Run transmitter at low power initially, gradually increasing level to determine the safe maximum level for the given set of instrument parameters.
- Collect trial data and analyze.

As part of the shakedown procedures a series of QC checks were performed as outlined in Section 2.1.4. This included logging the background magnetic field activity with a sensor sitting stationary on the ground at several different locations around the site.

Prior to each day of surveying, a test data set was collected at a designated calibration point with known co-ordinates to test the DGPS for positional accuracy, and to acquire data over a standard test item.

5.5 Data Collection

The data collection methodology has been outlined in detail in Section 2.1.3. Slightly different survey strategies were applied to the Calibration / Blind Grids compared to the Open Fields, but only with respect to the method of sighting the traverse lines, and loop layout. Table 8 summarizes the number of grid/loop layouts required at each of the surveyed scenarios.

In the case of the Open Fields, they were set up with grid markers at 30 m intervals on rectangular grids oriented with the UTM grid north meridian, and with survey lines running north-south. This meant the data was collected with an earth-field magnetic declination of -11.6° at APG and 11.7° at YPG.

Figure 1 illustrates the normal field layout for data collection. A 40 m x 40 m wire loop was laid around the 30 m x 30 m survey grid and the Generator/Transmitter was positioned at one corner, approximately 20 m away from the loop. Non-metallic survey chains were laid along the northern and southern boundaries of each grid and navigation along each survey line within the grids was aided by visual sighters located on these chains, marking the beginning and end of each line. Additional sighters were positioned at the 15 m mark on each of the 30 m traverse lines. Operators would line the trolley up in line with the sighters and follow the imaginary line between them. As each line was completed, the sighters were moved to define the next line, using the survey chain to indicate the new sighter position, 1.5 m along the chain from the previous position. After each grid was completed, the loop was moved to the adjacent loop, and the Generator/Transmitter was positioned so it only needed to be moved every second loop. That is, each vehicle position was selected to allow access to two adjacent loops.

Relevant survey parameters include line spacing, sensor spacing and height of sensor above the ground. At both of these demonstrations the line spacing was 1.5 m and sensor separation was 0.375 m. At APG2, sensor height above ground was 0.34 m, and at YPG this was reduced to 0.26 m. These parameters were selected to ensure optimal spatial sampling frequency with respect to the smallest ordnance sizes present and the depths at which they were buried. For an average walking speed of about 1 m/s, the spatial resolution along line was about 0.27 m, as indicated in Table 9. Between line resolution was 0.375 m, as determined by the sensor spacing.

A single-turn, square loop measuring 40 m x 40 m surrounded each 30 m x 30 m survey area, leaving a nominal margin of 4.5 m. The current in the loop varied between 380 and 410 amps, providing a primary field strength at the centre of the loop of between 8300 and 12000 nT.

Maintenance tasks on the survey equipment included overnight recharging of batteries, daily checking of cables and connectors, and checking the tightness of nuts/bolts on trolley. Daily maintenance tasks on the transmitter and generator includes refilling the generator engine's fuel tank, checking the oil level, and a general check of all cables, connectors and moving parts. The transmitter itself was monitored on a continuous basis throughout the day and each evening the digital log of parameters such as current, voltage, temperature and wire resistance was checked.

Survey crews for both APG2 and YPG included 1 supervisor and 3 field technicians. Task breakdown was:

- For data collection, 1 trolley operator (sensors), 1 instrument operator (backpack), 2 assistants moving sighter cones and realigning sensor angles at the end of each line. Tasks were rotated on a grid by grid basis.

- For loop set-up, all 4 personnel were involved in moving cables and loop layout, but only the supervisor was involved in moving of the vehicle and operating the generator/transmitter.

Figure 26 MPTX and Cart at APG2

At APG2 a Polaris Ranger was used to transport the generator and MPTX transmitter around the site and was positioned to reach two grids at each new location. The MPTX modules were spaced apart on the trailer to ensure good airflow around the fans which are required to prevent over heating (refer to Figure 26).

Figure 27 Quad Sensor Trolley at APG2

Figure 27 shows the array of 4 x Cs sensors and DGPS antenna on a three wheeled trolley. Note the angle of the sensors which are rotated at the ends of each line to ensure they are at the optimal angle relative to the earth field in order to minimize ‘drop-out’. This step was necessary because the earth field at Aberdeen has an inclination of 67 degrees, which is enough for the magnetic field vector to move into the sensor drop-out zone during the positive on-time, when an extra 10000 nT is added to the 50000 nT earth field.

Figure 28 Field Crew at APG2

The recommended field crew is four people (Figure 28), rotating the tasks between individuals to minimize fatigue. The two extra operators not carrying the equipment are kept busy moving the orange sighters as each line is completed, and rotating sensors ready for the next line. All four are then involved in moving the loop as each grid is completed. One operator can monitor the MPTX from a distance using a BlueTooth link and a hand-held PC.

Figure 29 Copper Wire - 40 m Loops

The transmitter loop is comprised of 4 x 40 m lengths of braided copper wire (Figure 29) with a diameter of 15 mm, capable of passing a 500 amp current. In normal conditions the wire becomes warm but is never too hot to handle. As a precaution, operators would usually wear gloves when moving the wire.

Figure 30 MPTX and Cart at YPG

In Figure 30, because of the very high daily air temperature encountered at YPG, it was found that the system operated much better when kept out of the direct sunlight. This step was particularly necessary with respect to the engine fuel system, using a plastic marine-style fuel tank and rubber hoses.

Figure 31 Quad Sensor Trolley at YPG

Figure 31 has been included to illustrate the obvious difference between the APG2 and YPG environments. It also serves to illustrate an important operational requirement whereby the second operator carrying the magnetometer controller, DGPS and batteries must walk a few meters back from the sensor, so as to not provide a measurable response that might clutter responses from targets in the ground. The front operator and trolley are completely metal free, apart from the sensors themselves and the GPS antenna.

Data confirmation methods in the context of quality control were applied all the way through the process, with some running in real-time as the data is being collected, and others during the data processing. They are summarized as follows:

- The TM-6 firmware/Ui has a sophisticated monitoring and alarm system that we relied upon during the course of the actual surveying to indicate whether or not the system was functioning correctly. If problems were encountered that adversely affected the data, they were remedied on the spot. These include problems with the DGPS that could affect the positioning or time synchronization with the transmitter, sensor output levels, data storage and battery condition.
- Data was transferred from the CF card in the TM-6 to a laptop PC twice daily before leaving the site, and this was usually checked using graphical aids in MagPI. During the scanning process to display the data, the software automatically checked for inconsistencies and any encountered were written to a separate processing log.
- In addition to the data files, there were also log files that provide a highly detailed record of the TM-6 functioning during the session, including details of lines and files, internal system checks, warnings and error messages relating to various operating parameters and system calibration values relating to the timing accuracy being maintained.
- The sensor and DGPS data was stored in a proprietary format with very detailed header information summarizing instrument parameters, survey parameters, time and other information that can be entered by the operator for data tracking and management purposes.
- The MTPX maintains a continuous log that records all significant operating parameters, including all information being sent to the user interface for real-time monitoring. This

log would generally only be used if problems were encountered that needed to be diagnosed, in case they were found to be recurring.

- Each grid was processed nightly using the pre-processing software MagPI.
- Pre-processing of data included checking DGPS track plot as well as profiles – raw and processed – mainly checking for sensor drop-outs, spikes or other anomalies.
- Data confirmation occurred at different levels – inspection of raw data, processed profiles of anomalies (TMI and TFEMI separated) and gridded color maps.
- As each grid was processed and checked, the daily written records were also checked and updated to ensure any important facts from the day's events were written into the record.

The data confirmation methods in the context of the performance criteria are summarized in Table 6. Some of the confirmation of quantitative performance was provided by ATC when they evaluated the submitted results using their standardized procedures. Conformation of the qualitative criteria was much more straightforward and relied on detailed written records from both GapGeo and ATC (which they include in their report). Some of the performance confirmation was based on digital information incorporated into our dataset as part of the normal operating procedures.

5.6 Validation

The Calibration Grids provided the primary validation data at the start of each survey because detailed information about all of the items buried in that grid are available to the public.

Other truth data that has been made available during the time frame of this project includes the Blind Grid, Open Field, Tree Area and Moguls Area for our APG1 survey in 2004, the Blind Grid data for our APG2 survey in 2007, and the majority of the Open Field data from the APG 2007 survey.

These data sets have been invaluable to develop training data sets for statistical analysis of response parameters.

6. Data Analysis and Products

6.1 Preprocessing

Figure 8 is a graphic illustration of the data reduction procedure from raw data (as collected and stored in the TM-6) to profile data output from the MagPI software as an XYZ file ready for input into the GeoSoft package. Section 2.1.5 provides a brief summary of the main processing steps. Table 10 is a summary of the main processing software, showing the relationship between the various input files, processes and output files.

Table 10 Summary of Data Processing

Package	Input	Process	Output
MagPI	*.TMB	Waveform Stacking/FIR Comb Filtering TFEMI: generate decay file TFEMI: integration, normalization, rescaling, generate profile file TMI: additional averaging and down-sampling, generate profile file	*_TFEMD.XYZ *_TFEM.XYZ *_TMI.XYZ
GeoSoft	*_TFEM.XYZ *_TMI.XYZ	TFEMI: gridding, mapping TMI: gridding, mapping	*_TFEM.GRD, *_TFEM.MAP *_TMI.GRD, *_TMI.MAP
MagSys	*_TFEM.GRD *_TMI_GRD	TFEMI: anomaly picking TMI: anomaly picking, inversion	*_TFEM.ITP *_TMI.ITP
UXOLab	*_TFEM.XYZ	gridding, inversion	*_TFEM.EMI
MagPI	*_TFEMD.XYZ *_TFEM.ITP *_TMI.XYZ *_TMI.ITP	extract profiles and decays from list of interpreted targets	*_DB.CSV

Matlab	*_DB.CSV	model TFEMI decays as a sum of two exponentials	*_DB.CSV

The SAM UXO system provides two complementary data sets (TMI and TFEMI) that are perfectly geo-referenced because the same sensor is used to acquire both data sets simultaneously. For these technology demonstrations the individual data sets were processed separately to the point of producing the XYZ files, followed by grid files and maps. Results were presented as a single joint interpretation, using selected information from each data set. In the specific case of small ordnance items (such as grenades and sub-munitions), the TFEMI response was often below the noise floor, in which case the interpretation was based on the TMI alone. For other items, a weighted average of the two responses was used.

(i) Processing with MagPI

During the progress of a SAM UXO survey, the TM-6 stores the accumulating magnetic field and DGPS data in a binary format combined with the header information into a file referred to as the TMB file (the file extension name). The data is stored on a CompactFlash card and for each 30 m x 30 m grid this file typically has a size of about 50 MB. At APG2/YPG, twice daily the raw data was transferred to an office PC, where it was backed up onto an external hard-drive, and subjected to a quick review to determine if there was any bad data in the form of drop-outs (loss of signal from the magnetometer sensor due to saturation) or other noise, as well as any problems with the positioning and spatial coverage of the grids.

The GapGeo proprietary software package referred to as MagPI is used to read TMB files (raw TM-6 data files) and perform preliminary processing functions. It includes a number of graphical options that have been specifically designed for quick reviewing of the raw data. It also provides some limited editing facilities that can be used to fix minor problems. The main preprocessing procedures including separation of the magnetic (TMI) and electromagnetic data (TFEMI) sets, waveform stacking, removal of unwanted frequency components such as 60 Hz noise, TFEMI decay curve integration, decimation, merging of DGPS time/position and low-pass filtering.

An important first step in the processing sequence is to check the header, since it stores all of the instrument configuration parameters that would have already been entered into the TM-6 using the user interface. Any errors if present can greatly influence the results; however MagPI includes many checks and warnings that simplify the detection of such errors. MagPI processing parameters will mostly stay fixed for the duration of any given project, and these include the selection of filter coefficients, number of stacks and boundaries of the integration windows. For this project, the final selection of these parameters was determined after an exhaustive analysis of the data collected over the Calibration Grids.

The stacking and filtering process combines the data along successive fixed window lengths with the main objectives being to remove the 60 Hz power line signal, to enhance the signal-noise ratio and to separate the two components (TMI and TFEMI). The limit on the number of stacks is determined by the requirement to maintain an adequate spatial sampling frequency. FIR filtering is used for the averaging process, with two separate passes and careful selection of the weighting coefficients being used to produce either the TMI (low-pass) or TFEMI (high-pass) data sets. The data is then integrated over fixed window lengths to produce the final profile output sequence at a much reduced sampling interval. In each case, the overall process incorporates stacking, FIR comb filtering and decimation into one processing step. Integration windows are different for the TFEMI and TMI sequences because in the case of the TFEMI data, the appropriate portion of the decay needs to be selected so that the induced response from the target is maximized (located at the start of the off-time). In the case of the TMI data, this is simply a decimation step, since the TFEMI component has already been removed. However, the actual window is selected at the end of the off-time where any contribution from any TFEMI decay still present after the comb filtering process would be minimal. The processing steps just described are graphically illustrated in Figure 8.

The creation of the profile TFEMI data is an extremely important step since this goes on to form the basis of the anomaly detection once it has been gridded and mapped. One very necessary step at the completion of the integration is normalization of the data to remove the effect of a varying primary field within the grid. Because the magnetic field is being continuously recorded, one can use the late-time portion of the on-time to obtain a very good estimate of the primary field and use this value to normalize the corresponding integrated decay. This results in a dimensionless number (nT/nT) which is then multiplied by a constant to bring it back to a sensible value for the rest of the processing.

As discussed previously, for an average walking speed of 1 m/s, the final processed data will have an along-line spatial resolution of about 0.27 m, for the APG2/YPG data records that were collected with a frequency/duty cycle of 7.5 Hz/25%, and then stacked 8 times with a 50 % overlap. Given that the DGPS record is available once per second, this position sequence is being interpolated to produce new positions for each sample spaced approximately 0.27 m apart. The merging process is extremely accurate because both the DGPS and magnetic field data inputs are time-stamped by the data logger with high precision and resolution.

MagPI has a batch processing capability which will automatically process the series of data files representing the different grids collected during the day, without needing operator intervention. Detailed log files are created to check for errors and summarize important features of each grid file. The output files are referred to as the TMI and TFEMI XYZ files, and these are then used in the next processing step. However, prior to that, one would normally use the MagPI graphical facilities to perform a final QC check on track plots and line profiles. In addition to the TMI and TFEMI XYZ files, which are designed to produce line profiles and maps, the other important file produced by MagPI is referred to as the TFEMD file which contains the full TFEMI decay for every data point location.

All MagPI output can also be selected in the form of Microsoft Excel compatible CSV files. This allows for quick input into Excel which is often a more convenient environment than Geosoft for preliminary viewing of the data or basic statistical analysis.

