University of Southern Queensland

Faculty of Health, Engineering and Sciences

Real world 3D accuracy achievable of Australian Standard 5488-2013 Classification of Subsurface Utility Information using electromagnetic field detection

A dissertation submitted by

Mr Samuel B. Hathaway

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Abstract

There are hundreds of kilometres of underground services - pipes and cables that carry vital services such as water, electricity, communications and gas are buried throughout Australia and that number is increasing every year. Damage to these vital services is not only costly it is also disruptive to the surrounding community; there is also the risk of personal injury and or death that could be caused by damaging underground infrastructure.(Dial Before You Dig, 2015)

The importance of locating these vital utilities before construction to aid in avoiding them is well known. Currently the most readily used technology used to locate these services is electromagnetic field detection. This technology is used to pinpoint the service location to an X, Y and Z position.

Can this technology meet the new Australia Standard - Classification of Subsurface Utility Information for positional accuracy in a real world test? To determine this, a test site was chosen that contains an underground line. After using a range of electromagnetic field detection equipment to locate the line, the true position will be revealed using non-destructive digging methods.

The derived position of the line from different electromagnetic field detection equipment will be compared against the true position surveyed points. An error analysis will be provided showing a comparison of the methods and thus determine if they meet the quality specified in the Australian Standard.

University of Southern Queensland

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ENG4111/ENG4112 Research Project

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Samuel Hathaway
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Signature

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Date

Acknowledgements

I would like to thank following for their support and help with this project;

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Last but not the least; I would like to thank my partner Stephanie for her understanding and support.

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Glossary of terms and definitions

Asset/Service/Utility: An underground or submerged conductor, pipe or structure used in providing electric or communications service (including, but not limited to, traffic control loops and similar underground or submerged devices), or an underground or submerged pipe used in carrying, providing, or gather- in gas, oil or oil product, sewage, storm drainage, water or other liquid service (including, but not limited to, irrigation systems), and appurtenances thereto.

Dial Before You Dig(DBYD): The Dial Before You Dig referral service for anyone to make an enquiry for plans and documentation from underground Asset Owners to enable location of all underground services prior to underground excavations.

Excavate or Excavation: Any operation using non-mechanical or mechanical equipment or explosives used in the movement of earth, rock or other material below existing grade. This includes, but is not limited to, auguring, blasting, boring, digging, ditching, dredging, drilling, driving-in, grading, ploughing-in, pulling-in, ripping, scraping, trenching, and tunnelling.

Non-conductive Assets: An asset composed of material that does not conduct electricity or electromagnetic radiation and does not have a tracer wire affixed or in close proximity to enable the detection by locating equipment. E.g. plastic pipe, optic fibre cable. Pothole: Exposure of an asset by careful hand digging to locate the precise horizontal and vertical position of underground infrastructure.

Electronic detection: An non-intrusive, remote sensing methods used to determine the approximate location of subsurface utilities from the surface.

Locate: Determine the position of an underground utility.

Subsurface Utility Engineering (SUE): An engineering process for accurately identifying the quality of underground utility information needed for excavation plans and for acquiring and managing that level of information during the development of a project.

Tolerance: The amount by which the recorded location can deviate from the actual location of the utility and still meet the requirements of the quality level.

Trace: Physically locate a service by generating an induced electromagnetic signal from the utility along its entirety within the area of interest.

Quality Level: A classification reflecting the precision and accuracy of utility location and attribute information.

Vacuum Excavation: Vacuum excavation is defined as a means of soil extraction through vacuum; water or air jet devices are commonly used for breaking the ground.

Validate: Direct physical access and verification of the absolute spatial position and detailed attributes of the utility infrastructure.

Chapter 1. Introduction

Buried utilities are everywhere, yet there isn't an easy way for people to know where they are located. Compounding the location problem is the fact that the conduits for the services range from metallic materials, such as steel and cast iron, through to traditional materials such as clay and concrete, to synthetic materials such as polyethylene and polyvinyl chloride. Similarly the contents of the pipeline (gas, fluid, cables, optic fibre), its diameter, its depth and the properties of the ground surrounding it can all vary.

For the construction industry the unknown location of underground utilities is becoming a significant cost for projects if pre construction planning around utilities is not undertaken. Research by the Federal Highway Administration in the United States of America has found a cost benefit of $4.62 for every dollar spent on up front investigation (Lew 2000).

Records of utility locations are relatively limited, and even when records are available, they almost always refer the positions relative to physical features that may no longer exist or that may have been moved or altered. The lack of accurate positioning records of existing services as mentioned above can cause expensive construction delays and safety hazards when work is carried out in the area of buried services. But if these vital services are damaged it is not only costly it is also disruptive to the surrounding community; and there is also the risk of personal injury and or death.

Currently the most readily available and most used equipment to locate utilities is electromagnetic field detection equipment.

1.1 The Problem

Manufactures all specify a certain degree of accuracy which they believe the equipment can achieve, but is this accuracy really achievable in the real world and if so can it meet and or exceed the new Australian standard.

Currently if you walk around any major city and look down on the pavement you'll undoubtedly see an array of lines and numbers in different colours painted on the ground. Anyone would assume the utility would be directly under the line, and be exactly that depth marked. On the ground there is no mention that the utility might be 50mm offset that line or even 300mm offset.

In 2013 with the introduction of the Australian Standard 5488 - Classification of Subsurface Utility Information within it there is references to quality levels. It states how close the actual position of the line has to be when compared to where it was marked/located.

The problem is, do what the manufacture's says stack up to what is required in the AS-5488. This project seeks to examine if the AS-5488 can actually be achievable in the real world using existing equipment available on the market.

1.2 Project Aim

The aim of this project is to evaluate the real world 3D accuracy achievable of Australian Standard 5488-2013 classification of subsurface utility information using electromagnetic field detection.

Research will be conducted into methods of electromagnetic detection, the Australian standard, electromagnetic field detectors, past papers on electromagnetic field detection accuracies.

The accuracy will be verified in two different respects. The different equipment will be tested and compared to each other by analysis of the results obtained and compared to the real position verified by using vacuum excavation equipment to safely expose the service.

This report is not designed to improve the methods of electromagnetic detection. The aim of this report is to evaluate statistically the results that can be obtained using electromagnetic detection techniques available to the ordinary surveyor.

The overall aim is to give a better understanding of accuracies of electromagnetic detection in relation to the Australian Standard.

1.3 Project objectives

The objectives of this project are:

1. **Research field procedures and electromagnetic equipment used to locate services.**
   This will provide the background for the requirement of accurate locating equipment.
2. **Research sub surface mapping specifications**
   The current Australian standard AS 5488—2013 - Classification of Subsurface Utility Information will be researched.
3. **Create a field procedure to enable the collection of utility information**
   A field procedure will be designed to enable independent collection between the different equipment.
4. **Analyses the collected data statistically**
   This will allow conclusions to be drawn from the results.
5. **Critically evaluate the performance of the service locating methods including any recommendations when compared to the Australian standard.**

1.4 Justification

Surveyors are often measuring what's on the surface of the land and creating a plan for designers to use to help them design future developments. Yet hundreds of kilometres of underground services - pipes and cables that carry vital services such as water, electricity, communications and gas are buried throughout and that number is increasing every year. Damage to these vital services is not only costly it is also disruptive to the surrounding community; there is also the risk of personal injury and or death that could be caused by damaging underground infrastructure.(Dial Before You Dig, 2015)

In 2013 a new Australian Standard was released being AS 5488—2013 - Classification of Subsurface Utility Information. This standard makes use of a quality system to classify the precision and accuracy of utilities that are surveyed. Quality B is the second highest quality achievable and the highest achievable without the use of non-destructive digging. This quality specifies a relative spatial position of ± 300 mm horizontally and ± 500 mm vertically.

For a surveyor who typically works within a 5 millimetre accuracy, to be able to measure the utilities to the required quality it should be quite simple. The only weak link is; what is the real accuracy that can be obtained from the four electromagnetic field detection equipment: and do they all meet quality B.

