University of Southern Queensland

**FACULTY OF ENGINEERING AND SURVEYING**

# Investigation into the effectiveness of reflectorless technologies on Structural Surveillance Monitoring

A dissertation submitted by

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In fulfilment of the requirements of

**Bachelor of Spatial Science: Surveying**

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# ABSTRACT:

This project investigates and evaluates total station reflectorless measurements and their effectiveness and accuracy in various surveying situations. Instruments tested in this investigation include the Trimble S6, Leica Flexline TS09 and the Topcon GPT9005A.

Technology has aided manufacturers of reflectorless total stations to quote accuracies for reflectorless measurements comparable to that of traditional electronic distance measurements (EDM). This technology enables distances to remote objects to be measured with similar ease as a conventional surveying prism.

The instruments selected for this investigation have undertaken various field-testing to determine the effects that varying the angle of incidence has on the distance obtained. Additionally testing also has included analysing limitations of obstructions to the line of sight and minimum approach distances to surface edges.

Results obtained from this investigation indicate that the angle of incidence can have a significant effect on the accuracy of the distance measured, and all instruments tested observed similar inconsistencies with respect to the angle of incidence. This investigation concludes with recommendations on best practices for utilising this technology and possible future field testing to expand on results obtained from this investigation.

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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.

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**October 2009**

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# NOMENCLATURE:

| | |
|---|---|
| **EDM** | Electronic Distance Measurement |
| **Reflectorless** | Electronic Distance Measurement without the need of a dedicated survey reflector |
| **DR** | Direct Reflex, reflectorless measurement mode utilised by Trimble total stations |
| **QA** | Quality Assurance |
| **GPS** | Global Positioning System |
| **TOF** | Time of Flight, method of reflectorless technology utilising many short infrared light pulses |
| **Phase Shift** | Method of reflectorless technology utilising a coaxial intensity modulated optical measuring beam |
| **Class 1 & 2 laser** | Laser system not requiring any additional precautions and deemed safe to be used in the working environment |
| **Laser Class 3R** | (Visible radiation) is a relatively new laser class which is regarded as 'Low level eye risk' if precautionary measures are not applied |
| **System Analyser (SA)** | Leica technology that utilised both time of flight (TOF) and Phase shift reflectorless methods |
| **Kodak Grey** | Recognised standard test card in professional photography, reflecting precisely 18% of white light |
| **Kodak White** | Recognised standard test card in professional photography, reflecting precisely 90% of white light |
| **Tribrach** | Surveying equipment that is used to locate the total station or reflector adaptor to the surveying tripod |

**Forced Centring** Is to exchange surveying equipment on a tripod without affecting the location over the survey mark, thus cancelling out any plumbing error when the instrument is replaced with a reflector

**Index Error** Instrument error that is present in all measurements read, regardless of the distance, an index error of +2 results in a distance reading longer by 2mm

**Scale Error** Instrument error associated with distance measurement, this error is proportional to the distance read, with a 5PPM scale error resulting in a 5mm error of a 1km distance

**PPM** Parts per million, refers to scale error associated with a particular instrument or quoted accuracy of the instrument. Atmospheric conditions namely air pressure and temperature affects the size of this PPM correction

# Chapter 1

# Introduction

## 1.1 Project Topic

*Investigation into the effectiveness of Reflectorless Technologies on Structural Surveillance Monitoring.*

## 1.2 Project Aim

This project aims to determine if reflectorless technology can provide accurate and repeatable distance measurements that can be utilised in structural surveillance roles. Using this investigation, it is hoped best practise methods will be determined and possible new methods developed for structural surveillance monitoring.

## 1.3 Project Background

Surveillance monitoring of dams and other structures rely on accurate and repeatable distance readings, along with precise angular measurements. Most current large scale surveillance monitoring systems rely on either Global Positioning Systems (GPS) observations or total station Electronic Distance Measurements (EDM) observation, or a combination of both. Whilst GPS has its place in large scale surveillance, it cannot be used when accuracies of less than 1cm are required.

Conventional structural surveillance of earthen/concrete dams is required to an accuracy suitable to identify any structural movement, nominally in the order of millimetres. To obtain reliable distances to this level of accuracy requires a total station taking EDM readings to a reflector. In recent times survey equipment has progressed significantly in the precision and accuracy of measurements taken to surfaces directly without requiring a dedicated reflector. This reflectorless technology can be found in conventional total station packages alongside traditional EDM measurement procedures.