(ii) Processing with GeoSoft

The Geosoft Mapping Package is used for data management, gridding, map creation and display, and other specialized filtering.

MagPI produces two XYZ files in the Geosoft format (separate files for TMI and TFEMI data) that are read into a Geosoft database file, with one 30 x 30 m grid per file. As a first step, this profile data is median filtered to create a zero mean across all profiles. The data is then gridded using the minimum curvature option (with a cell size of 0.05 m) to produce GRD files (the file extension name) which are then used by other software as well as being viewed and printed as a map image in Geosoft with amplitude variation assigned to a color scale.

The graphical features of Geosoft are also used for QC by superimposing the track plot on top of the color map and linking this with the profile images to inspect selected anomalies, check for holes in the data and any other irregularity. The small size of the basic data unit being inspected in Geosoft (a 30 m x 30 m grid) means that it is relatively easy to check the ground coverage and detect holes. During the AGP2/YPG processing, the data processor also had access to field notes that reported occurrences of holes due to physical obstructions.

6.2 Target Selection for Detection

Two proprietary products referred to as 'MagSys' (GapGeo) and 'UXOLab' (University of British Columbia') are used for additional interpretation of the gridded data, in order to provide automatic anomaly picking, calculation of certain anomaly parameters, forward modeling and inversion.

MagSys will accept the Geosoft GRD files (both TMI and TFEMI) as input and is used to select anomalies of interest using simple amplitude thresholding. Some judgment is required to select an appropriate threshold level that will aim to minimize false targets that are just noise

Selected anomalies are then subjected to further analysis that includes calculation of parameters in MagSys such as anomaly full width at half peak amplitude and TMI inversion. The TMI inversion process fits a spheroid model and provides estimates of XY location, depth below sensor and induced dipole moment as well as providing an indication of possible ordnance types by matching the data to modeled responses from a selected target list.

It is convenient to apply a threshold as a simple means of making specific selections from the TMI or TFEMI dataset based on the value of a certain parameter being above or below the nominated threshold. For the selection of data submitted to ATC for the Response Stage, the threshold was applied to the signal amplitude. Any anomaly amplitude above the selected threshold was added to the target list, and any anomaly below that threshold was ignored. Because the SAM UXO system provides two complementary data sets, the actual signal amplitude used was a weighted average of the two contributing signals (the TMI and TFEMI). This selection procedure was applied to gridded data.

6.3 Parameter Estimation

Parameter estimation is a topic that is beyond the scope of this document. The work was still in progress at the time this document was finalized. The results of that work will be reported in the future using other means such as presentations at the UXO Forums and the annual SERDP/ESTCP meeting in December. Instead this section outlines the method being adopted for parameter estimation.

The processing package UXOLab is used to accept the Geosoft format XYZ files as input, along with a list of targets and their XYZ coordinates determined from the MagSys TMI inversion and perform a constrained inversion on the TFEMI data to provide an estimate of the induced dipole moment. In the earlier demonstration (APG1) we applied a co-operative inversion scheme that proved inconclusive due to the restricted nature of the UXOLab tool which was used in prototype form with limited opportunity to modify it as required. In future work, the use of UXOLab will be mainly centred on providing the TFEMI induced dipole moments. On-going development may then see fuller implementation of inversion, depending on the results of this preliminary step.

Once the list of ordnance items has been created, MagPI accepts an input file containing the XY coordinates of all targets of interest and searches through the various TFEMI and TFEMD XYZ files (profiles of integrated decays and full decay listings) to create a database file that contains just the profiles and decays associated with the selected target anomalies. This file then becomes the primary data file for performing the additional detailed waveform analysis, using a combination of MagPI, Matlab and Excel.

The best decay from each target (usually corresponding to a location directly overhead) is analyzed and modeled to produce a range of parameters that include an estimate of the inductive limit (the decay amplitude at time zero), parameters describing the transition of the decay from power law to exponential, and the late time dominant time constant that is considered to correspond to the largest physical dimension of the target.

6.4 Classifier and Training

Target Classification is a topic that is beyond the scope of this document. The work was still in progress at the time this document was finalized. The results of that work will be reported in the future using other means such as presentations at the UXO Forums and the annual SERDP/ESTCP meeting in December. Instead this section outlines the method being adopted for data training and target classification.

Excel will be used along with a statistical 'Add-In' called 'statistiXL' to collate all the target parameter data and perform statistical analysis such as linear discriminant analysis.

A number of parameters are being extracted from the data for each target. These include peak amplitude, full width at half-height (FWHH) and induced dipole moments for both the TMI and TFEMI, as well as the TFEMI decay estimate at time zero (inductive limit), the TFEMI decay time at the point where the late time transition to purely exponential decay occurs, the TFEMI late-time dominant time constant and other decay model parameters.

The statistical method known as discriminant analysis will be used to determine linear combinations of our independent variables (target parameters) which best discriminate between the two groups (ordnance and clutter). The discriminant function is derived from training data (the known truth data that we already have) and can then be applied to the newly acquired unknown targets. The calculated value of the discriminant function using the new data set as input will provide an indication of the likely target. Receiver Operating Characteristic (ROC) curves can be used to assess the performance, using the discriminant function itself to provide a scale that can be thresholded to determine the optimal separation point between the two groups. The curve itself will indicate the trade-off between P_d or true positives (with an associated risk that ordnance may be incorrectly classified as clutter and therefore potentially not investigated) and P_{fa} or false positives (also known as false alarms that have an associated cost if clutter is incorrectly classified as ordnance and therefore unnecessarily investigated).

One of the intermediate steps during the discriminant analysis is to assess the relative contribution of the individual parameters to the final function that is derived. Although there are a number of standard measures of their relative importance, the ROC curves themselves can also be used to assess different discrimination schemes. However for this to happen it is important to have a good training set. Our existing database of target responses will be used for this task. Following accepted practices, some of the data available for training will be kept aside and will not actually be used for the derivation of the discriminant function. Once the function has been derived, the unused data can then be used to test the accuracy of the function. In general it will always be a problem to ensure the derived function can be used more generally, and not just with data similar to that used for training. That is why it is important to have a good cross-section of target sizes, depths and orientations, as well as clutter.

An important measure of performance for detection/discrimination technologies is the Receiver Operating Characteristic (ROC) curve, a plot of P_d versus P_{fa} as the threshold for target selection is varied. The ordnance discrimination problem is essentially a two-class classification, with the two classes of ordnance and clutter. The ROC curve is a commonly used method of comparing classification schemes. It summarizes the performance of the two-class classifier across the range of possible thresholds and an ideal classifier hugs the left side and top side of the graph, with the area under the curve approaching 1.0. A random classifier would plot a curve along the diagonal with an area of 0.5 and illustrates that the classification scheme is no better than tossing a coin.

The process of utilizing a ROC curve involves the selection of an optimum decision threshold which equalizes the probability of misclassification of either class; i.e. the probability of false-positives and false-negatives. The approach to be taken in this further work will be to develop the decision threshold that is simplistic and based on the idea that there should be some linear combination of data parameters that sufficiently separate the two classes so that the function that describes that linear combination can be directly used as the source of threshold value.

Given the initial volume of data, the task of reducing the dimensionality of the many target responses to a manageable level is quite involved, but in the end it comes down to a straight forward statistical analysis just like many other research problems. At this point in time the main unknown is what parametric description of the data is best suited to use in a linear classifier. For this reason we will calculate quite a number of different parameters, some being simply derived (anomaly amplitudes and FWHH), others being more involved (induced dipole moments calculated by inversion).

6.5 Data Products

Results were presented to ATC in an Excel spreadsheet that conformed to their required format, supplied as a template. Each scenario was submitted separately in its own spreadsheet and each was scored and reported separately. For the Response Stage, the main objective was to supply a list of XY coordinates of all interpreted targets, with no consideration being given to whether they might be ordnance or clutter. Targets were selected if their amplitude exceeded a pre-determined threshold. The actual signal amplitude used was a weighted average of the two contributing signals (the TMI and TFEMI).

To conform to the requirements of the Standardized UXO Sites Program, the results were presented in an Excel Spreadsheet with columns based on the headings specified below and rows representing each individual target selection. Separate spreadsheets were presented for each scenario.

i. Location – using a letter and number to specify the grid cell location in the Blind Grids and NAD83 UTM Easting and Northing in the Open Fields and Moguls.

ii. Response Stage – a single number assigned to each interpretation to indicate some measure of the level of response or signal amplitude above the noise. This was a single composite value derived from the signal levels of both the TMI and TFEMI data sets.

iii. Discrimination Stage or Ranking – not submitted.

iv. Classification – not submitted.

v. Type – not submitted.

vi. Depth – estimated depth of the target below the ground surface

vii. Azimuth – not submitted.

viii. Dip – not submitted.

Each column s described in detail as follows:

(i) Location

In the case of the Blind Test survey, each grid cell location has a designated reference based on a letter and number. In the case of the Open Field, anomaly locations were primarily based on the location of the peak amplitudes. Locations were reported as NAD83 UTM Eastings and Northings based on the output from the Ashtech or Novatel DGPS positioning systems. If the TMI signal/noise ratio was too low, the location estimate was based solely on the TFEMI anomaly peak.

(ii) Response Stage

The measure of the level of response was based on a quantitative assessment of the amplitude of both the TMI and TFEMI anomalies. The reported result was a weighted combination of both values that takes into account their respective signal-to-noise ratios, based on anomaly features such as peak-peak amplitude.

(iii) Discrimination Stage or Ranking

If this data set is submitted for assessment in the future, each interpreted anomaly will be described by a set of parameter values, derived from direct observation of certain anomaly features, as well as from the results of inversion. Parameter values derived from direct observation include anomaly width and amplitude, direction of the line between anomaly highs and lows, late time decay constant (TFEMI) and modeled amplitude of TFEMI decay curve at time zero. Parameters derived from inversion include dipole moments, XYZ coordinates (from the TMI) and estimates of orientation.

The data set obtained from items in the Calibration Grid can be used to form a training set in a statistical analysis to determine which parameters are the most significant descriptors of ordnance items. An existing data base from the previous APG1 (2004) work is also being used for this same purpose, but also provides an opportunity to analyze clutter, and determine if the parameter set can provide significant differences between the two classes. This information will be used to rank the unknown Blind and Open Field Grid anomalies using statistical methods such as linear discriminant analysis. Other methods will also be considered, and in general terms the objective is form a linear equation that combines the various parameters with an appropriate weighting where the value of that function is used directly to indicate which of the two classes the target in question belongs to. The function provides a means to establish a continuous range of values or scale as each item is individually evaluated (by applying its parameter values to the function). This then provides a means to rank the targets, and an appropriate threshold will be chosen to separate the two classes.

(iv) Classification

Interpreted items will be classified as either ordnance or clutter according to their discriminant function value, and whether they fall above or below a nominated threshold number on the scale that is established to separate these two classes. The classification scheme will be conservative in the sense that it will be chosen to ensure the risk that an ordnance item is misclassified is very low. That is, one would accept some level of cost by allowing an acceptable false alarm rate to be traded off against a low risk of missing an ordnance item by classifying it as clutter.

The actual rank values and the criteria used to rank specific items will be determined once the data set has been analyzed and will be primarily based on the results of the analysis of the Calibration Grid, although other data sets obtained from previous surveys and controlled experiments will also be taken into account.

(v) Type

The determination of the type of ordnance will not be attempted at the present time.

(vi) Depth

The estimate of depth is primarily based on the results of the TMI inversion, but can be refined after consideration of other parameter values including the results of the TFEMI inversion. If the TMI inversion is poor quality, other parameters such as the TFEMI half-amplitude width can be used to derive an estimate of depth.

(vii) Azimuth and (viii) Dip

The estimation of azimuth and dip will not be attempted at the present time. The uncertainty in this is based on the fact that previous inversion studies have shown the SAM TFEMI generated with a uniform primary field does not excite the targets sufficiently as they are with say the EM-61 from different directions as they pass overhead. However, we are working on the idea that we can obtain a very good estimate of the response relating solely to the largest dimension of the target (its longitudinal axis) and this analysis may prove to provide a reasonable estimate of orientation.

7. Performance Assessment

Some of the performance assessment criteria are project specific and are aimed at highlighting the improved hardware performance achieved by the development of a new purpose-designed transmitter. Other general performance criteria will be used to provide an indication of how well the SAM UXO system compares with other contemporary systems that have been involved in the Standardized UXO Sites Program.

Some of these criteria are quantitative and have elements relevant to comparing hardware, but they are generally more geared towards evaluating the processing, anomaly selection, discrimination performance. Quite apart from any comparisons with other systems, the detailed account of this systems performance according to the stated criteria will also provide information that may guide interest in the system towards more trials at other locations, outside the framework of this ESTCP funded development. Hopefully this would eventually lead to general acceptance of the system as a viable new technology.

7.1 Qualitative Criteria

1. Ease of Use:

In Section 3.1, it was stated that the SAM UXO system was given a vote of confidence from its operators, who considered the system to be easy to use despite its obvious physical presence and apparent complexity.

The SAM UXO system has some components that are much larger and heavier than most other survey systems. The size of these components has been dictated by the level of performance required in order to make the method work. These mostly relate to the power generator and transmitter. The physical size of these components is based on practical considerations such as the minimum size of a loop that provides a useful survey area. Starting with this design survey area, ordnance size and depth will determine the required primary field, which determines required current, which determines cable size, transmitter power output and engine power generation capability.

The problem of equipment size is solved through the use of mechanical means to support the field crew – a small all-terrain vehicle with a trailer is used to move heavy items around the site. Cable lengths are limited to 40 m with quick release connectors to simplify dragging them from grid to grid. Clever design of the transmitter optimizes power output by taking into account how it is used. The transmitted waveform has a significant off-time, so the system incorporates a large capacitor bank to store the power generated during that time and effectively increase the total output well above what one would normally expect from an engine without this enhancement, resulting in the need for a smaller engine/alternator to generate the required primary field.

The recommended field crew is four people (Figure 28), rotating the tasks between individuals to minimize fatigue. The two extra operators not carrying the equipment are kept busy moving the orange sighters as each line is completed, and rotating sensors ready for the next line. All four are then involved in moving the loop as each grid is completed. One operator can monitor the MPTX from a distance using a BlueTooth link and a hand-held PC.

Although the system can be used with a hand-carried frame of lightweight components for sensor carriage (as used at APG1), both APG2 and YPG were surveyed using a wheeled trolley for the sensors, and this was considered to be a significant physical aid that contributed significantly to the ease of data collection, despite the fact that it presented challenges at times in maneuvering through gullies and around vegetation at Yuma. Other aspects that contributed in this way were the attention to detail with ergonomics through use of a high quality backpack and harness, and encouragement of the use of high quality footwear. The use of the latest technology in batteries (Lithium Ion) which helped to keep weight to a minimum was also something clearly recognized as ‘making a difference’.