Chapter 2. Literature Review

A brief review was undertaken; the purpose of the review was to gather relevant information about:

- The history of underground utilities and electromagnetic field detection
- Electromagnetic Field Theory
- AS5488
- Specifications of detection equipment

To give a background about what the aim of the dissertation is about, the history of underground utilities, electromagnetic field detection equipment and AS5488 will be presented.

2.1 Introduction to Underground Utilities and Detection

Utility detection is the process of producing and then detecting electromagnetic fields on buried utilities. In Australia 1856 was the year the first underground utility was laid. The South Australian Government's appointed Charles Todd the Superintendent of Telegraphs to construct a line from Adelaide to Larges Bay. A six-wire cable was laid underground in iron pipes. Now in Australia alone there are hundreds of kilometres of underground services - pipes and cables that carry vital services such as water, electricity, communications and gas are buried throughout.

Sixty years ago when utility lines were first being installed underground, it was probably unimaginable for the owners to visualise how congested things would eventually become. Some utility owners did create plans to show the layout of where the lines have been placed, though very basic. To most owners the exact location of the lines was never the issue, as it was more important to know the capacity and for use when undertaking maintenance and normal operations.

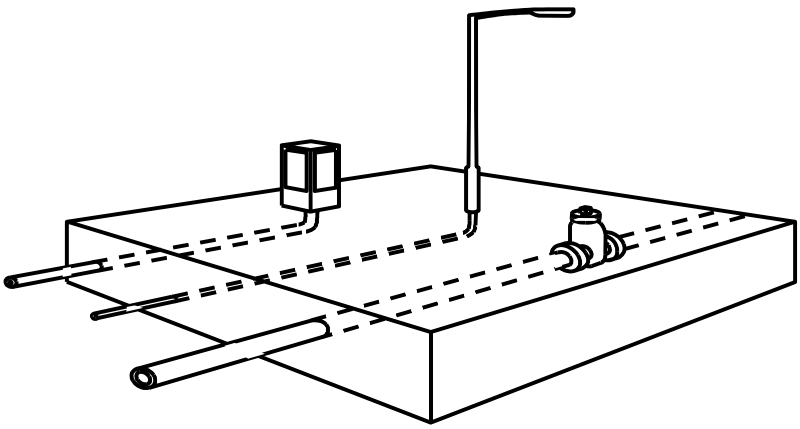

Figure 1. Typical street segment

A locator's job is to find the correct horizontal and vertical positon of a utility line in order to prevent them from being damaged or destroyed during construction activities. There have been three basic types of electromagnetic locaters over the years. Split box, transmitter and receiver with separate peak/null modes, and transmitter and receiver with combined peak/null modes. The middle option is the one most currently used.

The big issue now is trying to avoid damage to the services and the related cost to repair or move a service.

"Research by the Federal Highway Administration in the United Sta0tes of America has found a cost benefit of $4.62(USD) for every dollar spent on up front investigation." (Lew 2000)

This research concluded that the benefit of the money spent in investigating underground utility's far out ways the cost of damage or delays in projectsif this initial investigation is not undertaken.

Telstra phone and internet services lost after cable cut in Sydney

THOUSANDS of businesses and homes in Sydney's CBD could be without phone, internet and mobile phone coverage for up to a week after a contractor accidentally severed crucial cables.

Figure 2. News extract from SMH

The above headlines are what contactors don't want to be associated with. It's not only costly for them it can also put their workers at risk if they strike an underground utility.

2.2 Electromagnetic Field Theory

Electromagnetic waves are present all around us. Many of these waves are natural, while others are created by us. The earth itself generates an electromagnetic field that moves from the north pole to the south pole. The electricity supplied to us is generated in an electromagnetic wave at 50 hertz, the broadcasts from television and radio stations are electromagnetic waves. All electromagnetic waves have three measurable characteristics: frequency, wave length and amplitude. Frequency being the time interval between waves, wave length being the distance between the waves and amplitude is the strength of the wave. One other characteristic of electromagnetic waves is speed, all electromagnetic waves travel at the speed of light.

The person who enabled the detection of the underground utilities was Michael Faraday. He was one of the founders of modern physics and an expert in electro-magnetic physics. He invented the generator, electric motor and discovered electromagnetic induction.

The radiating field around the current is what gets detected. The signal detected by an electromagnetic locator is the electromagnetic field radiating around a current that is applied by the transmitter. Since the electromagnetic field is a force around the conductor, not the conductor itself, it is also much larger than the conductor. It always radiates around the conductor in a wide pattern. The larger the conductor, the wider the electromagnetic field signal, but the deeper the conductor, the less electromagnetic field there is to detect.

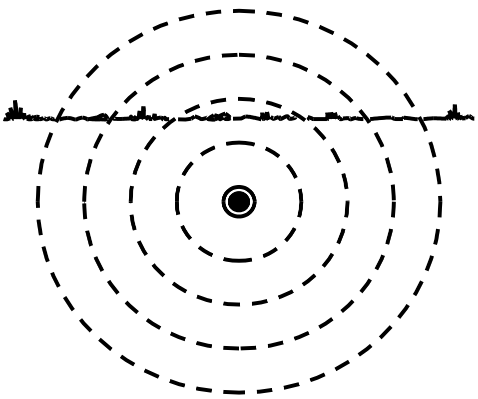

Figure 3. Section of an under line showing the radiating field

2.3 History of Electromagnetic Utility Detection

The first instruments which could detect a buried utility were manufactured in England in the early 1920's, but at the time the usefulness of the instrument was not well regarded. Only in the 1960's did new instruments become commonly used, that being a split-box locator.

The Split-box Locator is a hand-held instrument, consisting of a transmitter and a receiver.

Figure 4. Split Box Locator

The underground line is energized with a radio-frequency signal generated by the transmitter and then detected by the receiver.

Currently the one most widely in use is the modern transmitter and receiver, which will be mentioned in more detail

Figure 5. Modern Locating equipment – Receiver and Transmitter

2.4 Electromagnetic Utility Detection

Utility detection is the scientific method of determining the position of underground utility lines.

Electromagnetic field theory principles are used in two ways to locate utilities:

- To impose a signal onto a buried utility by subjecting it to a magnetic field set up by an signal transmitter in the vicinity,
- To detect a signal from a buried utility by amplifying the tiny voltages induced by its field in the aerials of a receiver

The standard equipment is an electromagnetic field locator. This is a two piece powered machine.

The transmitter applies the current onto the conductor, and the resulting signal is detected and traced out by the receiver. The current is an alternating current, and as it moves along the conductor it will radiate an electromagnetic field around the conductor.

The electromagnetic field is detectable with the receiver, and it is always the electromagnetic field that gets detected, never the service itself. Locating frequencies can be divided into three categories: low frequency, mid frequency, and high frequency. Low frequency being below 1kHz,, mid frequency being between 1kHz and 10 kHz, and high frequency 25kHz and higher.

Electrical current can only flow if a circuit is present. A locating circuit is a closed loop between a transmitter and a conductor. The loop is created when current flows from the transmitter, through the conductor (utility), and then back to the transmitter. The better the circuit,(less resistance) the more efficiently the current can flow, and the stronger the locatable signal.

For current to flow, and signal to be generated, the target utility must be continuously metallic down it's entire length. PVC, concrete and clay are nonmetallic, and therefore not conductive. Also, insulated joints or gaskets can stop or impede the current's flow, depending on the frequency being transmitted.