In structural surveillance it is a costly and technically difficult exercise for the controlling body to install dedicated surveying stations for periodic monitoring, especially if the surveillance is to be undertaken on large mining machinery. Direct distance measurements to surfaces of large mining and industrial machinery/structures would enable efficient, cost effective methods of monitoring structural deformation. Thus this project sets out to test current surveying instruments ability to read accurate, reliable and repeatable distances directly to required surfaces for deformation monitoring.

The reflectorless total station has been considered an advantage to many surveyors, being able to gather field data much more efficiently as well as some data they say that was virtually unattainable before (Brown, 2004). Today's surveyors are utilising new technology to improve productivity and undertaking jobs that may not have been feasible prior to reflectorless measurements.

## *1.4 The Problem*

The introduction of reflectorless capabilities to modern total stations has enabled today's surveyor to take a remote distance reading to a given point and have some certainty that the distance read would agree to that of a traditional Electronic Distance Measurement (EDM) within the tolerances of that unit. The ease at which objects can be coordinated remotely can create the problem of uneducated confidence in the instrument returning a distance and assuming it is correct. For example there is a requirement to accurately measure the dimensions of a structural beam and coordinate its position so additional structures can be designed to 'fit' with the existing structure. This would be an easy task for a survey team to measure the beam with a tape and coordinate its position with a reflector. The problem is the beam cannot be accessed due to proximity of high voltage lines that cannot be isolated in the timeframe required to obtain the data. The instrument in use on this particular job has reflectorless capabilities and the surveyor takes a few observations coordinating the beam. The beam itself was partially obscured by surrounding objects making it possible to only take observations from one place so no additional check measurements can occur. The surveyor in this instance has to make the decision as to if the beam has been coordinated accurately and has he/she got the confidence in the instruments ability in returning a sound distance. The fact that the instrument returned a distance has little relevance to the quality of the distance obtained if in fact the measurement had interference affecting its quality. What checks and independent measurements can be undertaken to verify this measurement? and for quality control and QA documentation how was this measurement verified?

In a deformation or monitoring survey, there needs to be enough redundancy in the network to satisfy an error generated by the geometry of the observations. If not the initial observations may hide a bias in the network that is always evident and only emerges when a change to the geometry of the network takes place.  The testing methodology found in chapter four will address these questions and determine the viability of reflectorless technologies.

## *1.5 Conclusion*

This chapter has identified that reflectorless total stations are becoming utilised more and more in areas of obtaining data from sources of restricted access, indicating that errors associated with not physically obtaining the measurement via conventional survey prisms may be present and independent checking of the integrity of this data is required to satisfy survey tolerance.

This research aims to analyse common scenarios when reflectorless measurements can be utilised in industry and thorough examination of the survey integrity will be undertaken to validate if this technology meets its stated tolerances with respect to varying field conditions.

# Chapter 2

# Literature Review

## *2.1 Introduction*

Techniques commonly used for structural measurement include tape measurements combined with hand recording, and optical methods, such as theodolite intersection (Banister et al. 1998). More recently active methods, including reflectorless EDM's and time-of-flight laser scanning systems (Mills et al. 2004) have become viable options for the capture of structural measurement.

During the 1980's, close-range photogrammetry emerged as a serious alternative to conventional monitoring surveys. Close-range photogrammetry has the advantage of being a non-contact measurement, without requiring direct contact with the surface measured. Another benefit is the short acquisition time required for the photography. Whilst close-range photogrammetry techniques offered undoubted benefits, the disadvantages are also numerous. The requirement for complex and expensive equipment ran by highly specialised staff meant that the expense of the technology was significant and was not widely adopted (Nichols, 2002).

Significant analysis has been undertaken on the viability of dedicated laser scanning systems for large scale feature pickup and deformation monitoring in recent times. Reflectorless technologies associated with traditional total stations have not been exposed to the rigorous testing that their more expensive terrestrial laser scanning counterparts have endured, and there is minimal literature available on their ability to return reliable distance measurements under differing field conditions and constraints. Manufacturer's technical specifications quote distance ranges and tolerances of their given machines under 'ideal' conditions with known reflective surface properties. These specifications are worth noting when it comes to purchasing an instrument, but determining if the chosen instrument can reliably perform under constraints due to field conditions and location need to be proven.