The modular construction of the system allows for easy mobilization, with the only real issue being the need for 4 people to be available to man-handle the engine at the start and end of the survey as part of the mobilization tasks. Although pretty rare in UXO geophysics, small engines are very common in minerals exploration geophysics, so certain consequences of working with engines might seem unacceptable, when in reality they are no more than just part of the job. One good example of this is the need to deal with hazardous goods transport issues when it comes time to freight the engine around. It requires more effort in preparation for mobilization, with extra expense and fewer options in choice of freight companies but the best solution is to plan on a time frame of work that allows road transport to be used rather than rely on air freight, as is common practice.

The field methodology has been designed around practical survey requirements such as choosing a suitable size of loop that is a compromise between survey efficiency considerations and engineering capability to achieve the required detection. An inherent advantage for operators that was not actually part of the design criteria is that the field methodology of alternating loop set-up and grid survey provides operators with an opportunity for natural breaks and change of activity which has implications for both productivity and fatigue, and definitely contributes to the ease of use.

2. Environmental Factors Affecting Performance:

The influence of environmental factors on performance was discussed in Section 3.1, where it has been stated that the most significant environmental factor affecting performance was the high summer temperature at Yuma. The high temperature did influence the system function, but not to the extent that it had an adverse effect on the system or significantly influenced the outcome. Refer to Section 3.1 for a more detailed account of this performance criterion.

3. Reliability:

The reliability of the system has been determined as having attained an adequate level of performance, mainly on the strength of the very small amount of time that was lost due to equipment failure, during the project trials. Refer to Section 3.1 for a more detailed coverage of this performance criterion.

4. Versatility:

The versatility of the system has been discussed in detail in Section 3.1 with reference to the types of terrain to which it can be deployed and the ability to configure it for different UXO problems. Figure 32 illustrates three different environments where the system has been deployed. Given the stark contrast between these three locations, the system has to be considered quite versatile.

Figure 32   Three Different Environments where SAM UXO was Tested

5. Maintenance:

As discussed in Section 3.1, maintenance activities are quite minor. This performance criterion has to be considered as being successfully met since these activities have been kept to the minimum level required for operations, such as daily charging of batteries and refueling of the engine.

6. System Function:

System function has been satisfactory and both the transmitter and receiver have been meeting their specification parameters throughout the course of these trials. Apart from minor enhancements to firmware that occur on a continuous basis, the only area that is being considered for change on future versions of the hardware is the cooling system, through the introduction of larger fans, to keep the system cooler when being operated in the very extreme environments.

7. Site Coverage:

The SAM UXO system has proven itself to be capable of achieving the same level of ground coverage as any other system. The sensor / receiver component is identical to the set-up used for traditional TMI surveys, and can be configured as a hand-carried array or 3-wheel trolley, depending on the terrain. Refer to Section 3.1 for more details.

8. Readiness for Commercial Application:

Refer to Part 8 Section 3.1. The SAM UXO system is considered to be ready for commercial application in all aspects relating to the hardware. In the software, it is only in the area of discrimination that more work needs to be done. At the present time it is still possible to select a target list with the currently available software, but more work will provide for refinement of the target list in terms of providing information about target size and shape.

7.2 Quantitative Criteria

1. Target Signal/Noise Ratio:

Target SNR's have been calculated from profile data after the profile containing the peak response has been determined from the grid data, by inspection of the anomaly on the color map, followed by correlation with the profile data that overlays that grid. In many cases, the peak amplitude of an anomaly on two adjacent profiles will be close in value, and will yield very similar SNR values. Once the coordinates of the peak response have been determined, the rest of the process to extract the required profile from the database is automatic. Thus, the profile with the peak target response is selected to estimate SNR, according to the ratio between the peak amplitude and the RMS noise level calculated from a window of data on the profile located well away from the target anomaly. The *_DB.CSV files referred to in Table 10 are used to provide this data. An alternative data set of target SNR's, based just on the gridded and mapped data, is also available for comparison purposes, and can be derived using MagSys and stored in the ITP files.

2. Target Detection Depths:

This criterion aims to highlight hardware performance through the illustration of the achieved depth detection of different sized targets buried at a range of different depths, for which the truth data is known. Two methods of presenting the result are included as Figures 33, 34 and 39. In

Figures 33 and 34, a spreadsheet cell structure is used to organize the results, with columns corresponding to different ordnance items, and rows corresponding to the depths at which they have been located. Colors have been assigned to individual cells to highlight the achieved detection result. Figure 39 is an example of the other method, which is based on the use of truth data to generate plots of ordnance depth against diameter. This graph is well accepted in the industry and is a quick and simple method of illustrating the depths at which different sized items can be detected. For both methods, there is no indication of actual response amplitude or SNR, just an indication of whether the target has been detected or not.

Figures 33 and 34 summarize the detection performance on the Calibration Grid at APG2 and YPG respectively, using the new MPTX transmitter. These figures are only taking into account the TFEMI responses, and many of the items not seen in the TFEMI data have in fact been detected by the TMI. In Figure 33, items with crosses refer to those not detected with the GGT-10 transmitter during the 2004 APG1 survey. There is clearly a marked improvement in the TFEMI detection capability with the new MPTX transmitter. It should be noted that many of the deeper projectiles, that have been missed (red colored cells), are located at depths below the normal required detection limit based on 11 x diameter.

Figure 35 provides an example of color images of both the TMI and TFEMI data, in this case from the Calibration Grid at APG2. Color is used to represent the differing amplitudes, and the small black dots are the cell locations used to locate the different items on the grid. Peak positive amplitudes are assigned to red, and peak negative amplitudes are assigned to blue. It is apparent that the TFEMI responses take on the well known dipole structure that is typical of TMI data.

Figures 36, 37 and 38 are close-up views of selected anomalies that have been selected to highlight certain points about the results. In all three cases, the TFEMI data forms the left-hand image and the TMI data forms the right-hand image. Cells used to locate and reference particular ordnance items are designated by a letter and number corresponding to the grid locations. The two datasets are perfectly geo-referenced, since the same sensor acquires both sets. This is one of the most significant advantages of the SAM UXO method. It is also apparent that another benefit of a dual mode system is the illustration of point M19 in Figure 36, where the unknown item is quite obvious in the TMI image but missing in the TFEMI image.

Figures 37 and 38 are examples taken from the Calibration Grid at APG that illustrate the benefit of a dual mode system. It is apparent that the interpretation benefits from the use of two different datasets imaging the same targets. In Figure 37, A04, B04 and C04 are all 40 mm M385 grenades that would be undetected by TMI alone, but have a detectable TFEMI response with the SAM UXO system. Items J04 and K04 in Figure 38 are M42 sub-munitions that are seen to have an obvious TMI response but are undetectable with the TFEMI in this case.