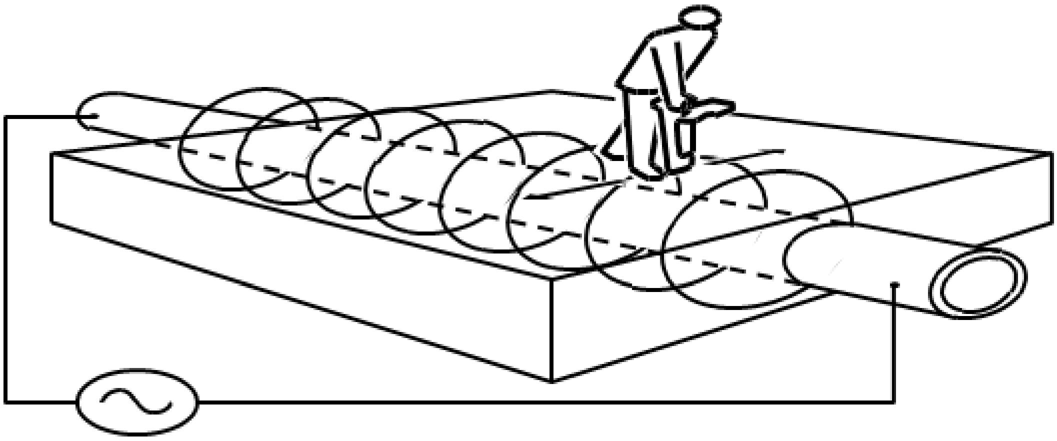

Figure 6. Section of an under line showing the radiating field

Every modern receiver has an audio visual display. It will have a read out of a number, a visual graph bar, and an audio sound. The user continually refers to the sights and sound on this display as the signal is being traced. The most noticeable readout on any receiver is the amount of signal being received. It simply indicates the percentage of possible signal the receiver can detect, and thus is known as the signal strength. This signal will be indicated on the numeric readout, but is also displayed as a graph bar.

Figure 7. Typical screen of a modern receiver

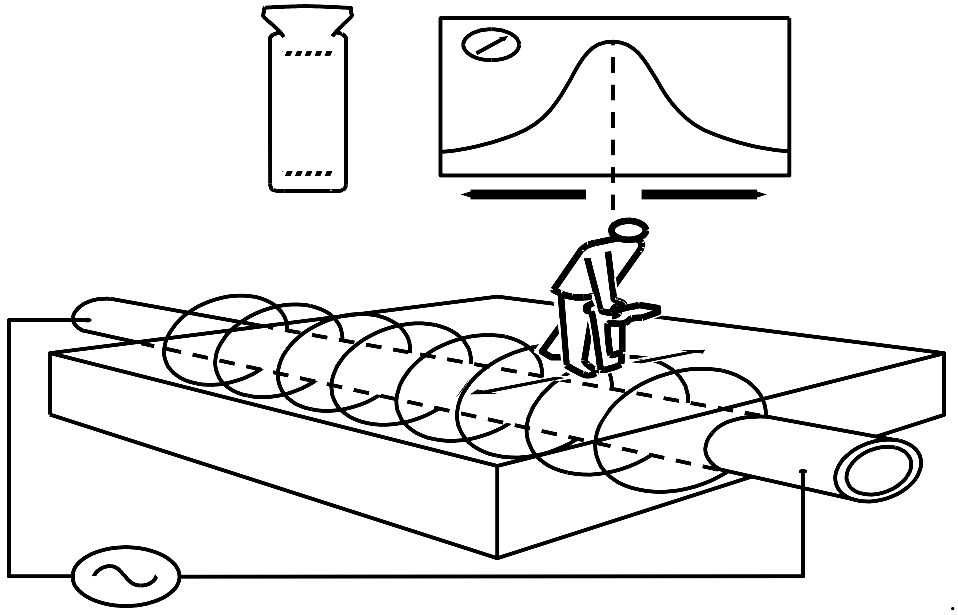

Figure 8. Section of an under line showing the radiating field with the peak repose shown

Most electromagnetic locators have depth measurement capability, but this is considered a secondary use. The main use is to find the horizontal position not the vertical position.

Benefits of the equipment

Electromagnetic location combines many advantages and facilities for obtaining information from underground that are not available from any other technique

• It can search an area from the surface to locate buried lines.

• It can trace and identify a target line.

• It can measure depth from the surface.

• The equipment is portable.

• The equipment is easily handled and can be successfully used

• The equipment works in all soil conditions;

• The component parts of the technology are low cost.

(Spx.com, 2015)

Accuracy of the equipment

The equipment's ability to find the correct position of a buried line and its depth is difficult to define and is often ignored. Electromagnetic locators do not locate pipes and cables; they locate alternating magnetic fields. Errors of accuracy can arise from two factors:

• The locator's capability to measure the precise point at which a magnetic field is at a maximum (or minimum) and to correctly measure a field gradient.

• The cylindrical magnetic field around a line can be deformed or distorted so that the maximum value is no longer directly above the target line and the field gradient is not suitable for making an accurate depth measurement. (Spx.com, 2015)

No information relating the accuracy to an actual distance was able to be found.

2.5 Applications and Limitations of Electromagnetic Utility Detection

In general, electromagnetic utility detection work well for metallic utilities, utilities that have tracing wire or metallic tape installed above them and utilities that can accept a metallic conductor or transmitter (sonde) inserted into them (e.g. empty conduits, storm/sanitary sewers with access, empty and accessible pipes, etc.). Non-metallic utilities without tracing wire or metallic tape installed or without access for sondes or wires cannot be imaged with this method.

Advantages:

- Can be fast
- Not labour intensive
- Relatively affordable

Limitations:

- Will not locate plastic pipes without a trace wire.
- Underground Congestion-"Signal Jump"
- Connection Points access needed
- Adjacent metal objects can interfere with signal

2.6 Relevant Electromagnetic Utility Detection Research

"Underground Facility Pinpointing [Project #3133] PRINCIPAL INVESTIGATOR: Alicia Farag"

The researchers found that electromagnetic locators are cost effective, efficient, easy to use, and a fast way to find buried conductive pipe. Of the 14 models tested, the majority (12) had a horizontal accuracy >80%. Vertical reading capability was available on 10 models and 7 models had a vertical accuracy >80%.

"Uncertainty-aware geospatial system for mapping and visualizing underground utilities"

In their paper Li, Cai and Kamat, 2015 Talks about inaccurate utility location information leads to falsely instilled confidence and potentially misleads equipment operators into unintentional utility strikes. And how there is a great need to map underground utilities and to model and communicate uncertainties to end-users for safe excavations. They don't talk about electromagnetic detection to achieve this.

Conclusion of past research

From the literature review above it was found there was no information relating quality of the 3d position attainable from the use of the electromagnetic methods compared to a standard, most focus on newer technology like ground penetrating radar and ignore the older and most used techniques. This project will fill this missing information gap and inform people on real world results.

2.7 Australian Standard

2.7.1 Introduction

The new standard has been prepared by Standards Australia Committee IT-036, Subsurface Utility Engineering Information, made up of 19 organisations with an interest in the issue. These included;

- ANZLIC—The Spatial Information Council
- Australasian Railway Association
- Australian Institute of Mine Surveyors
- Australian Local Government Association
- Australian Services Union
- Austroads
- Dial Before You Dig
- Energy Networks Association
- Engineers Australia
- Geospatial Information and Technology Association
- Heads of Workplace Safety Authorities
- Institute of Public Works Engineering Australia
- National Broadband Network
- National Utility Locating Contractors Association
- NSW Streets Opening Conference
- Surveying and Spatial Sciences Institute
- Telstra Corporation
- University of New South Wales
- Water Services Association of Australia
- WorkCover New South Wales

All who played a significant role in ensuring that the standard is truly Australian and not simply a replication of the US standard.

Colin Blair, Standards Australia chief executive, said: "The primary objective of this Australian Standard is to provide utility owners, operators and locators with a framework for the consistent classification of information concerning subsurface utilities.
"The standard also provides guidance on how subsurface utility information may be obtained and how that information should be conveyed to users." "knowledge of the precise details of subsurface utilities can protect the asset lifecycle and reduce interference to infrastructure."

2.7.2 Specifications

Quality Level D (QLD) information is likely to be associated with feasibility or business case activities, providing due diligence utility investigations and reporting from site sketches, DBYD enquiries, anecdotal evidence and the like to determine the existence of underground utilities within a project. The information does not encompass any field verification involving direct measurements,

Quality Level C (QLC) information is likely to be associated with conceptual or preliminary design activities, forming a database of existing utility information from feature topographic surveys and/or site measurements supplemented by any information obtained and classified as QLD. This collated information allows the identification and reporting of likely conflicts/clashes from existing and known utility designs within a project. The information does not indicate the location of the utility with respect to the surface feature, nor its depth.