## 2.2 Background Information

Previous work has compared reflectorless measurements to conventional EDM observations utilising the one instrument (Ernst, 2007). This involved taking true distance readings to a variety of surfaces and comparing to results obtained via reflectorless means. The instrument chosen for testing was a Trimble 5600 DR200+, circa 2001. The material surfaces chosen for testing were wood, vinyl, brick, concrete, asphalt and metal. Testing was undertaken over distances of 100’, 200’ and 400’, and at perpendicular to line of sight and 45$^{o}$. Evaluation of results proved that different surfaces yielded varying results but did not indicate any trend in the data. This may be due to the errors associated with testing procedures and setup of testing facilities. Distances obtained perpendicular to line of sight rated within the tolerances of quoted specifications. What was evident in the testing are significant differences to results obtained at 45$^{o}$ to those obtained at perpendicular to line of sight for all materials tested. This indicates that the angle of incidence/angle of reflection has a direct relationship to the measured distance. Since only perpendicular and 45$^{o}$ to the line of sight were utilised it is evident that further testing would be required to determine if the errors associated with the oblique nature of the measurement have a linear relationship, and if a given instrument has a limit of measurement to the surface orientation relative to line of sight.

Modelling the size, shape and orientation of cylindrical surfaces via reflectorless means has been tested and verified with comparisons made to a best fit surface generated via least square adjustment (MacMaster, 2004). This testing was undertaken utilising a Leica TCRA1101 total station.

## 2.3 Methods of reflectorless observations

Trimble’s DR technology enables surveyors to accurately measure remote points without first locating a physical target at each point (Höglund R, 2005). This is achieved using either of two EDM technology methods; Time of Flight (Pulsed Laser) or Phase shift. Trimble offers both of these technologies with the S6 Total Station, which utilises Time of Flight technology for its DR300+ and phase shift technology for its DR Standard method.

### 2.3.1 Time of Flight (TOF) -

As the name suggests Time of Flight (TOF) precisely measures timing information to calculate a range measurement by generating many short infrared or laser light pulses, which are transmitted through the telescope to a target. The round trip for each light pulse is determined electronically, hence the time of flight is known. The velocity of light through the medium can be accurately estimated, along with the travel time, giving the ability to compute the distance between instrument and target.

The TOF method typically produces the longest range whilst meeting the highest standards for eye safety, because the intervals between the laser pulses prevent the accumulation of energy, typically 20000 pulsed laser measurements are taken every second. Trimble's DR300+ TOF method utilises patented signal processing techniques to achieve both a long range up to 800m and high accuracies of ± (3mm+3ppm) (Höglund R, 2005).

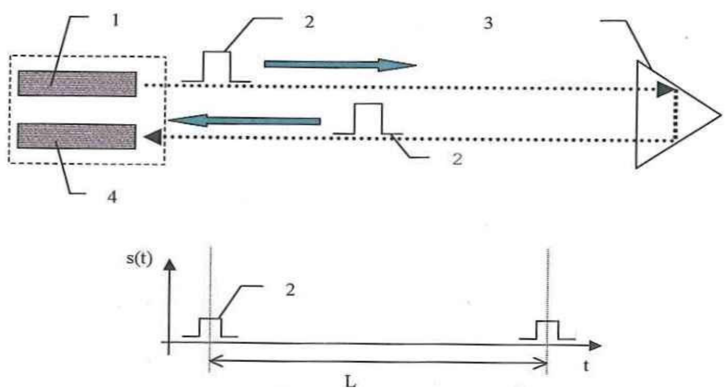



**Figure 2.1** The principle of the TOF method (Source: Leica's Pinpoint EDM Technology).

Figure 2.1 illustrates the time of flight method. A transmitter (1) emits a light pulse (2), which is detected after reflection by the target/retro-reflector (3) to the receiver (4). The distance is computed (L) as being the time difference between the start time (S) and the time of reception (E).

### 2.3.2 Phase Shift measurement –

In DR Standard mode the EDM transmits a coaxial intensity modulated optical measuring beam that is scattered by a surface on which the beam is directed. The phase difference between the transmitted light and the reflected received light is detected and represents the distance. The EDM transmits a collimated visible red laser beam to the target point and the distance is calculated between transmitted and received light.