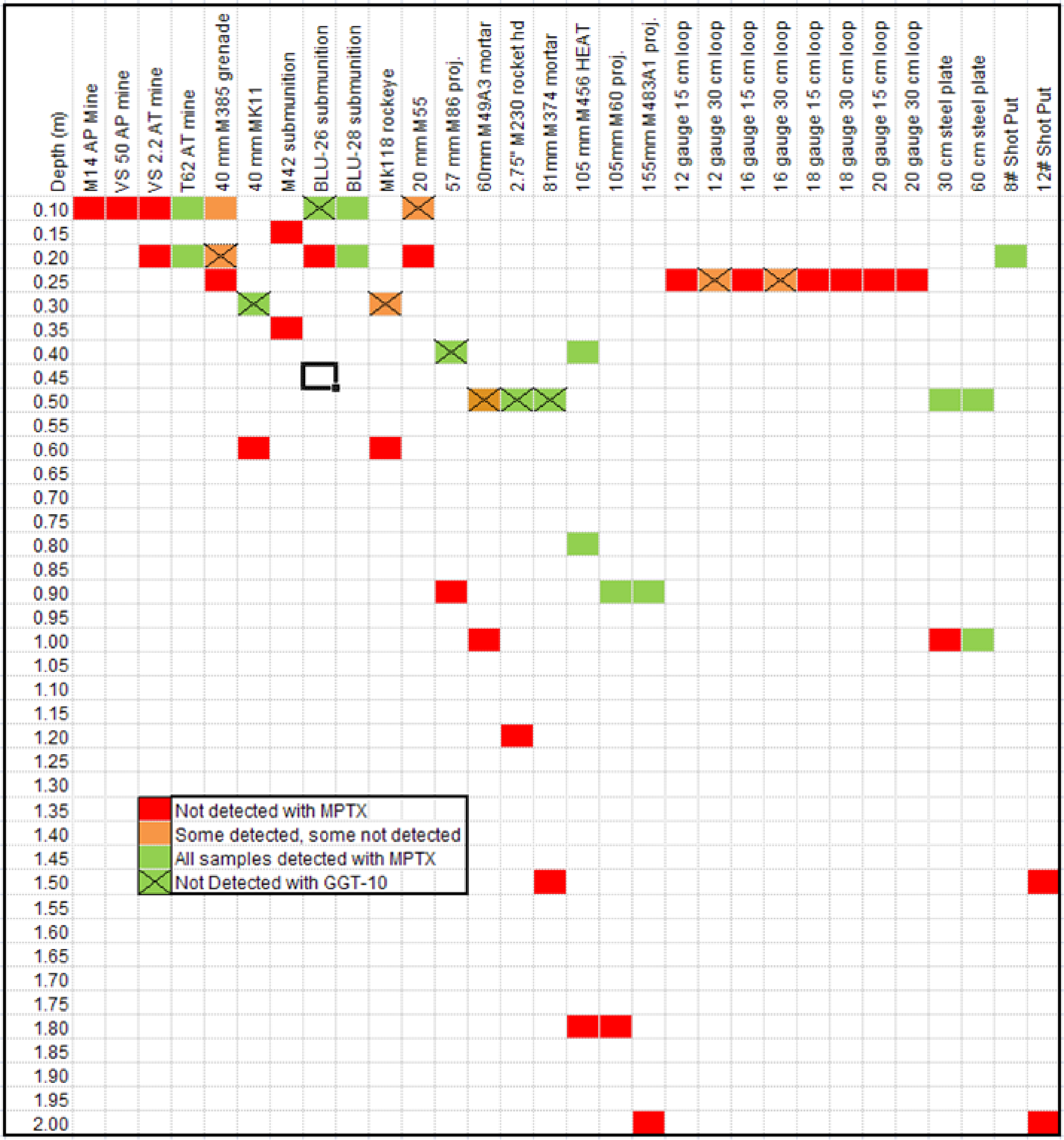


Figure 33 Summary of Depth Detection Achieved at APG2 Calibration Grid

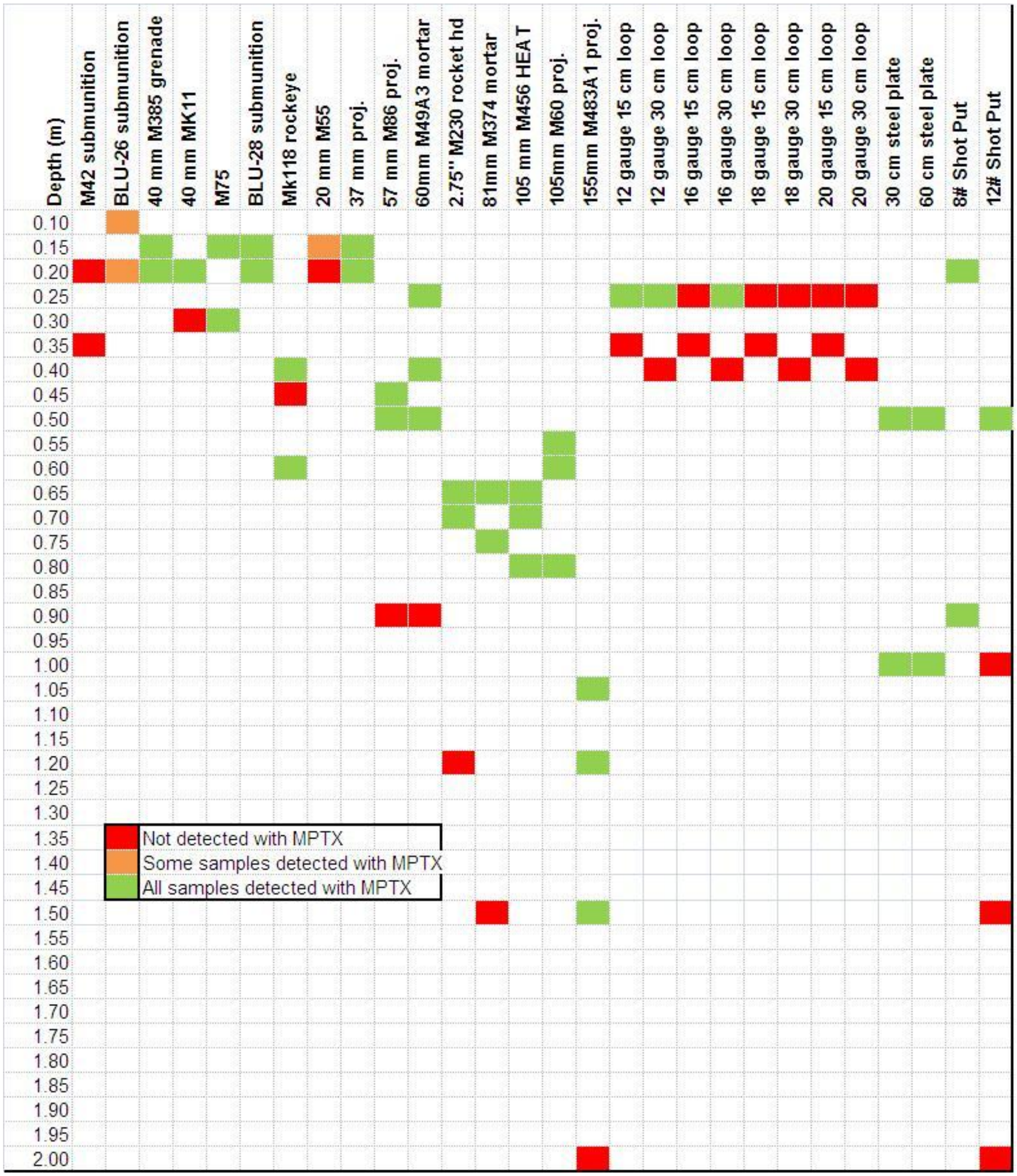


Figure 34   Summary of Depth Detection Achieved at YPG Calibration Grid

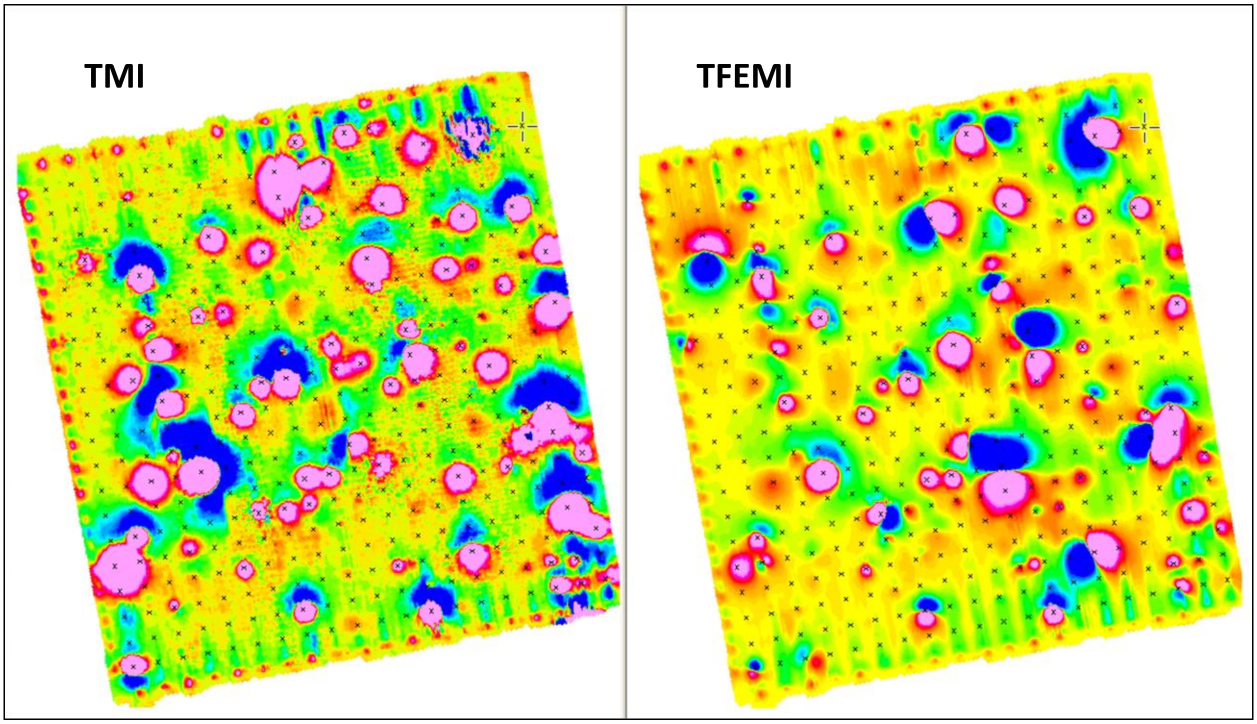


Figure 35 Color Images of the APG Blind Grid TMI and TFEMI Datasets

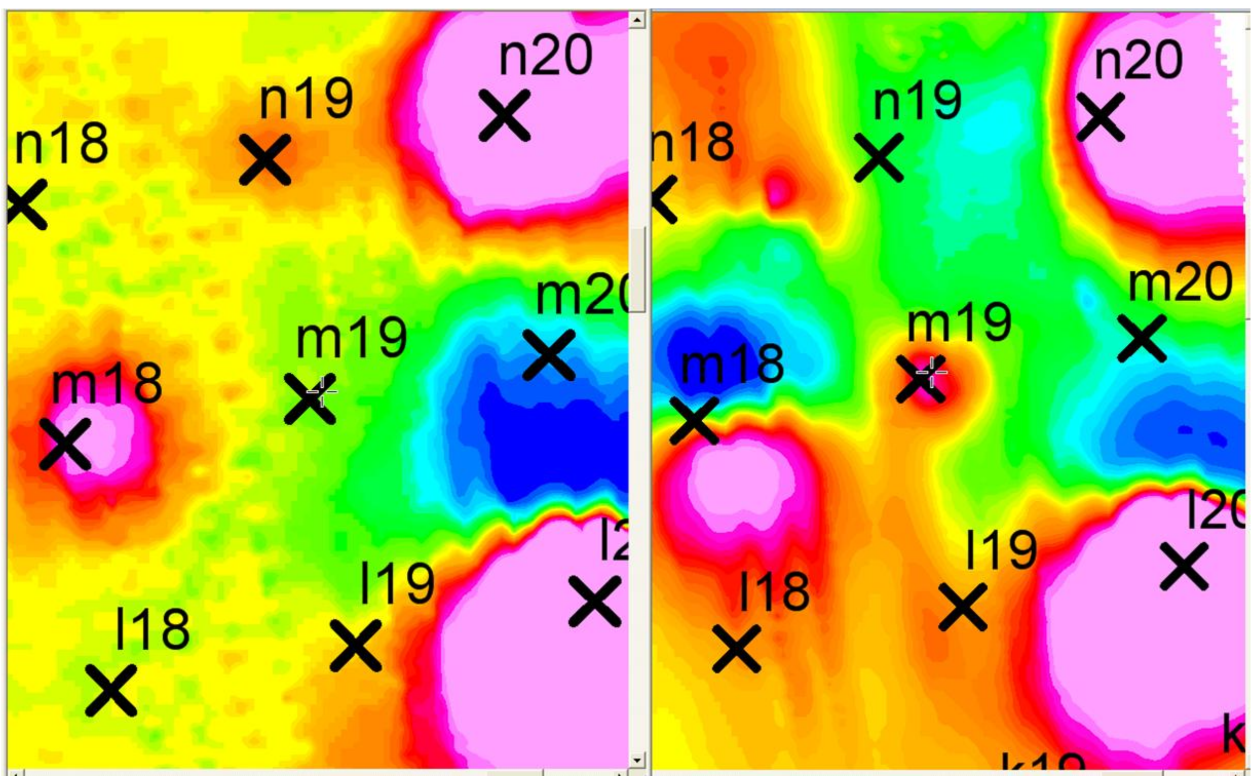


Figure 36 Close-up of the TFEMI (left) and TMI (right) Images at M19

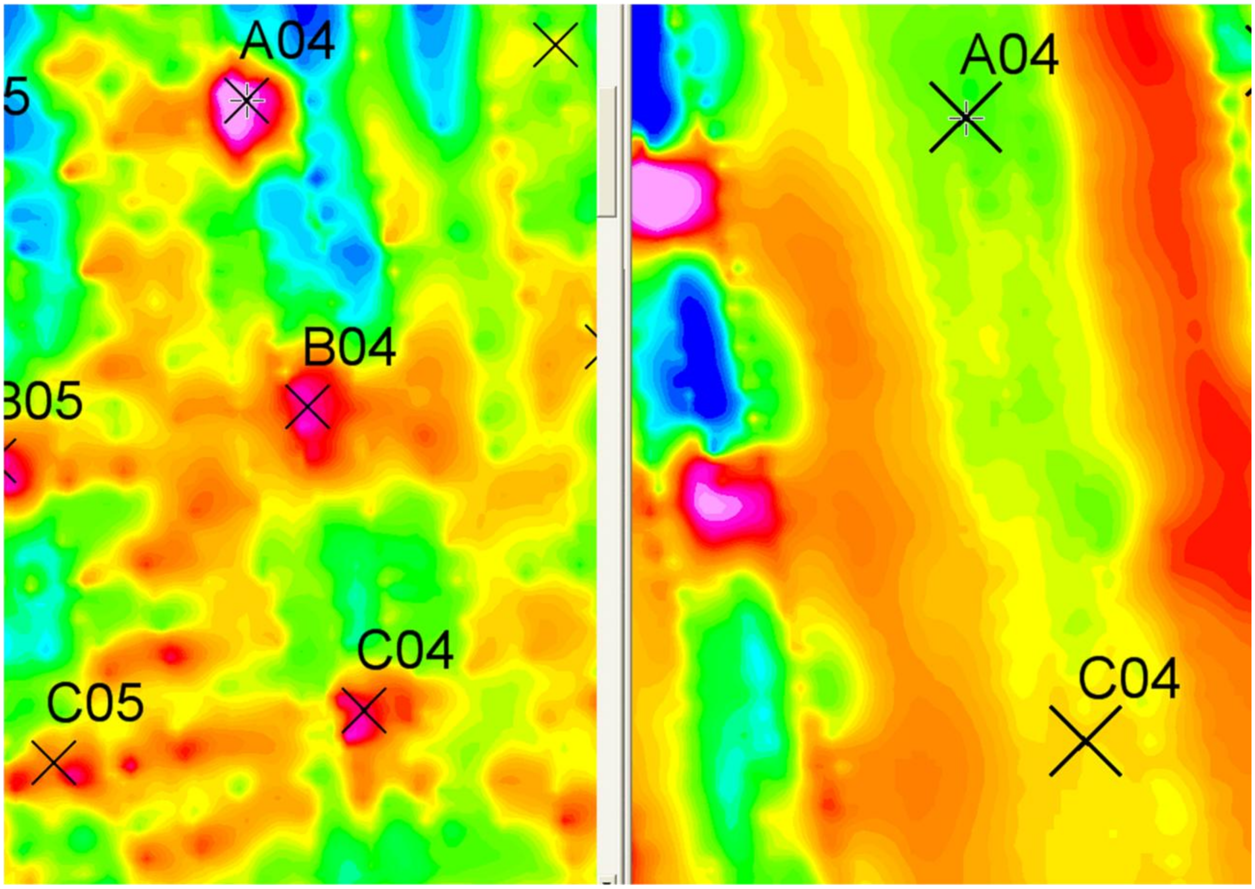


Figure 37   Close-up of the TFEMI (left) and TMI (right) Images at B04

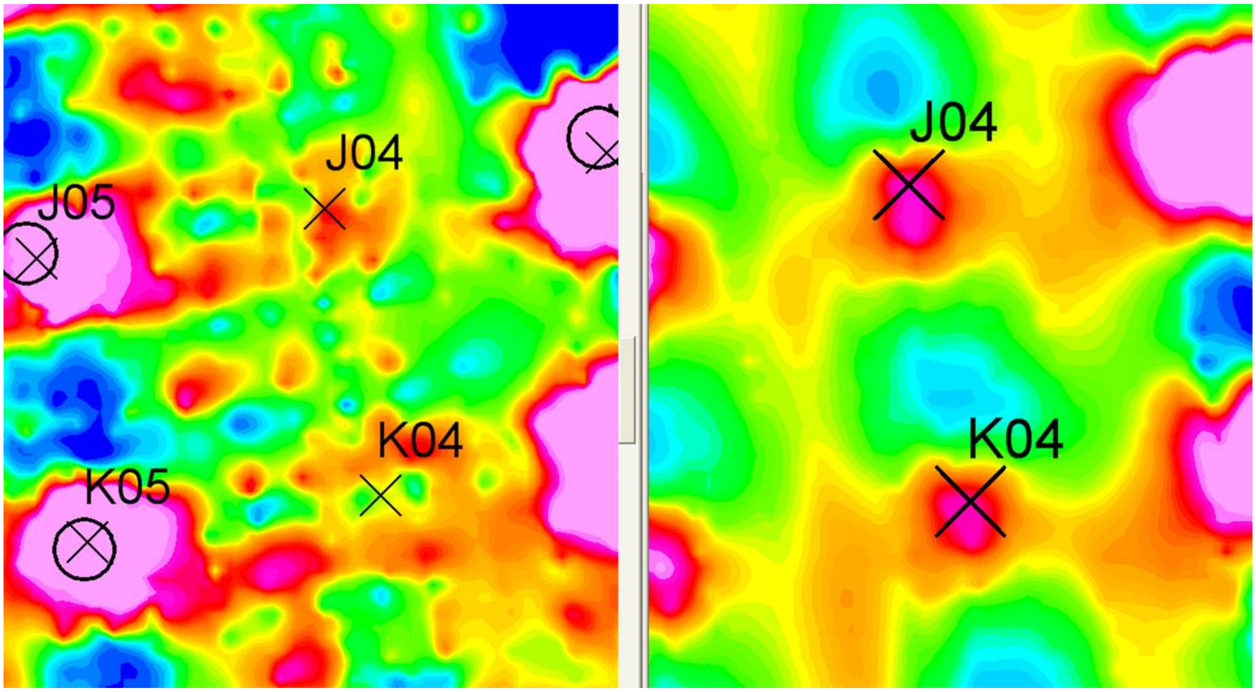


Figure 38   Close-up of the TFEMI (left) and TMI (right) Images at J04

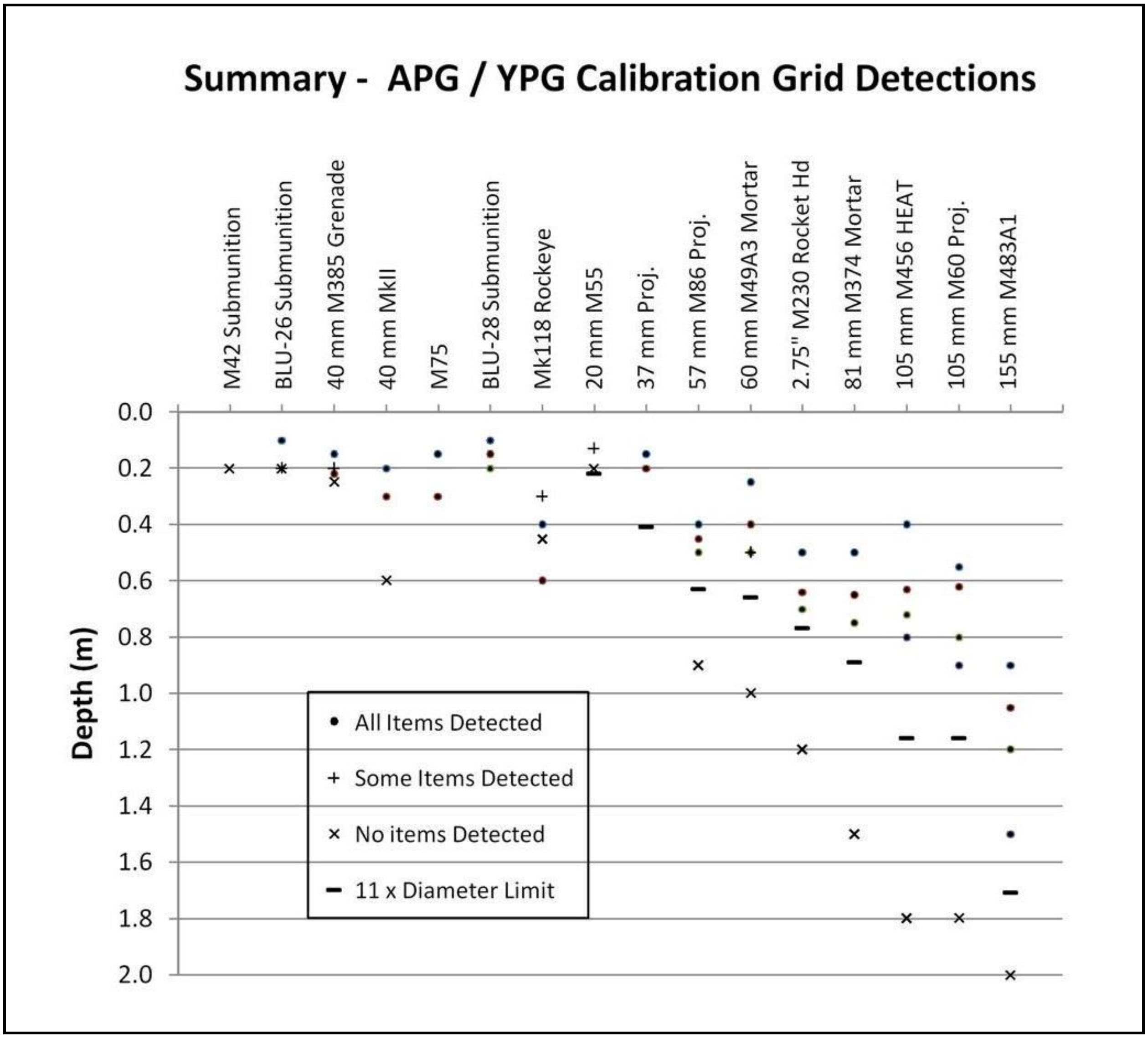


Figure 39 Summary of the APG2 / YPG Calibration Grid Ordnance Detection

Figure 39 should be viewed with reference to Figure 21 where it is apparent that the spread of ordnance at APG/YPG and Newholme (GapGeo's seeded site in Australia) is notable in that the experience at the Newholme site highlights the real strength of this system as being well suited to the detection of large and deep ordnance. Because there has been limited opportunity to highlight this feature with the APG and YPG results, some of the data obtained from various trials at Newholme prior to deployment to the USA are being included here.