Quality Level B (QLB) information is likely to be associated with design development activities, based on electronic surface detection and supplemented by any information obtained and classified as QLC, collating a database of existing and known utility design information to develop protection and/or relocation strategies to those existing utilities in direct conflict within a project. The location of the utilities are to a maximum horizontal tolerance of ± 0.3m and maximum vertical tolerance of ± 0.5m. The information does not validate the utility horizontal & vertical locations.

Quality Level A (QLA) information is likely to be associated with detailed design activities, based on a utility database from validated/positively identified horizontal and vertical components of existing and known utility design information, supplemented by relevant information collated and classified as QLB and in some instances QLC. The location of the utilities are to a maximum horizontal & vertical tolerance of ± 0.05m.

The quality level this research will look at is only Quality Level B and just relating to the horizontal and vertical positing only, not the associated attribute data.

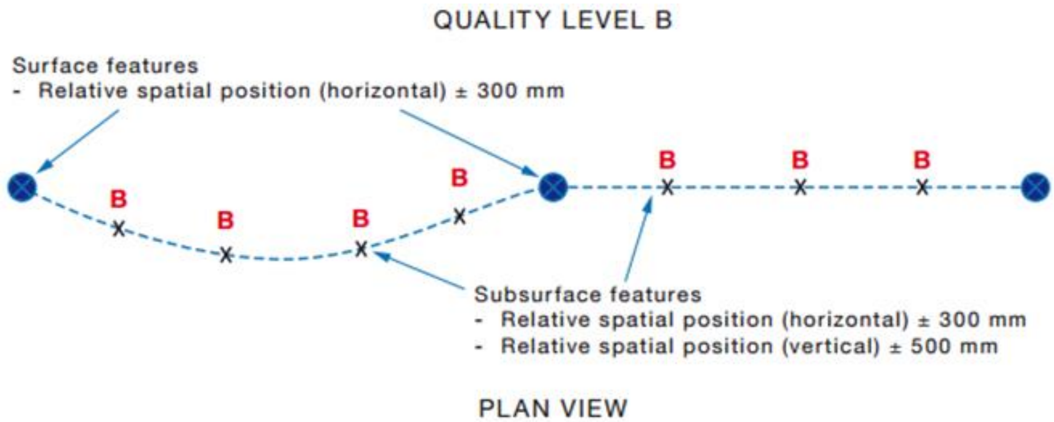

Figure 9. Plane view of a quality level B survey

2.8 Electromagnetic Utility Detection Equipment

2.8.1 Overview

Electromagnetic Utility Detection Equipment is made and sold by an array of manufactures. All promise to be able to locate a subject line. I have chosen four different manufactures to compare in my research.

2.8.2 Metrotech 610

- Single Frequency
- Ergonomic Receiver is Comfortable to Carry
- Manual Gain Adjustment
- Single Push-Button Depth

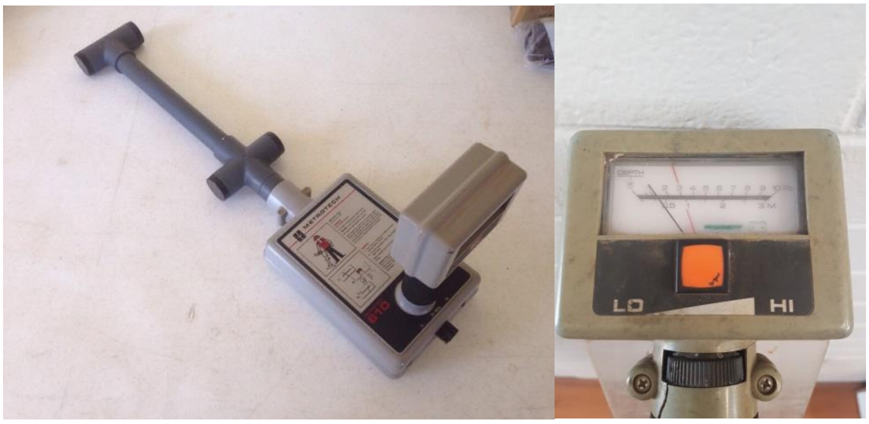

Figure 10. Photos of Metrotech 610

2.8.3 Leica Digicat 200

- Fully automatic sensitivity setting, no adjustments needed
- Audio and visual display of signal reception
- Digital signal processing – robust and error free location in the construction environment
- Easy to use – requires only minimal training
- Large push button operation – speed of use in field conditions
- Robust and waterproof – designed for tough working conditions

Figure 11. Photos of Leica Digicat 200

2.8.4 Radio Detection RD4000

- Highest performance digital Receiver even in the presence of interference
- Fast, clear, positive response even in congested areas
- Multiple active frequencies and modes provides sophisticated location tools
- Peak, null and single antenna modes
- Position and depth measurement
- Current measurement to identify individual networks
- Real Sound - audible perception of locating dynamics

Figure 12. Photos of Radio Detection RD4000

2.8.5 SPAR 300

- Only casual contact to the centreline position is needed
- Line position is constantly known in 3-D
- Depth information is continuous
- Confidence (precision) box always displayed
- Fully automatic sensitivity settings

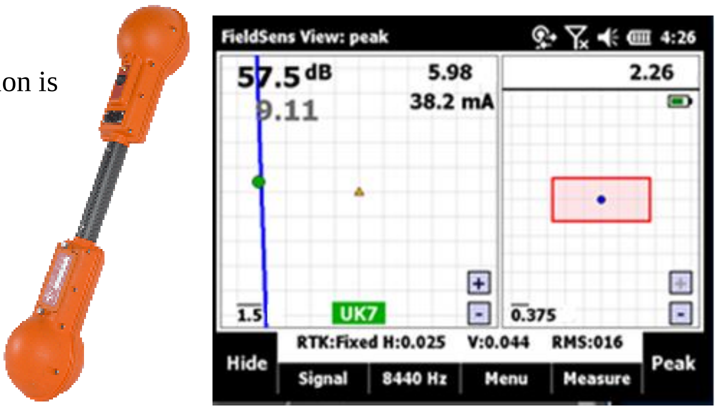

Figure 13. Photos of SPAR 300

2.8.6 Equipment Comparison

	Metrotech 610	Leica Digicat 200	Radio Detection 4000	SPAR 300
Manufacture Year	1986	2006	2006	2012
Sensitivity Adjustment	Manual	Automatic	Manual	Automatic
Horizontal Accuracy	6% of depth	5% of depth	5% of depth	5% of depth
Depth Accuracy	20% of depth	10% of depth	2.5% of depth	5% of depth

Table 1. Comparison of the different electromagnetic equipment

Chapter 3. Methodology

3.1 Introduction

Details of office and field procedures undertaken for the project will be delineated in this chapter. The experiment involved collecting data of the same underground utility line using four different manufacturers of electromagnetic field detection equipment. The results gained will then be statistically analysed and compared to a validation survey which involved, direct physical access and verification of the absolute spatial position of the underground utility line by Vacuum Excavation.

3.2 Programme

3.2.1 Selection of Appropriate Site

Selection of appropriate site, is made with the help of Dial Before You Dig, which is an on-line national referral service that is provided free of charge to a user to search for underground networks in a particular area, without having to contact the utility organisations individually.
I have created the following criteria for the site:

- Must have detectable underground utilities present
- Must be away from pedestrians(Safety reasons)
- The location of the site must be easily accessible

Using the above criteria I was able to find a suitable site. A field inspection of the site confirmed the suitability. The services contained within the site include water, electrical, communications and gas, the sizes of the conduits/pipes all differ and the material they are made out of are all different. At this site the focus will be on a single underground communications line. Shown below in figure 14

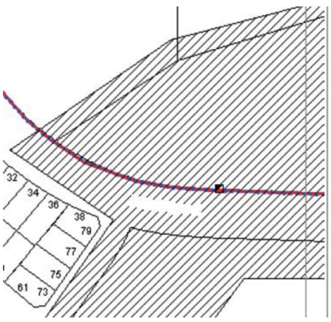

Figure 14. Plan showing the approximate position of the underground utility

3.2.2 Field Measurements

The chosen utility line is to be identified on site and white lines painted every five metres from the paint marked on the ground for 35 metres. These white lines are where the location of the utility is going to be measured by each of the locating devices. Refer to below figure.