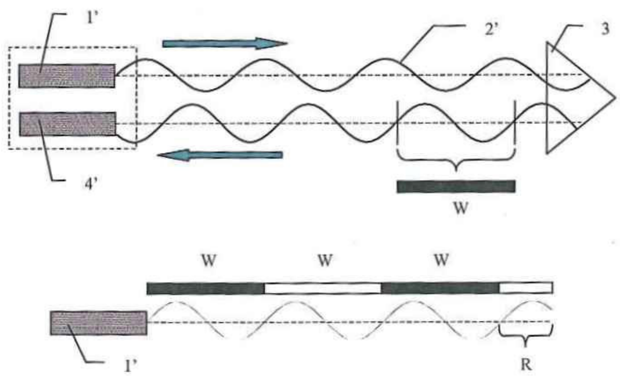



**Figure 2.2** The principle of the phase shift method (Source: Leica's Pinpoint EDM Technology).

Figure 2.2 illustrates the phase shift method, in which the transmitter (1) emits modulated light signal as a light wave (2) to a target which may consist of a retro-reflector (3), with the reflected signal received by the receiver (4).

The instrument measures a constant phase offset despite inevitable variations in the emitted and received signal. Initially, a cycle ambiguity prevents the total distance from being estimated directly, this is resolved using multiple measurement modulation wavelengths, which provides a unique integer number of cycles. Once the integer number is achieved, the distance to the target can be very accurately determined. Phase Shift technology has the ability to resolve a distance to a remote object to a range of up to 240m with an accuracy of ±(3mm+2ppm) ((Höglund R, 2005).

## *2.4 Measuring conditions and potential errors–*

In comparison of the two different technologies, the TOF method produces longer ranges and is more tolerant of external influences like obstructions and wet surfaces than phase shift with only a slight degradation of accuracy. The phase shift method utilises a much narrower beam divergence resulting in better results when measuring to surface edges (Bayoud, 2006).

The TOF method provides greater flexibility to return a distance when reading measurements to wet surfaces. It also improves the possibility of successful measurement to surfaces that do not provide ideal reflective properties and to oblique surfaces. Inherent properties give the TOF measurement mode a higher possibility of measurement to narrow objects. All these properties will determine the success of the instruments to proposed field testing procedures (Hoglund et al. 2005).

### 2.4.1 Beam Divergence-

Beam divergence causes the footprint of the laser beam to have a certain extent, meaning that the laser spot hitting the surface is not a defined point but a beam with a physical shape similar to an elongated ellipse. The size depends on the distance from the EDM system; the greater the distance, the larger the laser spot size. Indicative magnitudes of beam divergence for the Leica 1200 are shown in Table 2.1 below.

| Distance | Spot size (horizontal x vertical) |
|---|---|
| **20m** | **7x14mm** |
| **100m** | **12x40mm** |
| **200m** | **25x80mm** |
| **300m** | **36x120mm** |
| **400m** | **48x160mm** |
| **500m** | **60x200mm** |

**Table 2.1** Beam divergences as a function of the distance from the EDM Instrument. (Courtesy of Leica)

Trimble has a quoted beam divergence of 4cm per 100m horizontal and 8cm per 100m vertical for its S6 DR300+ Total Station and 2cm horizontal and 2cm vertical for its S6 High Precision Total Station (Trimble S6 datasheet).

Beam divergence may generate two types of errors. The first one is a result of surface characteristics of the target and its vicinity. Depending on the characteristics of the vicinity surface, the waveform of the laser beam scattered back by the surface may be a rather distorted version of the emitted pulse. This makes matching difficult, resulting in uncertainties in the distance. A second type of error is caused by depth differences between the target and its vicinity. When the target is located on a plane that is not perpendicular to the line of sight, time differences will occur between the reflections. The part of the plane that is closest to the instrument will reflect the beam first whilst the part that is farthest away will reflect last. Fortunately, the effect is negligible as long as the plane has homogeneous reflectance characteristics. The effects of beam divergence become more severe when discontinuities are present in the vicinity of the target. In particular, when the depth differences do not exceed one-half of the pulse length, the reflected pulse will be treated as stemming from one surface. Since the reflected pulse will be quite elongated, the time of flight cannot be detected accurately, resulting in an inaccurate measurement (Capman, 2004).

## *2.5 Leica System Analyser (SA)-*

Leica has developed a new optomechanical concept that allows the combination of a reflectorless and reflector based EDM using a single laser beam emitter. This concept called System Analyser (SA) combines the advantages of the phase and TOF methods without having to mitigate their disadvantages, permitting accurate reflectorless measurements beyond 500 metres (Kodak White) within seconds (Bayoud, 2006).

The utilisation of a single laser diode results in coaxial stability of the EDM sensor, with a revolver wheel in place to allow the coincidence of the reflectorless and reflector measurements.