The GapGeo test range at Newholme, near Armidale NSW Australia has 38 ordnance items buried within a 1 hectare grid, at a range of depths from 0.2 to 4.2 meters. Table 11 summarizes the depths and orientations of seven of these targets, all Mk82 (500lb) practice bombs.

Table 11 Summary of Mk82 Truth Data at Newholme

ID	Bearing	Head Depth (m)	Tail Depth (m)	Centre Depth (m)
1	135	3.5	2.7	3.1
2	225	3.9	4.3	4.2
4	90	3.5	2.6	3.1
9	270	1.8	1.7	1.8
10	180	1.4	1.5	1.5
25	225	1.5	1.5	1.5
26	270	1.5	1.5	1.5

Figure 40 illustrates the variation in signal amplitude from a Total Field EM survey for the range of depths and orientations summarized in Table 11. The projection of a 'line of best fit' to 0.1 nT illustrates the maximum detection depth, which in this case is estimated to be 6 meters, for a primary field of the order of 7000 nT.

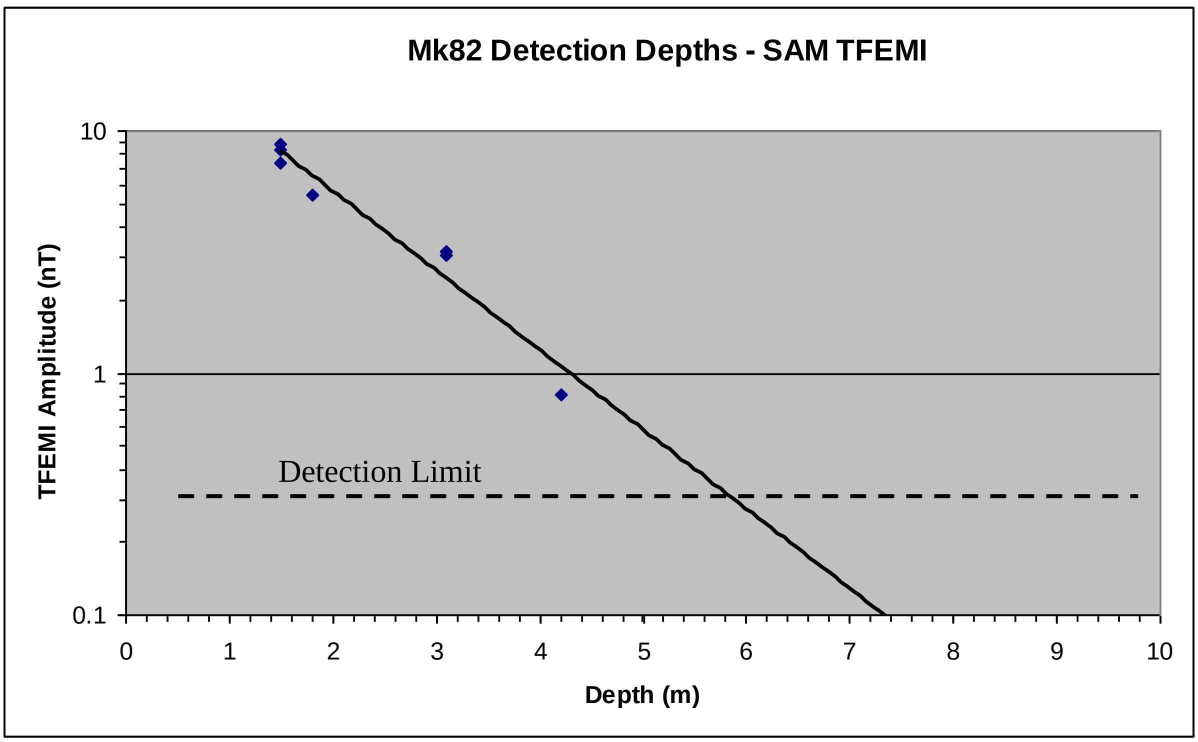


Figure 40 Mk82 Depth Detection at Newholme

The detection limit is assumed to be about 0.3 nT, based on the clarity of a typical weak anomaly from a smaller ordnance item with this amplitude, recorded at the test site, and presented as Figure 41. The figure clearly indicates that this anomaly with amplitude of 0.3 nT is easily distinguishable above the noise.

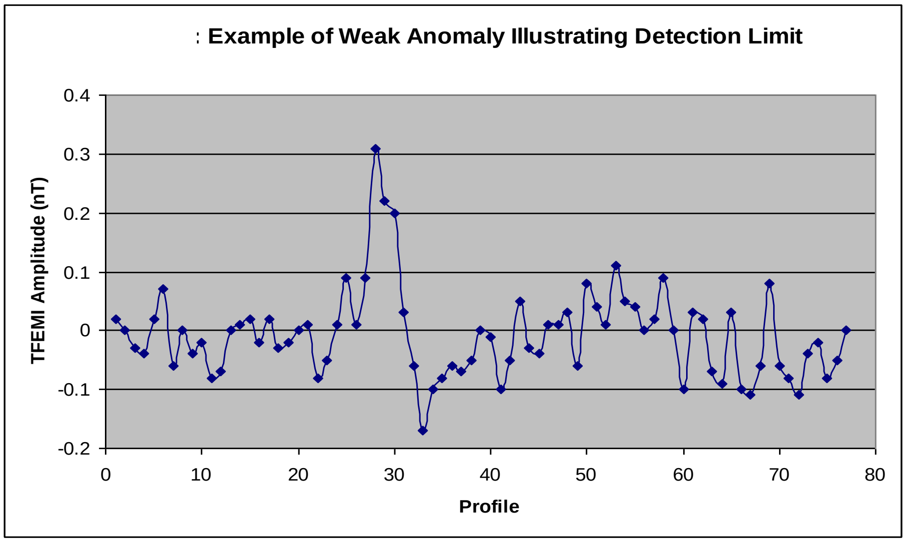


Figure 41 Illustration of Detection Limit with a Weak Anomaly at Newholme

There is a linear relationship between primary field strength and anomaly amplitude. The data presented in Figure 40 has been normalized to the primary field. Therefore, it can be used to predict the likely anomaly amplitudes for different primary field strengths, simply by multiplying the normalized data by the nominated primary field strength. Figure 42 illustrates the likely results that would be obtained if the primary fields were increased to 10000 nT and 20000 nT. The additional data in this figure was obtained by placing the sensor at different heights above the ground to simulate deeper items. Primary fields of between 8000 nT and 9000 nT were used for these additional trials. It is apparent that the detection depth for the Mk82 might be increased from about 6 meters to 10 meters, if the primary field is increased to 10000 nT.

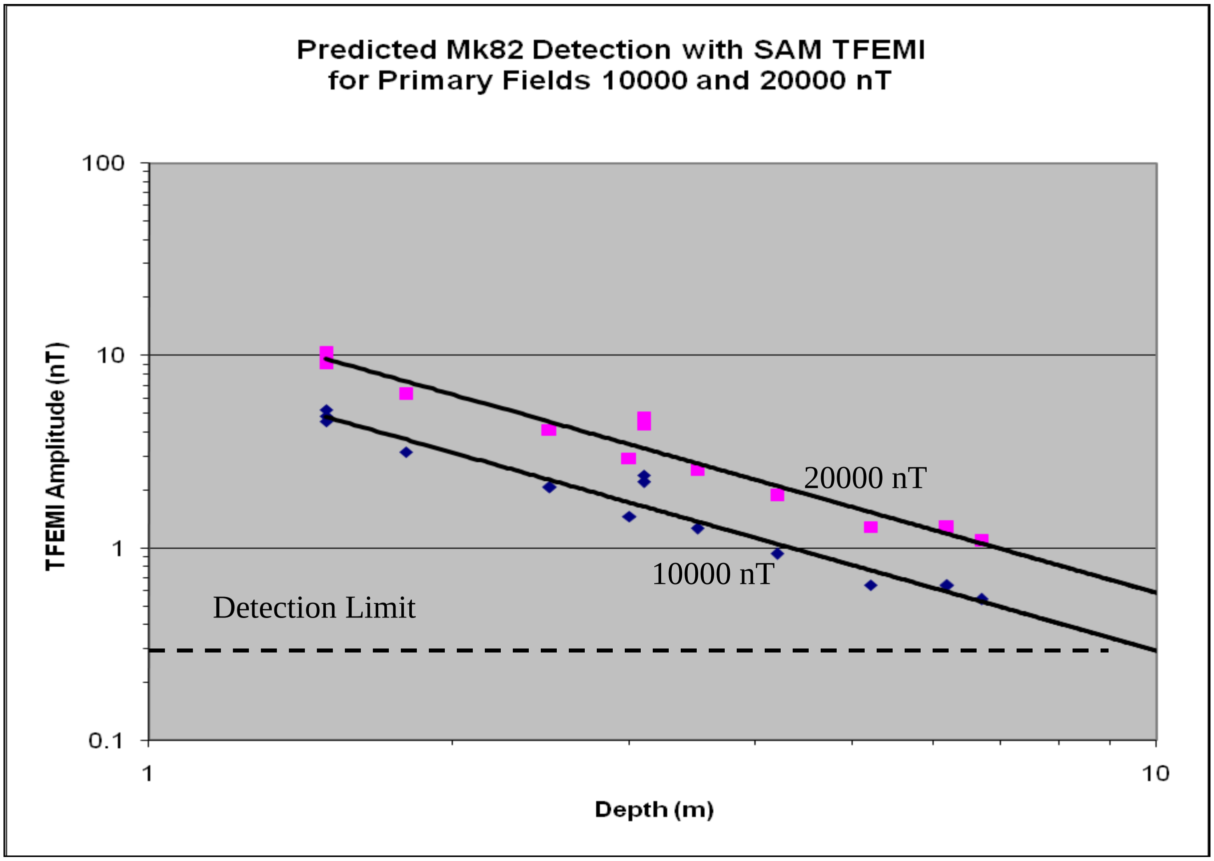


Figure 42 Predicted Mk82 Depth Detection for Different Primary Fields

3. EM Decay Quality:

This criterion aims to measure hardware performance by quantifying what is generally quite apparent visually when target decays are observed. The late-time portion of the decay is modeled as an exponential and the correlation coefficient is used to provide a measure of the deviation from the model, thereby quantifying the actual noise at late time.

A number of results from the Calibration Grid at APG2 were analyzed in this manner and the results are presented as Figure 43. The surprising result of this analysis was that even for quite low SNR's, close to 1, the correlation coefficient for the exponential model fit was very high. Figures 44 and 45 provide two examples of the typical models of items with medium SNR. The presented decays were originally sampled at 4800 samples per second. The number of samples in the decays has then been reduced by windowing with window lengths that increase logarithmically so the data points appear evenly spaced on the semi-log scale.