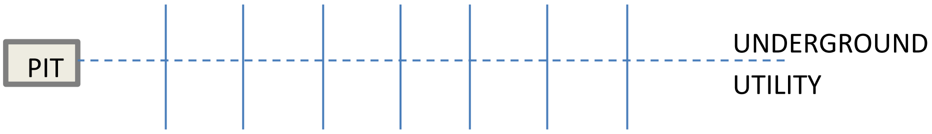

Figure 15. Plan view showing the markup of the site from the pit

Locating of the utilities:
The procedure for the locating the utilities is outlined below:

1. Ensure locating equipment is in working order and batteries are fully charged
2. Decide which connection point, or points, you will need to use in order to locate the chosen utility line.
3. Take the locate equipment to the connection point.
    - Set your transmitter at a 90 degree angle from the supposed direction of the line, and then push your ground rod into the earth farther out from the transmitter, but still at a 90 degree angle.
    - Connect the lead wire onto the ground rod and clean off any oxidation on the conductor then connect the lead wire
    - Turn on the transmitter, make sure a completed circuit is indicated.
4. Standing at least 5 meters from the transmitter, turn on the receiver. Turn up the gain if necessary to ensure that the receiver is registering some type of activity.
5. Now walk slowly in a semi-circle around the transmitter with the receiver pointed down, and facing away for the transmitter. Make sure you are far enough away from the ground rod, transmitter, and the connection wire, so that these items do not interfere with your signal.
6. As you are walking, stop at any point where the receivers signal becomes very high. Turn the gain control down until the graph is registering roughly in the middle . Do not turn the gain up for any reason, only down.
7. Keep walking in the semi-circle until you have gone as far around the utility connection point as you can go. If you come across another point where the receivers signal is extremely high, then stop again, and turn it down more until it is again back to a half-way point.
8. Now walk back in the same semi-circle. Turn the gain down a little if required, but do not turn it up. At this point you should now be registering one strong signal on the receiver. This is the target line.
9. If for any reason you did not end up with an obvious signal, then perform the sweep again. You must start out with one definite signal. This is the most critical part of any locate. Following the signal is very simple, but you must first make sure it is the strongest signal. Don't forget that any true signal will have a definite peak, and the signal will fall off on both sides of the peak.
10. Now you are ready to follow out the target line. Keep moving the receiver slowly across the signal while marking out the line. Be sure to hold the receiver as straight down as possible, and move it all the way across the signal, not just to one side. If the signal rises to any point, but there is not a drop off on both sides, then you have lost the signal.

11. Mark the location of the service and the note the depth.
12. Survey the located utility
13. Repeat the above steps for the remaining locating equipment.

Hydro-vac of the utilities:
The procedure for the use of the hydro-vac is outlined below:

1. Ensure the hydro-vac is in working order and pre-start check list completed.
2. Locate hydro-vac near utility line to be verified.
3. Start up the engines
4. Commence non-destructive excavation
5. After the utility conduit has been surveyed: fill in the hole, and clean up the site.

Measuring of utility locations marks
The procedure for the observation of the data is outlined below:

1. Ensure total station is in working order and batteries are fully charged
2. Setup total station as per generally accepted procedures
3. Record all the information needed using the correct codes.
4. End the survey, ensure all information has been pickup correctly before the equipment is packed up
5. Data is retrieved from the controller and backed up.
6. Process is repeated for each test.
7. Particular attention must be paid to ensuring the pogo height is correct before any observations are recorded.

The idea is the same utility conduits will be located in the same spot with each locator and then surveyed, at the end the conduit will get exposed with the use of the hydro-vac and the true position of the conduit will be surveyed.

3.2.3 Obtain Results and Calculations

Once the results are obtained, the main section of the research project can begin. The results will be statistically compared to the real coordinates of the underground utility, and will also be compared to one another and analysed to determine how the different methods contribute to the accuracy of the results and whether it they meet the Australian Standard.

3.3 Resource requirements

The resource requirements for the project are as follows:

4 x Locating Equipment
1 x Motor Vehicle with tow ball
1 x Trailer Mounted Hydro Vac
1 x Robotic Total station
1 x Tripod
1 x Measuring tape
Temporary flags to mark detected services locations
PPE (High Vis, eye protection, hearing protection, steel cap boots)
Laptop access

Resource requirements are able to be met using equipment borrowed from my employer.

Chapter 4. Results

The procedures outlined in the methodology have been successfully preformed and have produced the following results.

4.1 Site Photos

Figure 16. Photo of test site

Figure 17. Photo at chainage 5 showing location detected on the surface

Figure 18. Photo at chainage 5 showing location of the underground utility line.

4.2 Individual Locator Results

The method of calculating the accuracy is to calculate the offset error to the known utility line. This has been shown in the following graphs. The quality level B parameters have been shown on the graph as well. All measurements are in metres, with the quality level B limits shown in red.

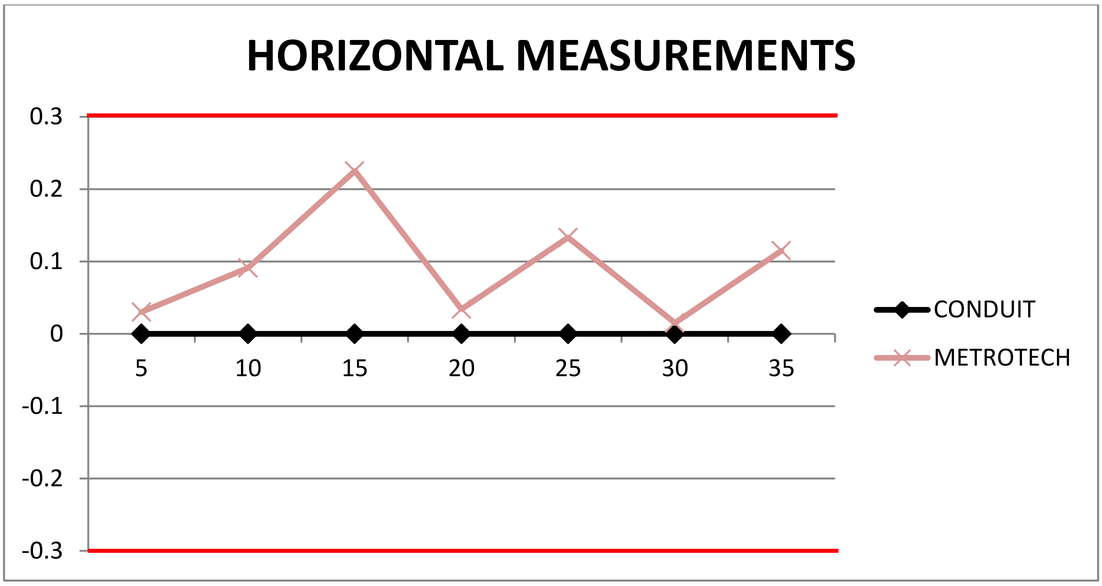

Figure 19. Metrotech Results

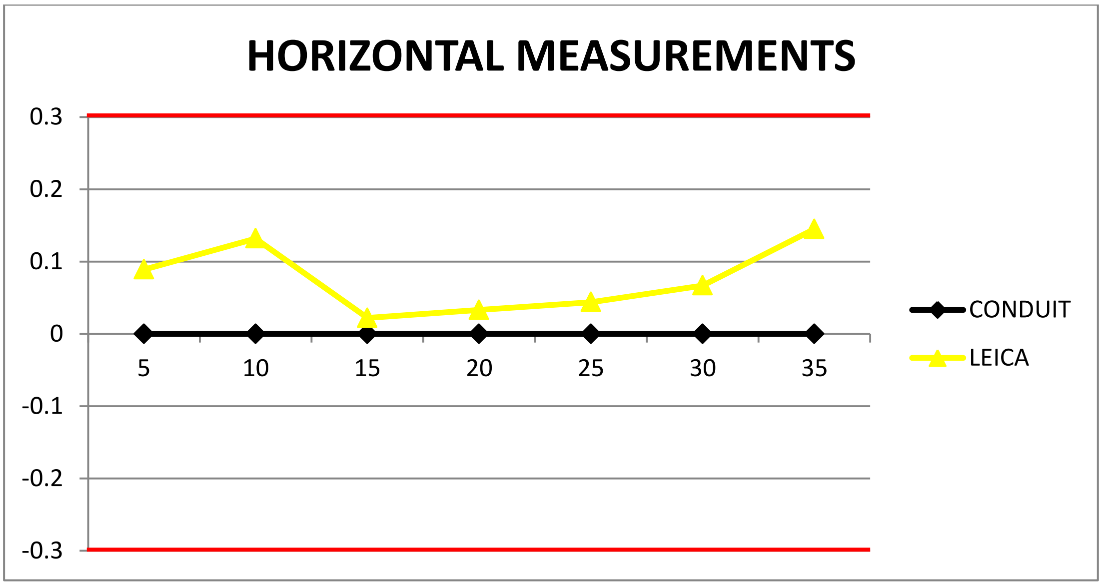

Figure 20. Leica Results

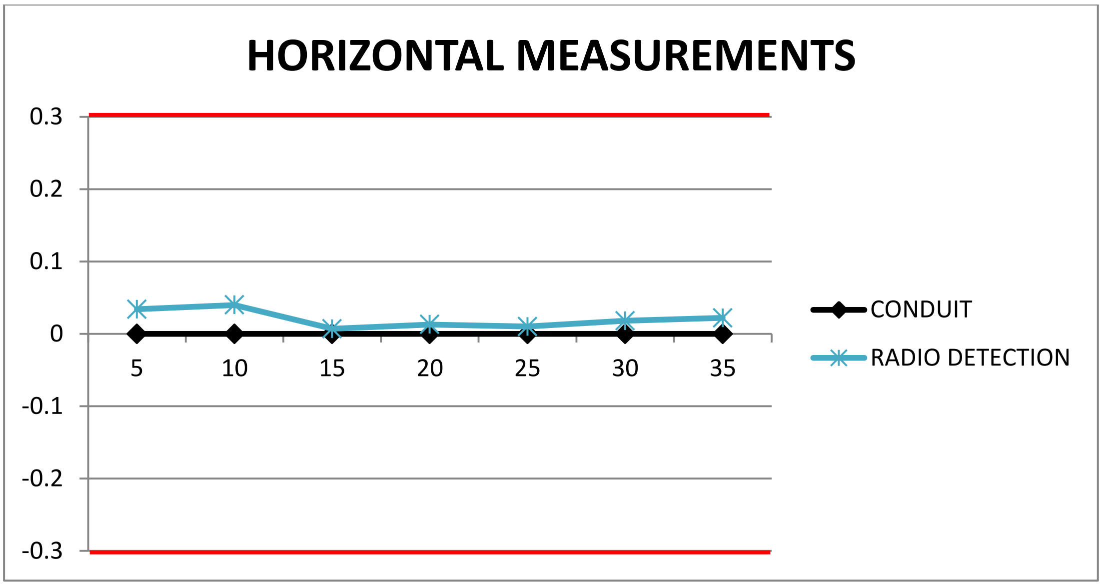

Figure 21. Radio Detection Results

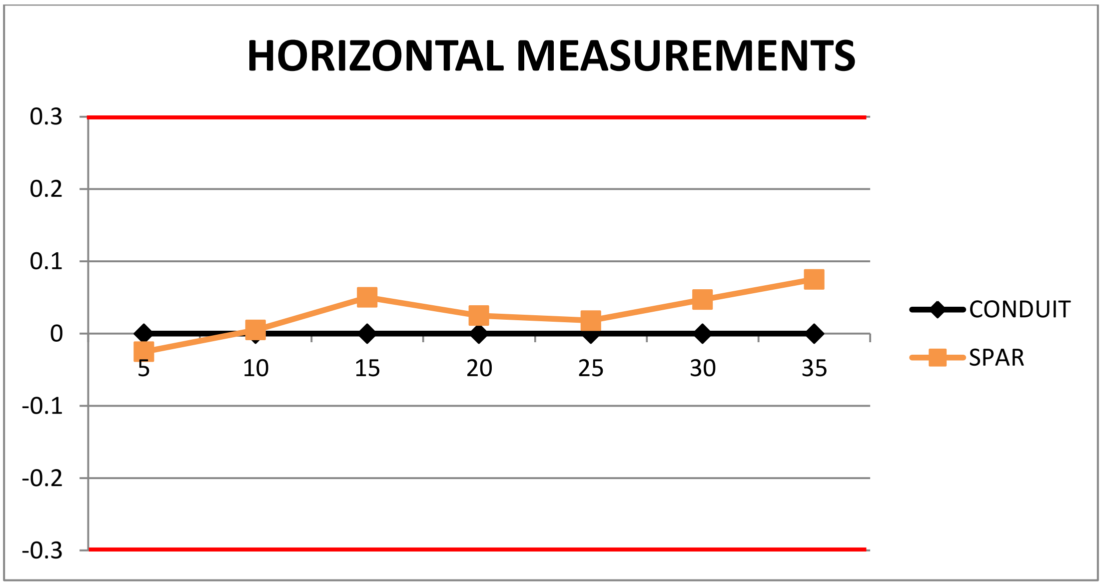

Figure 22. Spar Results

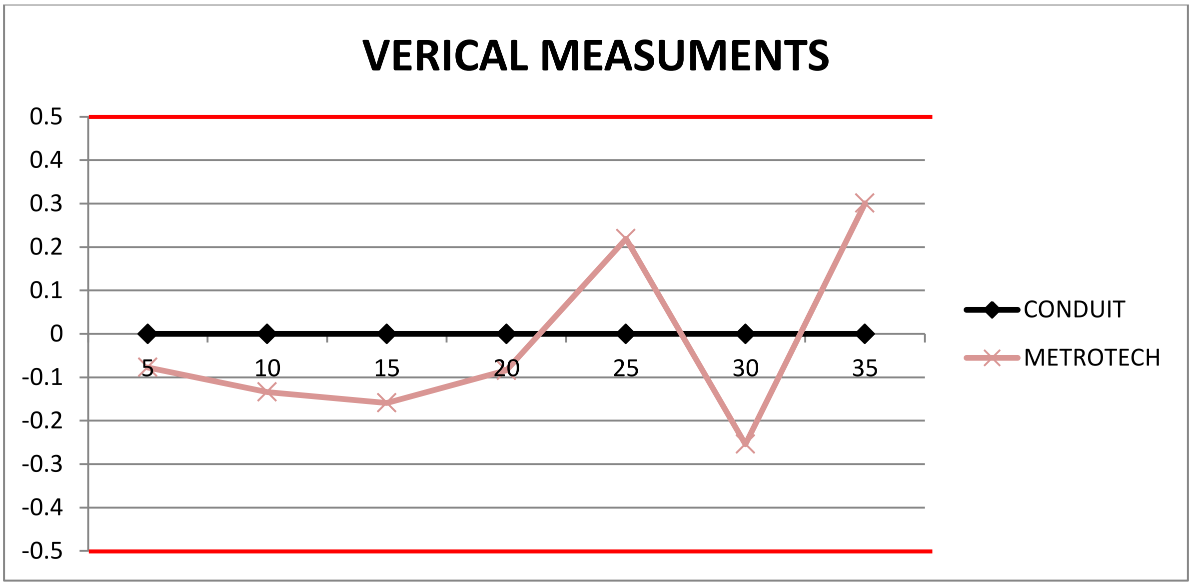

Figure 23. Metrotech Results

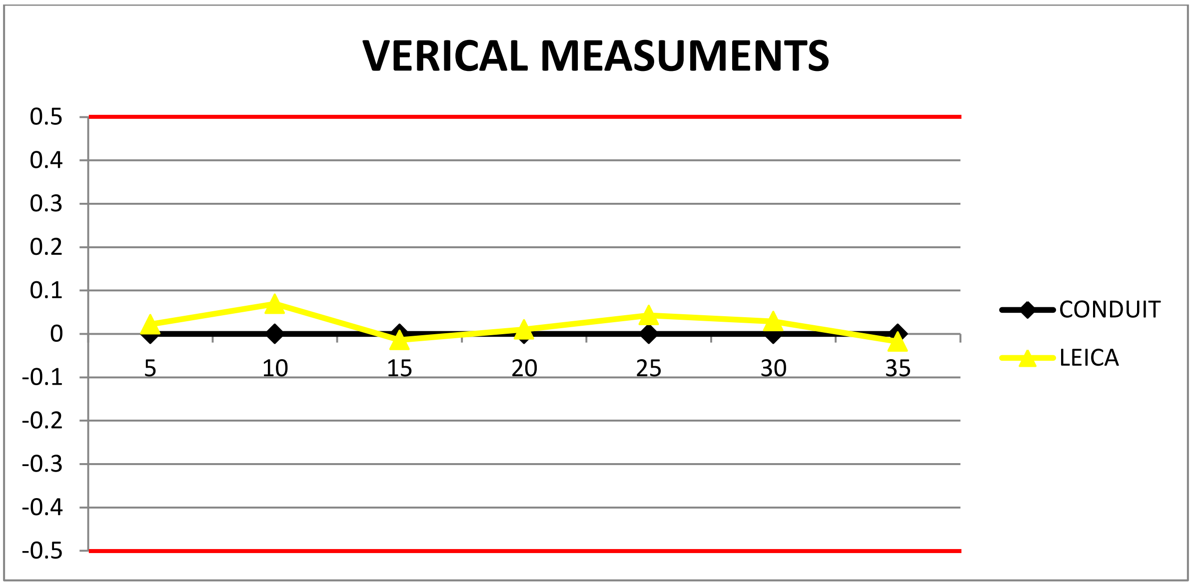

Figure 24. Leica Results

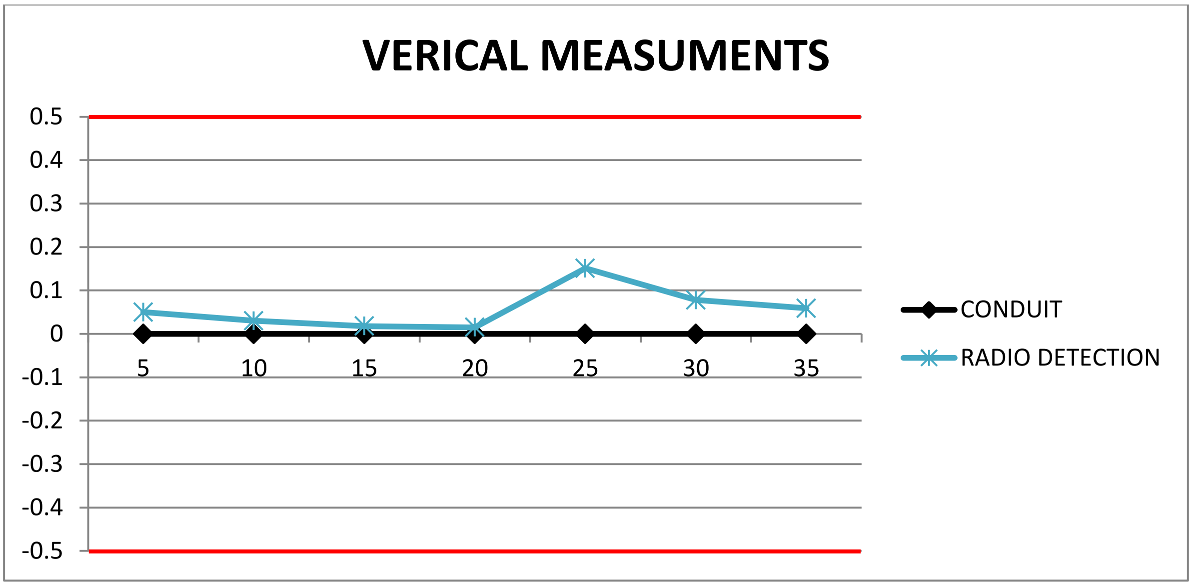

Figure 25. Radio Detection Results

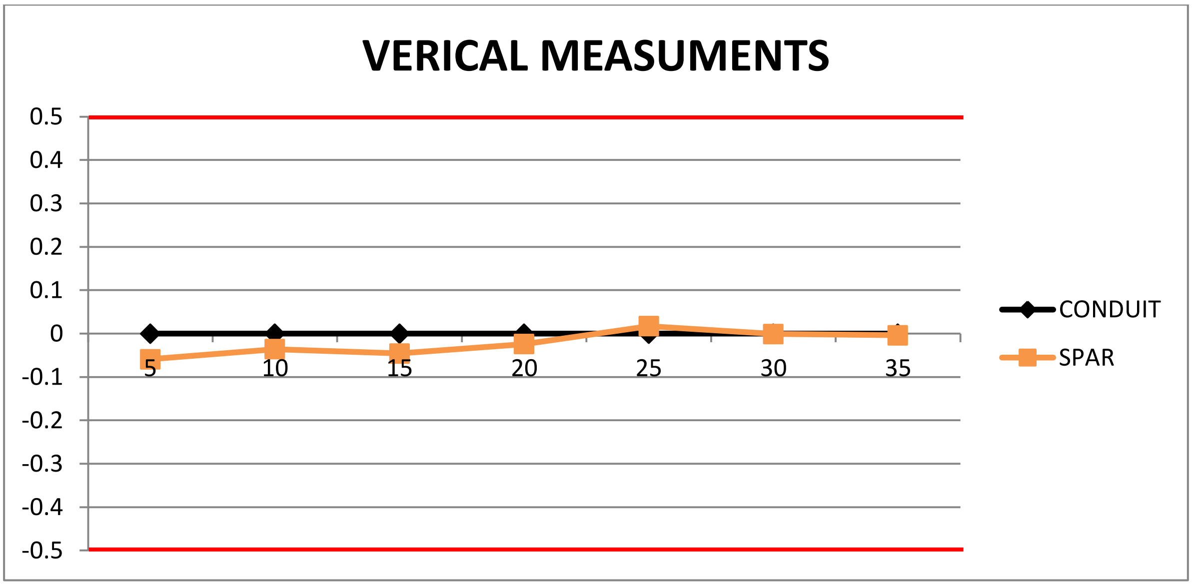

Figure 26. Spar Results

4.3 Combined Locator Results

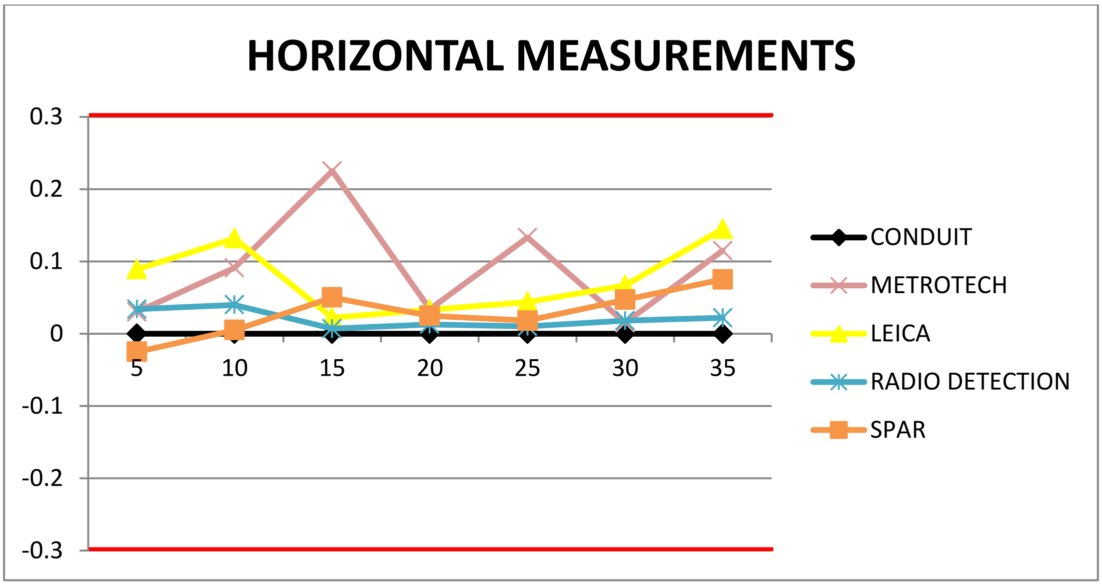

Figure 27. Combined Results – Horizontal Measurements

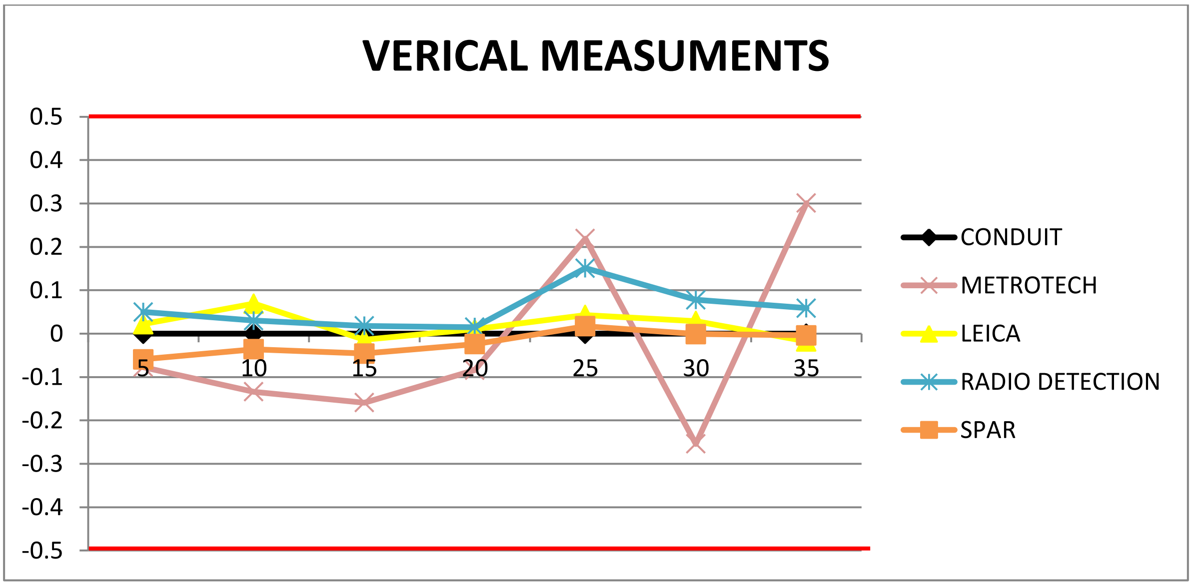

Figure 28. Combined Results – Vertical Measurements

4.3 Locator Results Compared to Manufactures Specifications

	5 Metres		10 Metres		15 Metres		20 Metres		25 Metres		30 Metres		35 Metres	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
Metrotech 610	1	23	61	34	189	39	4	16	85	59	9	174	55	101
Leica Digicat 200	59	38	97	1	15	60	3	49	13	19	33	39	110	50
Radio Detection 4000	8	35	7	10	32	5	17	3	26	129	18	56	16	36
SPAR 300	1	33	25	6	14	10	3	4	12	13	14	31	40	31

Table 2. Comparing results to manufactures specifications

Green = Within specifications

Red = Outside specifications

Number shows how close/far (mm)

Chapter 5. Analysis and Discussion

This chapter will focus on the analysis and discussion on the obtained results in relation to the AS-5488.

5.1 Results

The method of calculating the accuracy used involved calculating the offset error to the known utility line from the located position using the equipment at each chainage. Once this was done it was plotted on a graph with the utility line along the x axis at 0 and the equipment also plotted using the offset error calculated.

It can be seen in the graphs that a constant offset error does not exist, and it’s hard to predict how close the marked line will actually be to the true position of the underground utility. There is also no real relationship between the horizontal distance and the vertical distance that is given by the locating equipment. One could be really close to the true utility positon but the other one is not close.