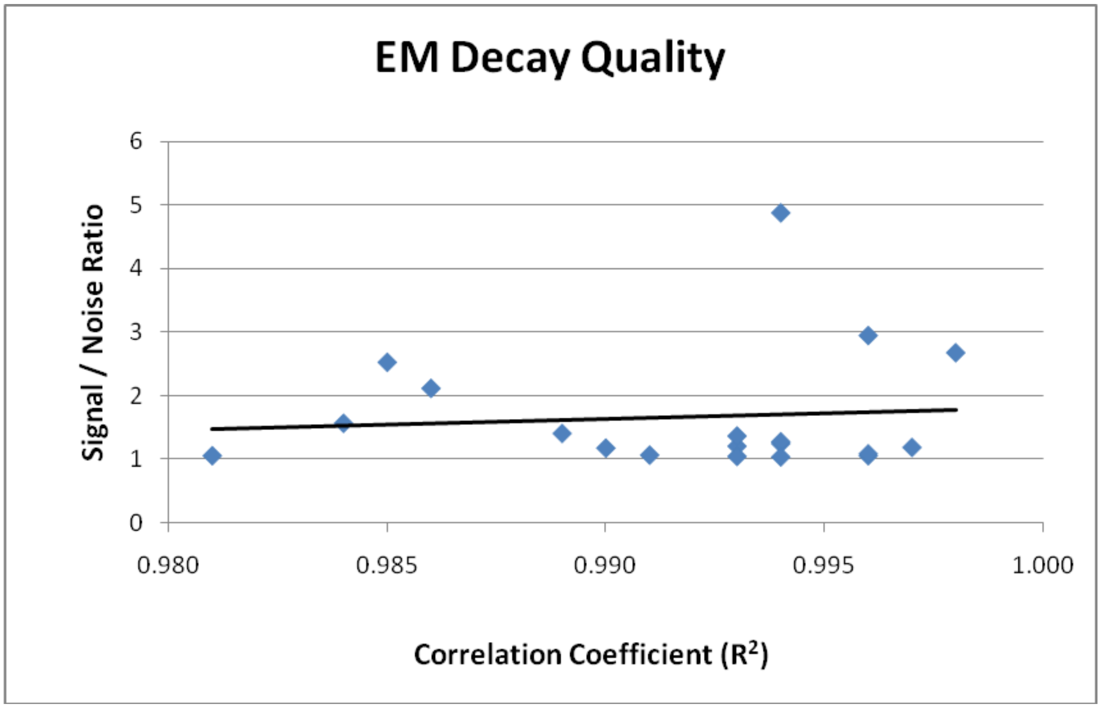


Figure 43 EM Decay Quality Based on Correlation Coefficient and SNR

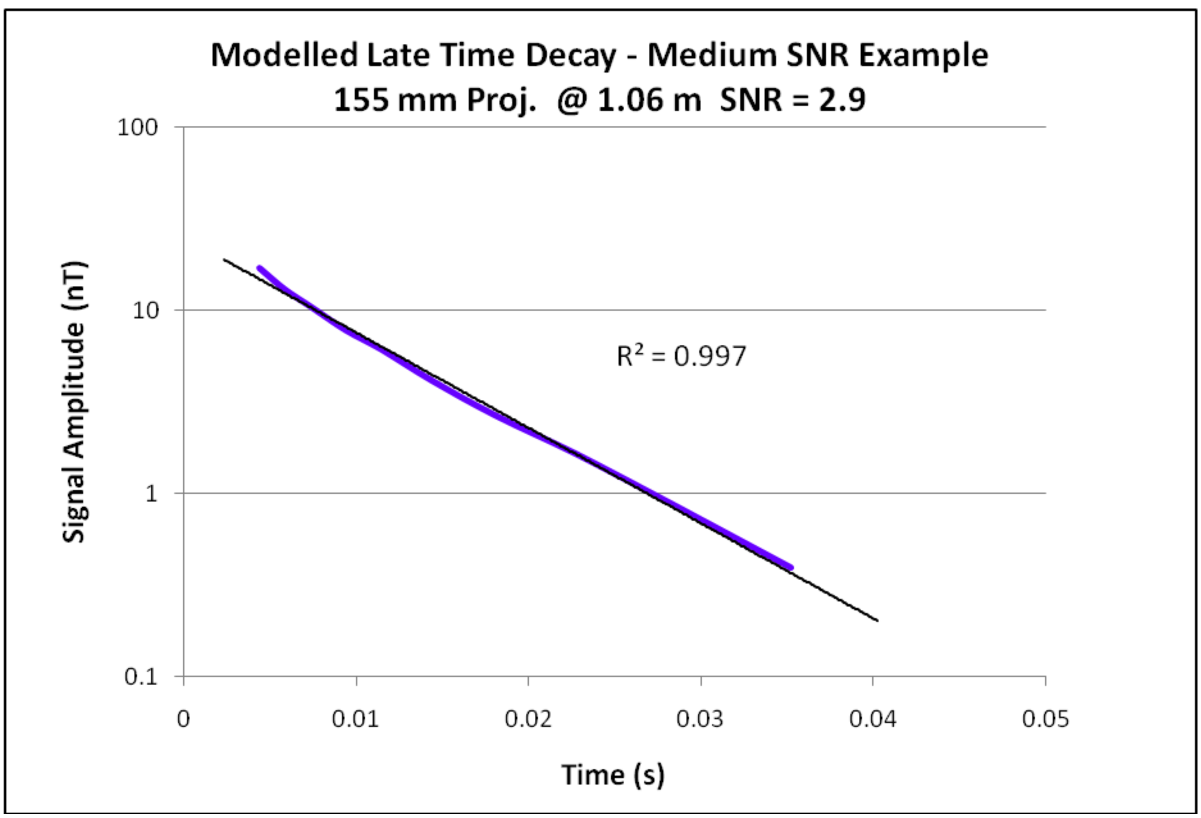


Figure 44 Example of Exponential Fit to Target Response with Medium SNR

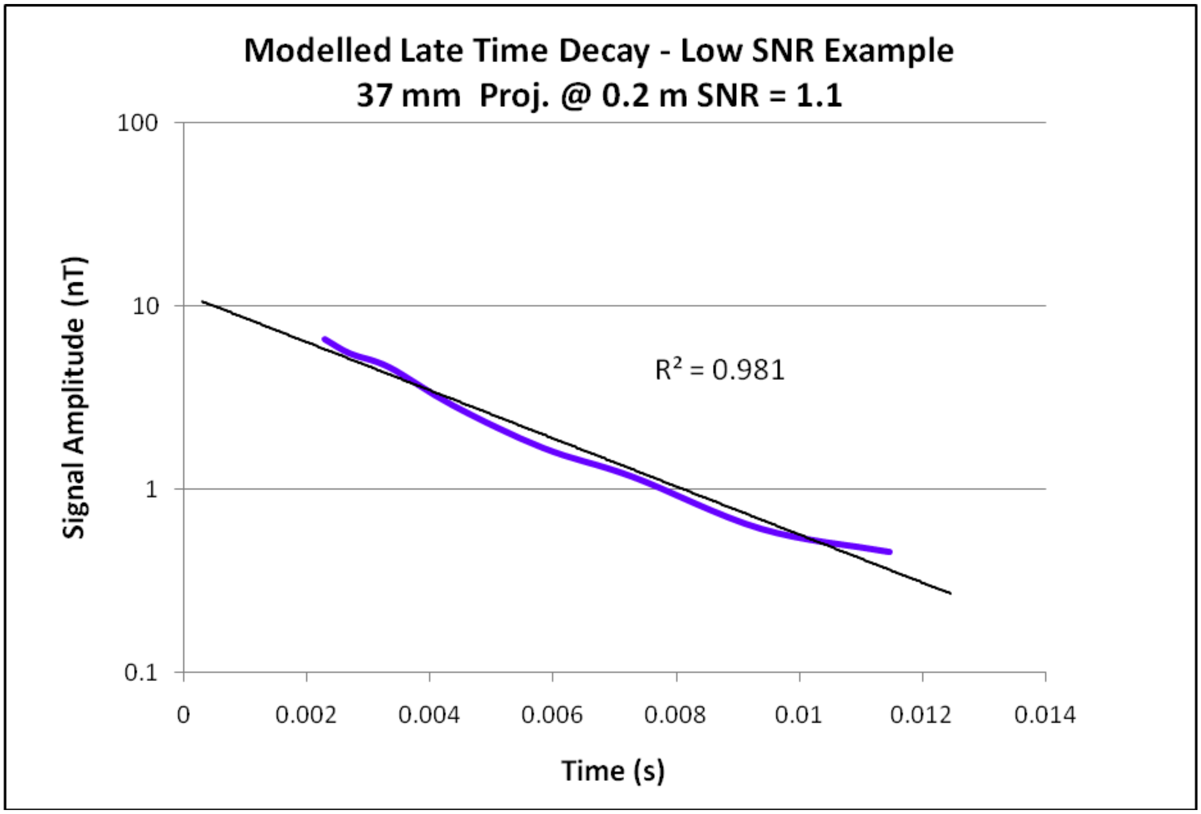


Figure 45 Example of Exponential Fit to Target Response with Medium SNR

Two other decay examples have been included as Figures 46 and 47 to provide an illustration of the degree to which the decays can vary. In Figure 47, the 60 ms off-time is seen to be about right for targets of the size of the 155 mm projectile.

In these two examples the difference between the two trialed transmitters is quite dramatic, especially in the case of the BLU-26, where the rapid switch-off with the new MPTX provides much higher frequency energy which is useful for exciting the smaller targets. The advantage of being able to use much higher power is also apparent because it raises the decay response higher above the noise floor at late time, providing a good quality decay for modeling purposes.

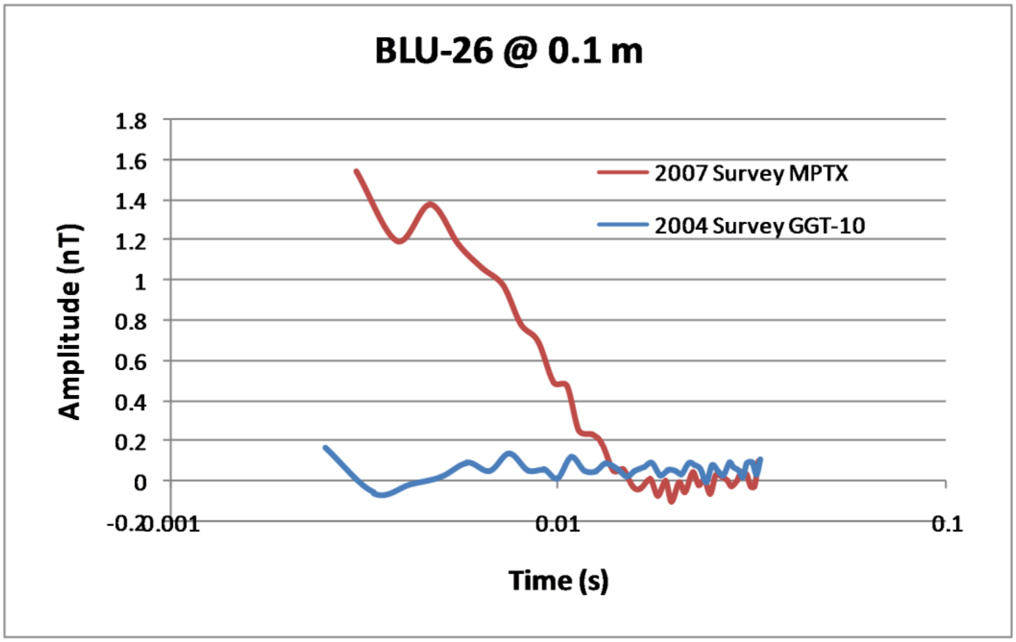


Figure 46 Transmitter Comparisons of Decays from Small Item

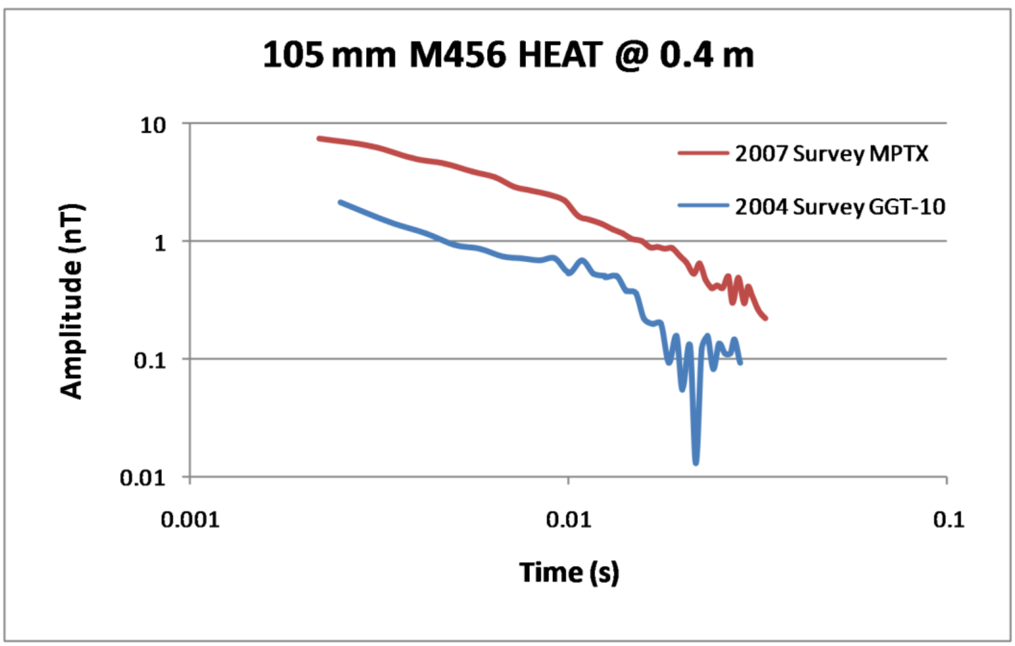


Figure 47 Transmitter Comparisons of Decays from Large Item

4. Probability of Detection:

Data summarizing the Probability of Detection (P_d) at the APG2 Blind Grid (BG) and Open Field (OF) and the YPG Blind Grid has been provided by ATC in various reports, and is summarized in Tables 12 and 13 for Ordnance and Clutter respectively.

Table 12 Probability of Detection of Ordnance

Location	Overall	Standard	Non-Standard	By Size			By Depth (m)		
				Small	Medium	Large	< 0.3	< 0.3 to < 1	>= 1
APG2 BG	0.60	0.70	0.50	0.40	0.80	1.00	0.55	0.65	0.65
YPG2 BG	0.75	0.75	0.80	0.75	0.80	0.80	0.85	0.80	0.00
APG2 OF	0.30	0.35	0.30	0.10	0.35	0.65	0.30	0.35	0.40

Table 13 Probability of Detection of Clutter

Location	Overall	Standard	Non-Standard	By Size			By Depth (m)		
				Small	Medium	Large	< 0.3	< 0.3 to < 1	>= 1
APG2 BG	0.75						0.75	0.80	0.65
YPG2 BG	1.00						1.00	0.95	N/A
APG2 OF	0.35						0.30	0.45	0.55

Results for Probability of Detection presented in Tables 12 and 13 are summarized in the column labeled 'Overall', but are then further broken down in Table 12 into categories of 'Standard' and 'Non-Standard', as well as three categories of size and three categories of depth (both tables). Standardized targets are members of a set of specific ordnance items with identical properties to other items in the set, whereas the non-standard items will have slight differences from the standard set relating to factors such as weight, magnetic remanence and configuration (e.g. whether they are fully intact).

Small ordnance items include those with a caliber less than 40 mm such as 20 mm proj., 40 mm proj.,BLU-26, BLU-63 and M-42. Medium ordnance items have a caliber between 40 mm and 81 mm and include 57 mm proj., 60 mm mortar, 2.75 in rocket, Mk118 Rockeye and 81 mm mortar. Large ordnance items have a caliber greater than 81 mm and include 105 mm HEAT, 105 mm proj., 155 mm proj., Mk82 500 lb bomb.

It is quite apparent from Table 12 that the P_d for medium and larger items was far better than for the small items. Another notable result was that the P_d at the YPG Blind Grid was better than APG2, where the benefit of being able to analyze truth data from APG2 had provide important indicators for the interpretation.

5. Background Alarm Rate:

The Background Alarm Rate (BAR) is calculated as the ratio of the number of reported detections that do not correspond to known emplaced items to the known number of actual emplaced items (i.e. known to ATC but not to us).

As stated previously in Section 3.2 the BAR = 0.05 is a result that reflects the fact that many of the interpretations have been selected with a threshold cut-off amplitude that is close to the noise floor, in order to maximize the chance of detecting the smaller ordnance items known to be present. For this reason we do not place too much significance to this result other than the fact that it provides another indicator of the problem the system has with small item detection.