In Summary it was found that all the equipment exceed the quality level B specifications of being; horizontally tolerance of $\pm$ 0.3m and vertical tolerance of $\pm$ 0.5m. It’s interesting to note when the surveyed locations are compared to the manufactures specifications, not one device was able to stay within the manufactures specifications each time it was used along the 35 metre test site.

5.2 Sources of Error

By using industry approved techniques any source of error is too small to quantify. And all sources of potential error are negligible, due to the larger range in the AS quality specifications.

5.3 Discussion

The results indicate that all the equipment exceeds the specification of quality level B from AS5488. But the analysis that has been undertaken should be treated with caution due to the small sample size that has been used. Any outliers cannot be reasonably detected and may have a significant impact on the results obtained. Repeat measurements with the same machine would improve the integrity of the data obtained but would not of produced real world results.

Through the analysis it is shown that there was a difference between each of the the different locating machines but, that can be related back to the manufactures specifications being different. The age of the machine and thus the accuracy it could achieve is displayed in the results.

It can be confidently said the locating equipment tested in this project can comfortably meet and exceed the Australian standard, but as shown they do not produce a consistent degree of accuracy.

Chapter 6. Conclusions

6.1 Conclusion

This project examined if the real world 3d accuracy is achievable of Australian standard 5488-2013 classification of subsurface utility information using electromagnetic field detection. This was achieved by locating an underground line with four different manufacturers' electromagnetic detection devices and comparing it to the actual location which was exposed and surveyed. The four locating equipment was then statistically compared to the actual location and also checked against the quality level B accuracies from the Australian Standard. (Being a maximum horizontal tolerance of ± 0.3m and maximum vertical tolerance of ± 0.5m)

It was found all the tested equipment meet and passed the specification of quality level B. The best results were produced from the latest equipment.

6.2 Recommendations

There is a danger of building false confidence if the user does not fully understand the quality levels. Visualising the underground environment can be a very powerful tool for the designer but they must be aware and always consider the accuracy of the depicted utility individually or even in sections of the same utility. Locators should also be aware of their equipment specifications and always be aware of how the locations they mark could be used.

6.3 Further research

Some further research items I came across whilst undertaking my research was;

- The electromagnetic frequencies used was the same for all the equipment in the test, can different frequencies produce better results?
- A larger sample size could be undertaken to reduce the likely hood of outlier results being used.

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Appendices

Appendix A

ENG4111/4112 Research Project

Project Specification

For:	Samuel Benjamin Hathaway
Title:	Real world 3D accuracy achievable of Australian Standard 5488-2013 Classification of Subsurface Utility Information using electromagnetic field detection.
Major:	Surveying
Supervisors:	Albert Chong
Sponsor:	Landmark Surveys
Enrolment:	ENG4111 – EXT S1, 2016 ENG4112 – EXT S2, 2016
Project Aim:	In 2013 a new Australian Standard was released being AS 5488—2013 - Classification of Subsurface Utility Information. This standard makes use of a quality system to classify the precision and accuracy of utilities that are surveyed. The aim of this project is to confirm if these standards are achievable in the real world.
Programme:	Issue A, 20th March 2016

1. Research field procedures and electromagnetic equipment used to locate services.
2. Research sub surface mapping specifications
3. Design a field measurement program to enable the collection of utility information
4. Analyses the collected data statistically
5. Critically evaluate the performance of the service locating methods including any recommendations for field procedures or limits of use.

If time and resources permit:

6. Try a range of electromagnetic equipment, or other equipment to locate services.
7. Design practical methods to increase 3D accuracy of services.