6. Location Accuracy:

Refer to Section 3.2 for the discussion of location accuracy.

7. Survey Rate:

The data file headers include a time-stamp corresponding to the opening and closing of the files. Given that we record each surveyed block as a single file, the time-stamp records have been used to summarize our data acquisition activity, in particular the time to complete each grid and the time taken between grids to lay out the loop. This data has been used to generate the plots presented as Figures 48 and 49. In these plots, the x-axis is elapsed time through the day, and vertical lines separate periods of consecutive loop layout or grid surveying. The two examples are for APG1 and APG2 respectively, and the differing survey rates achieved are based on the fact that at APG1, using the Zonge GGT-10 transmitter, a large feeder wire allowed only the loop itself to be moved each time, whereas at APG2 with the new MPTX, both loop and generator/transmitter were being moved.

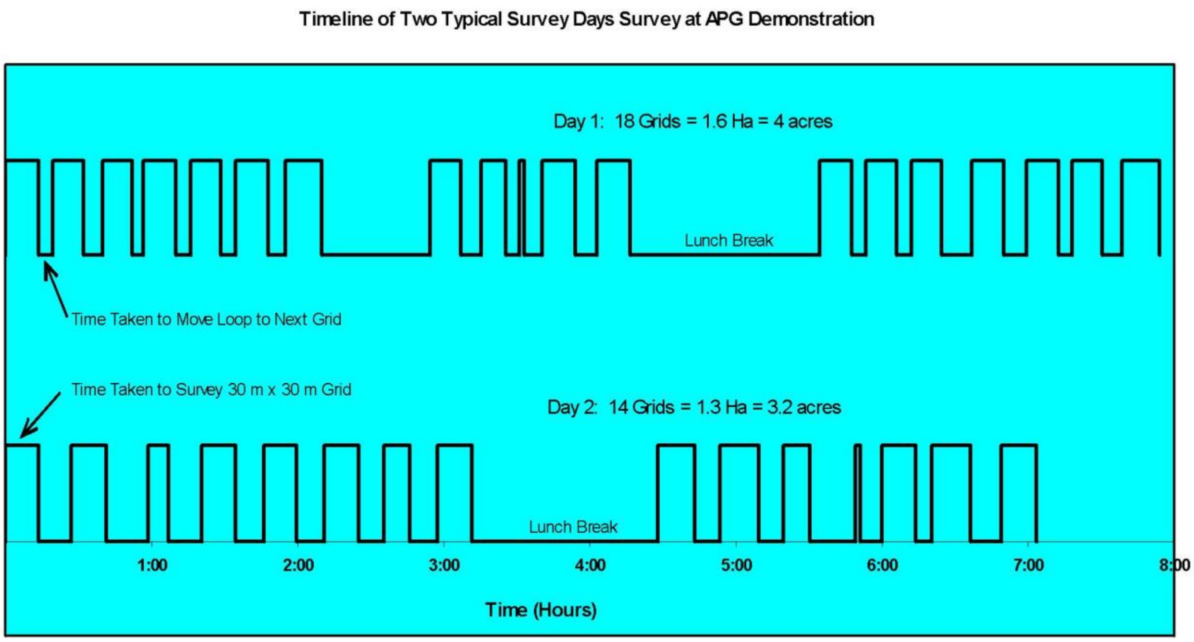


Figure 48 Elapsed Time for a Typical Working Day at APG1

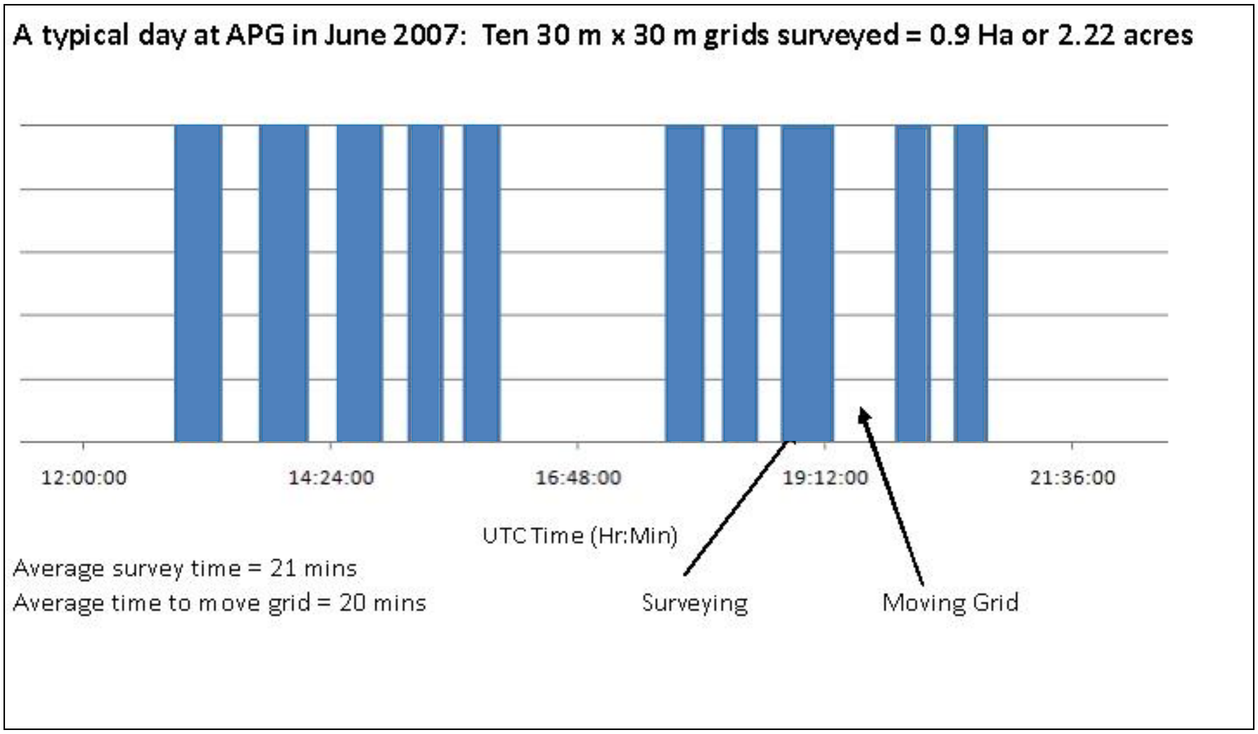


Figure 49 Elapsed Time for a Typical Working Day at APG2

In Figure 49, the blue block widths represent the elapsed time during the survey of each of ten grids. The white space in between represents the time taken to move the loop to the next grid

Table 14 Times Required For Activities

Location	Terrain	Initial MPTX Setup Time (mins)	Average Loop Move Time (mins)	Average Survey Time (mins)	Estimated Daily Productivity (acres)
Chevallier Ranch	Undulating	30	15	20	3
Limestone Hills	Very Rugged	60	20	22	1
APG1	Flat	30	11	14	4
APG2	Flat		20	21	2.2
APG2 (best day)	Flat				3.2
YPG (best day)	Flat		14	26	2.0

Table 14 summarizes survey rates achieved at a number of the trial surveys that represented a range of terrain conditions, climate and survey methodologies.

Although the SAM Method may seem to be labor intensive with the need to move the transmitter loop to each new grid, on average the coverage rate is still equal to other systems. This is mainly because of the use of a quad magnetometer sensor that is light and portable, with a wide swath, and easy operations. The results have shown that even the most rugged terrain (e.g. Limestone Hills) is no barrier to this method. It should also be noted that much greater survey efficiencies are possible with a 110 x 110 m loop, which is the preferred layout for searching for large items.

8. Processing Time

Refer to Section 3.2 for a discussion of Processing Time.

9. System Function:

There are a number of quantitative criteria relating to system function that are being included as primary performance criteria because they are considered as crucial factors in the overall system operations.

These are listed as follows:

- The output current level is extremely stable between successive on-times, test have shown the error in this variation to be about 0.03% when the constant current mode is used, and 0.2% when controlled current mode is used.
- A consistent primary field can be maintained within grids (during time taken to survey one grid) and between grids. This is estimated from the on-time data and then used to provide a value that to normalize the results.
- There is minimal noise from EM interference in the processed data because we are able to filter out any that is present, especially mains power. MagPI has a facility for providing plots of the amplitude spectral density. These will be used to look at the spectrum of the raw data to see if there are any spectral peaks which clearly relate to noise sources that happen to be located close to an odd harmonic, which is where the TFEMI information is located in the spectrum.
- We expect the system to function according to its specification as it has done in previous pre-demonstration trials
- Stronger primary field will result in anomalies with much greater Signal/Noise ratio.
- Low inductance single-turn coils allow faster current turn-off, resulting in generation of higher frequency excitation and less system response to smear the early-time part of the target response.
- The 110 m x 110 m loop will be suitable for use in a wide range of ordnance applications depending on the minimum sized item, resulting in greater efficiencies and lower cost.
- High current / low voltage signal allows much safer operation from the point of view of electrical hazard.
- Remote control of MPTX using Bluetooth allows operator to monitor transmitter while collecting data on the grid.

8. Cost Assessment

8.1 Cost Model

Table 15 summarizes the cost data for the two surveys APG2 and YPG, which were conducted over 14 and 15 day periods respectively, including on-site setup and surveys of the Calibration Grids, Blind Grids and Open Fields at both sites.

Table 15 Cost Model for the SAM EM UXO Detection System

Cost Element	Data Tracked During Demonstration	Estimated Costs (USD)	
		APG2	**YPG**
Instrument Cost	Transmitter/Generator/Cables TM-6 Magnetometer 4 x G-822 Sensors DGPS	$555 / 8hr day $465 / 8 hr day $540 / 8 hr day $368 / 8 hr day	$555 / 8hr day $465 / 8 hr day $540 / 8 hr day $368 / 8 hr day
Mob/Demobilization and Living (transport, accommodation, meals)	Travel of Personnel Accommodation/Meals Equipment Freight Vehicles	$8000 $8000 $3000 $1000 **Total = $20000**	$10000 $10400 $1500 $1200 **Total = $23100**
Site Preparation (set up grid)	Hours Personnel Equipment	2 hrs 2 @ $57 / crew hr $46 / hr **Total = $206**	2 hrs 2 @ $57 / crew hr $46 / hr **Total = $206**
Instrument Start/Finish Costs (assemble rig, test function, pack up at end)	Hours Personnel Equipment	9.1 hrs 4 @ $209 / crew hr $241 / hr **Total = $4095**	15.6 hrs 4 @ $209 / crew hr $ 241 / hr **Total = $7020**
Survey Costs Calibration Grid	Hours Personnel Equipment	13.1 hrs 4 @ $209 / crew hr $241 / hr **Total = $5895**	7.2 hrs 4 @ $209 / crew hr $241 / hr **Total = $3240**
Survey Costs Blind Grid	Hours Personnel Equipment	14.3 hrs 4 @ $209 / crew hr $241 / hr **Total = $6435**	3.3 hrs 4 @ $209 / crew hr $241 / hr **Total = $1485**
Survey Costs Open Field	Hours Personnel Equipment	90.5 hrs 4 @ $209 / crew hr $241 / hr **Total = $40725** **= $2973 / acre**	95.2 hrs 4 @ $209 / crew hr $241 / hr **Total = $42840** **= $2782 / acre**

Instrument Cost

- The system is currently not available for purchase and is only available for rental at the rates indicated in Table 15.
- The estimated equipment costs in Table 15 are based on a daily rental rate in US$. For the purpose of compiling this table, they have been converted to an hourly rate that assumes an 8 hr work day. In practice the number of hours worked per day is not actually taken into account.
- Actual survey operating costs would include equipment rental, supervision and participation by a minimum of one experienced operator, operator training, maintenance, and consumables that include oil and gasoline.
- Maintenance costs are included in the daily rental rate and would include such things as batteries, wire and engine drive belt replacement (all quite infrequent), and software/firmware upgrades.

Mobilization/Demobilization/Living

- Equipment would be mobilized from CEHNC in Huntsville, AL.
- The recommended method is road freight, due to the presence of hazardous cargo (a gasoline engine), high volume/weight, and size/volume to be freighted includes 2 pallets, 400 kg (900 lbs), 1.3 m^3 (45 cubic ft).
- At the present time, operation of the equipment in the USA, requires the mobilization of one operator from Australia.
- Costs in this category include transport of equipment to and from the work site, and might also include establishment of structures such as a site office and survey monuments. A substantial site office facility is needed in order to store the bulky equipment securely overnight.
- Site restoration costs after the survey would be minimal due to low impact nature of the work.
- Transport costs quoted in Table 15 only refer to transport of personnel during the course of the survey, since transport of equipment to the actual work area is included in the stated freight cost.
- Living costs such as food and accommodation would normally be assumed to be based on standard Govt. per diem rates.

Site Preparation

- Preplanning
    - map of survey area and determine waypoints for grid,
    - determine if suitable facilities at site e.g. overnight storage of equipment including facilities to charge batteries,
    - accurate survey monuments established within suitable proximity of all areas to be surveyed.

- An important first step at any new location is the establishment of DGPS base station monuments, at a suitable central location. In the case of APG and YPG these locations were already provided as part of the facility.
- Sites are covered as a sequence of 30 m x 30 m grids, which requires the area to be set out with marker flags on the grid to locate all grid corners. The TM-6 magnetometer and DGPS has the required software to allow this task to be performed very efficiently. All grid coordinates are preloaded into the system as waypoints, and operators are given the means to navigate to the required locations quickly. For example the 15.4 acre Open Field at Yuma was laid out by two personnel in 2 hours. A similar time was required for APG2.

Instrument Setup Costs

- This process can be undertaken quite efficiently if operators are familiar with equipment. At APG and YPG, 3 of the 4 operators were being trained on the job and this slowed the process. Operators caught on to the required tasks quickly, and were able to contribute significantly in a short time because of simple nature of most required tasks.
- The setup process starts with the unpacking of equipment – probably on pallets – then from packing cases. Additional cost factors to take into account include the time spent packing the equipment ready for the shipment from the home base, and repacking equipment at the completion of the survey work which usually takes longer than the initial unpacking.
- Unpacking is followed by assembly of the trolley for sensors and attachment of the sensors.
- Configuration of the TM-6 magnetometer and DGPS.
- Assemble generator from transport mode and prepare for operations – attach fuel system, attach engine start battery, fill fuel tank and engine oil reservoir – test engine operation.
- Setup rig for transmitter and generator – heavy generator required to be lifted onto back of small site vehicle – transmitter set out on small trailer – cables attached - system secured.
- Setup at APG was quicker due to equipment preparation off-site prior to the first day on job. At YPG the equipment was unpacked from the state it was in when initially transported.
- Some parts of the rig are still considered to be a prototype, so their setup time is probably longer than what would be anticipated for a final commercial version.

Survey Costs

- It is very important to be able to store mobile equipment in a secure weatherproof facility overnight that allows it to be quickly readied for operations at the start of each day and stowed away at the end. Wire used for loops would normally stay on the grid. If this practice was not possible, plan for time to reel in cable at end of day and redeploy the next day.

- The compilation of Table 15 has been based on stated ATC rates that were provided as a guideline of labor rates for 4 personnel, and use their data of the logging of our activities, which indicate the time spent on the various tasks. As mentioned previously, equipment costs are based on the daily rental rates and converted to hours, since this was how the time was compiled by ATC.
- At YPG there were more breaks during the day due to the high temperatures. That time was used to download and check data.

Data Processing Cost

- Requires access to Geosoft and UXOLab software packages.
- Software required to get to the point of XYZ file (fully geo-referenced and filtered) would be included with the rental of the hardware.
- Does not include time required to perform discrimination at this stage of the development.
- The major daily processing task is to sufficiently process data to determine if data quality meets the required standard, including checking for redo due to signal loss etc. and back-up data. It is difficult to fit these activities into the time frame of evening activities, after dinner, if that person has been in the field all day as an operator. In normal commercial work it is assumed a dedicated data processor would be used.

8.2 Cost Drivers

Productivity and false alarm rates are considered the most significant cost drivers.

Site specific characteristics that would influence cost are mostly factors that would influence all other geophysical methods as well.

- Terrain (has an impact on most methods anyway)
- Obstructions such as trees – impact on loop layout as well as DPGS reception
- Very wet ground
- High rainfall
- Lots of gullies impact on data quality
- Extremely high magnetic soils – gradients of order of 10000 nT or more over a few meters.

8.3 Cost Benefit

- Two data sets (TMI and TFEMI) are obtained in one pass of the survey site.
- The two complementary data sets are perfectly geo-referenced with each other due to the use of a single sensor for both, which can inherently reduce false alarms in some situations. E.g. magnetic soils may produce anomalies that look like ordnance but are in fact geology, and comparison of the TMI with the TFEMI would highlight these anomalies since they would not be present in the TFEMI.
- Potential for use of this system in the search for large deep targets is significantly better than other technologies currently available.

8.4 Additional Factors for Consideration

Capital Equipment Cost

The capital equipment cost of a SAM UXO system would be higher than the combined cost of a commercially available magnetometer and EM system such as an EM-61. However, because of the anticipated increased productivity associated with the SAM UXO system, the capital equipment cost component when factored into the overall cost of a survey would probably be quite competitive against the alternatives. For example, consideration needs to be given to the fact that there is no equivalent commercially available magnetometer that can be configured with four sensors, and provide a high sampling rate. Bearing this in mind, perhaps the system should be compared against the combined cost of two alternative magnetometer systems and an EM-61. Furthermore, the quality of the TFEMI decay needs to be considered when compared against the alternatives, and if a processing capability can be finally developed that can take advantage of this, one would expect that it is reasonable to pay more for it than an off-the-shelf EM-61.

Transport and Storage of Equipment

Transport and storage cost associated with SAM UXO system are significant because of the size and scale of components such as the generator, wire and transmitter. For example, there is a need to use pallets when freighting the generator and reels of wire, and this means there has to be forklifts available whenever the equipment is collected or delivered. Furthermore, the gasoline engine is rated as hazardous goods which also adds to the cost and restricts the options with road transport. Rigid polyethylene cases with foam inserts are used for the other system components, and although not totally necessary, it may also be convenient to transport these on pallets as well. In fact, these cases are designed for pallet transport with interlocking ribs that keep them together as a coherent unit when stacked.

Crew Related Factors / Survey Coverage Rates

A SAM UXO system survey crew would typically consist of three to four operators, although it would be possible to perform the work with a minimum crew of two. Experience to date has shown that productivity with a crew of four varies between 1 acre per day (extremely hilly and rocky terrain) to 4 acres per day (flat to gently undulating terrain). On average, 40 % of the time is spent with general set-up and moving the loops around the grids while 60 % of the time is spent actually collecting the data on each grid. Based on these figures, a crew of two should still be able to achieve a coverage rate of about 3 acres per day in good conditions.

If a crew consisted of two people, both would have to be well trained, but would not need to be geophysicists. However, they would have to be supervised by a geophysicist (who could be remote), who would also have to be involved in decisions relating to site coverage and in the determination of survey and instrument parameters. That geophysicist would have to be well versed in the theory and detail of the SAM UXO system. If a crew of three or four were being used, the extra people could contribute significantly to the team after a minimal level of training. The most crucial team member(s) would be the sensor carrier who has to maintain a straight line while trying to keep the sensor array steady. In this task, there is no substitute for experience. This operator does not necessarily need any formal qualifications.

Two key survey related factors that can influence the data quality are the sensor array orientation and the survey speed. A third factor with less potential for error is the ability of the operators to maintain straight line traverses. It is very important that the sensor operator tries to maintain the array as level as possible because for example any tilt in the array affects the positional accuracy which in turn can affect the quality of inversion. Survey speed can obviously influence coverage rate and so a compromise is required between a reasonable speed to ensure cost efficiency and one that is slow enough to ensure good spatial resolution, especially if the lower transmitter frequency is being used. The fact that 40 % of the time is spent setting up grids can help to hide a slow survey speed in the overall field work, if it is what is required at a given time for good data quality.

Discrimination / False Alarm Rate

The true worth of any detection system is closely linked to its ability to detect ordnance items with low risk (very few items remain in the ground undetected or have been misclassified as clutter and therefore not investigated further) and low cost (very few anomalies are investigated through digging unnecessarily because they might be clutter that has been misclassified as ordnance). The false alarm rate is always of interest and it is an important indicator of system performance so long as it appreciated that it depends on both hardware and software factors.

While the true discrimination capability of SAM is yet to be fully determined, there is a reasonable expectation that an analysis of two independent data sets (magnetic and electromagnetic) that are perfectly geo-referenced should enable the false alarm rate to be reduced through discrimination techniques, to an extent that is greater than what might be possible if the data seta are obtained singularly.

During the current phase of work some progress has been made in the area of discrimination, however this part of the work is an on-going task outside the scope of this report. The data obtained on all trials to date, but particularly APG2 and YPG form a crucial part of this future development.

Acquisition / Processing Costs

One of the attractive attributes of the SAM UXO detection method is its ability to simultaneously acquire magnetic and electromagnetic data in one pass over the survey area. This should be taken into account when comparing the cost of a SAM UXO survey with alternatives. Furthermore, even without the benefit of this cost efficiency, our belief is that an ability to survey a site at a rate that could be as much as 4 acres per day places the SAM UXO system well into contention with other systems, if acquisition cost is a key factor determining choice. However it is conceded that one factor that does need to be included in the equation is the mobilization cost, which is expected to be higher with SAM UXO than other systems.

We believe the SAM UXO system compares favorably with other systems in the areas of data acquisition and the time taken to process data to the stage of providing a list of hits (including ordnance and clutter together). However, the extra task of applying discrimination to separate ordnance and clutter is still in a research phase and is not yet ready to be part of any comparison that aims to highlight relative system efficiencies.

Terrain / Environmental Factors

The hand-carried magnetometer array has been proven able to be used in terrain conditions that would be difficult for the use of a larger-sensor system such as an EM-61. Quad-sensor arrays have been routinely used in some very severe conditions of terrain and vegetation (exceeding that accessible to an EM-61). Even the most extreme conditions could be surveyed with just a single sensor, so long as a person is able to traverse the terrain. Furthermore, extreme terrain conditions have not yet been encountered where it proved difficult or impossible to deploy the transmitter and wire loop. However, just like any other technique, extreme terrain conditions will slow down the coverage rate. Our experience has shown that this can be as much as a factor of 4 (1 acre per day in extreme terrain versus 4 acres per day in easy terrain).

Two environmental factors that will adversely affect the SAM UXO system are magnetic latitude and very high magnetic geology. Because the artificial vertical induced field from the transmitter is modulating the earth field that is then measured by the magnetometer, the relative angle between these two fields will influence the magnitude of the resultant vector representing the anomalous target response. As magnetic latitude decreases, the magnitude of the modulating waveform will decrease until, at the equator, it becomes too low to be distinguishable from the earth field. Very high magnetic gradients such as those encountered in the basalts of Hawaii will also influence the quality of the modulated signal to the extent that the modulating component (the TFEMI part) cannot be easily separated from the high gradient earth field.

One environmental factor that affects this and many other detection systems is tree cover and the extent to which this can mask the DGPS satellite reception. In some cases, the DGPS positional system simply cannot be used. Surveys in the wooded area at APG (other than in winter) have shown the extent of this limitation. The solution is to use alternative position technologies such as RTS and the cotton odometer. Both of these proved suitable for use in the APG wooded area in the previous demonstration.

Another problem, common to all UXO surveying, is the masking effect of exploded ordnance debris and small ordnance items either on the surface or just below. The usual solution is to remove this source of clutter prior to a digital survey using traditional clearance techniques. When the survey objective is to locate larger ordnance items, in the case of SAM UXO, the system has a natural discrimination capability that would require less initial clutter removal, simply because the difference in response between the large items of interest and the small surface clutter is great enough that the masking effect is minimal.

9. Implementation Issues

9.1 Environmental Checklist

With respect to the demonstrations being conducted at the two host facilities (APG and YPG), there were no known permits or regulations that were relevant to this technology. All activities at these venues were conducted under strict supervision and all guidelines were followed, which presumably accounted for any regulatory interest in our activities.

With respect to environmental regulations, there are no known permits or regulations that are relevant to this technology, and furthermore if there were any, our opinion is that there is nothing unusual about this technology that might cause it to being treated differently to any other technology being applied to the same application. The one exception to this might be controls over the use of a small gasoline generator that generates noise and exhaust emissions, but this is not known to be an issue at the host facilities, or any other location likely to be a survey location.

In terms of environmental impact, this technology has the same as all other ordnance detection methodologies in that it does require a certain level of vegetation clearance in order to properly deploy the sensors in an optimal manner. Usually this relates to clearing undergrowth such as grass and small bushes, and rarely relates to larger vegetation such as trees.

9.2 Other Regulatory Issues

This technology is driven primarily by regulatory issues relating to improving the probability of detection by using dual-mode sensor technology and the need to achieve this more efficiently. Information about this technology will be disseminated via technology conferences (such as the UXO Forum & SERDP/ESTCP Symposium), publications in the public domain such as scientific journals, by direct contact with appropriate government representatives working in UXO issues, and by direct contact with contractors who support government activities.

9.3 End-User Issues

CEHNC is the lead on this project because of their pressing need for better technology for DGM and UXO operations. CEHNC would be involved in advocating and pushing this technology into the user community if it is found to have a definitive role to play and is shown to meet the objectives defined herein.

One end-user issue relates to the cost of the methodology, but given that it might be deployed into an application where it is clearly the best option (such as detection of large, deep ordnance items) the cost of the geophysical survey is minor compared to all other remediation costs and it is not likely to be an issue that would discourage selection.

When the cost of the survey and acceptance of the system capability has been realized, a concern to be considered is the availability of the system. At the present time there is only one transmitter system available, and essentially this concern comes down to a problem of scheduling. The system is still new and largely unknown, thus this is not a problem that needs to be addressed. When there is more of a demand for the MPTX transmitter in the future, more systems can be manufactured to deal with that demand.

The current MPTX transmitter system is an engineering prototype, and any additional systems are quite likely to be identical, so there would be no further requirement for new development and design change, other than minor issues such as repackaging of the modules, and minor changes such as the use of larger fans for the hotter climates. The components of the receiver system are more readily available, with the Cs vapor sensors being off-the-shelf items that are widely available in the USA. The TM-6 magnetometer is only available from GapGeo in Australia, but there are many units currently available for rental, and more are being manufactured as an on-going activity.

As discussed previously, the one MPTX system is available for rental, but it has to be deployed with one experienced operator provided by GapGeo, who would have to be mobilized from Australia. Other personnel required for a survey could be provided locally and would be trained on the job just as they were for the demonstrations reported here. The need for any skills beyond what is normally expected of a geophysical survey technician or field operator is not required. At the time of finalizing this report, the one system available for rental is physically located in Australia where it is currently being used on projects. The system is available upon request for use in the Continental USA, it would be relocated to Huntsville, AL.

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APPENDICES

Appendix A: Points of Contact

Table 16 Points of Contact

Point of Contact	Address	Phone/Fax/Email	Role in Project
Lynn Helms	U.S. Army Corps of Engineers Engineering & Support Center-Huntsville 4820 University Square Huntsville, Alabama 35816-1822	Ph: 256-895-1625 Fax: 256-895-1602 lynn.helms@.usace.army.mil	Co-Principal Investigator
Stephen M Griffin	Gap Geophysics Australia Pty Ltd 10 Whipbird Ct Burleigh Waters Queensland 4220 Australia	Ph: +61 7 5535 1889 Fax: +61 7 3844 0022 sgriffin@gapgeo.com	Co-Principal Investigator

Table 17 List of Key Personnel

Name	Affiliation	Title	Involvement	Responsibilities
Lynn Helms	CEHNC	Engineer, Project Manager, Co-Principal Investigator	Pre-demo trials, APG/YPG demos (data acquisition)	Contract Management
Stephen Griffin	GapGeo	Manager of R&D, Co-Principal Investigator	Pre-demo trials, APG/YPG demos (data acquisition, processing, interpretation, reporting)	Quality Assurance Officer, writing demonstration plan, submission of results to ATC, writing final report.

John Stanley	G-tek	Original Co-Principal Investigator (2003-2005)	Pre-demo trials, APG1 demo (data acquisition)	Project management,
Malcolm Cattach	GapGeo	Chief Executive Officer, Principal Geophysicist	Pre-demo trials, APG/YPG demos (data acquisition, reporting)	Health and Safety Officer, administration of contract with CEHNC
Ed Campbell	GapGeo	Manager of IT,	Pre-demo trials, APG/YPG demos (processing, interpretation, reporting)	Development and maintenance of processing and interpretation software
Darryl Milligan	GapGeo	Senior Technical Officer	Pre-demo trials,	Construction and maintenance of TM-6's
Keith Mathews	Kayar Pty Ltd	Principal Electronic Engineer, sub-contractor	Pre-demo trials,	Design, construction and testing of MPTX
Chris Parker	ARM Group, Inc.	Field Geophysicist, sub-contractor	APG/YPG demos (data acquisition)	Assist with fieldwork component of demonstrations
Ian Wilson	ARM Group, Inc.	Field Geophysicist, sub-contractor	APG/YPG demos (data acquisition)	Assist with fieldwork component of demonstrations