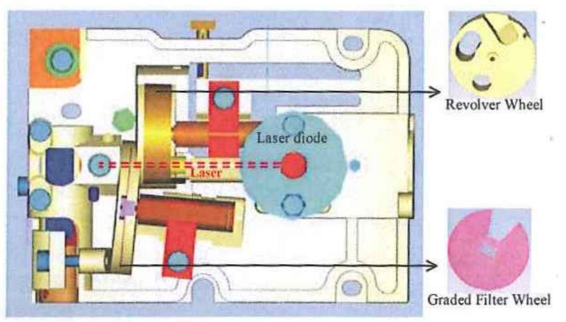



**Figure 2.3** EDM Mechanics of a Leica TPS1200+ (Source: Leica's Pinpoint EDM Technology)

## 2.6 Potential Industrial Reflectorless Roles

The following photo is of a cooling tower at Tru Energy Yallourn Power Station, which is a structure that can be monitored for structural cracking with reflectorless technology. The scale of these structures can be realised by seeing the size of the tripod and reflector in the foreground.

**Figure 2.4** Cooling Tower – Potential Surveillance Structure (*Photo: courtesy of Tru Energy Yallourn*)

The following is a mine dredger used to remove overburden so the brown coal can be utilised. Structures like these require deformation monitoring to determine alignment of conveyors, winch sensors, etc. This particular dredger has GPS machine guidance that controls the positioning of the bucket-wheel for precise grading for design and drainage purposes. The surveys undertaken to determine the exact dimensions required to enable the sensors and

GPS receivers to properly position the bucket-wheel are examples of surveying situations that could benefit from the abilities of reflectorless technologies. The scale of these structures can be realised by seeing the size of the tripod and reflector and the 4WD vehicle in the foreground.

**Figure 2.5** Mine Dredger – Potential Surveillance Structure (*Photo: courtesy of Tru Energy Yallourn*)

## *2.7 Conclusion*

This chapter has highlighted the background of reflectorless technology and associated testing that has been undertaken to determine the viability of this technology under various testing scenarios. It is evident that testing associated with 'real life' surveying conditions where the angle of incidence is uncontrolled is scarce, and currently most testing undertaken has been to known reflective surfaces like Kodak grey (Neutral test card) and Kodak white standards.

Using this background as a foundation, this project has applied this knowledge and taken a further step in analysing reflectorless measurements under varying field conditions via interpretation of the oblique nature of obtaining field data, and the integrity of this data.

# Chapter 3

# Methodology

## *3.1 Introduction*

Methodology examined within this chapter will detail procedures utilised to obtain relevant testing procedures and corresponding methods of obtaining data of sufficient quality and justification, to be utilised in rigorous analysis of reflectorless measurements.

The aim of this section is to outline the testing procedures chosen for testing reflectorless measurements along with conventional EDM distances; additionally the field apparatus chosen to enable the abovementioned testing will be determined along with potential testing instruments.

## *3.2 Research and Testing Objectives*

The testing methodology has identified testing objectives put in place to address limitations in the previous testing of total station reflectorless measurements.

### Objective 1: Identification and selection of direct reading methods

To identify and select suitable distances to measure, including testing that re-enacts scenarios common to structural surveillance monitoring situations. In addition to this a suitable site to do the testing on will be required, that will be free of obstructions and not be disturbed over a set period of time to satisfy required testing of selected instruments.

### Objective 2: Design and construction of suitable testing apparatus

To design an apparatus that can be used instead of a reflector to replicate a structural surface. This apparatus will need to have the ability to be force centred into a surveying tribrach for testing purposes.

### Objective 3: Selection of suitable reflectorless units

On the market today is a wide range of surveying instruments catering for all surveying needs and budgets. Research into instruments that meet a certain standard of accuracy for direct surface measurements needs to be undertaken with suitable candidates short listed for available testing.

### Objective 4: Identification of errors

Inherent errors associated with the testing methodology must be identified prior to any rigorous data analysis. Results from the testing will be compared to results obtained from baseline EDM readings and rectifying errors will result in a rational comparison of field data.

### Objective 5: Analysing and Evaluating results obtained

Upon completion of testing detailed and rigorous data analysis must be performed to compare results obtained from units to that of conventional distance measurements. From this analysis evaluations can be made as to the success or limitations of this technology.

## *3.3 Research and Testing Methodology*

### 3.3.1 Identification and selection of direct reading methods

The aim of the testing is to emulate scenarios where accurate and repeatable direct distance readings are required; therefore the testing methodology needs to address these scenarios. Distances chosen will be from 10m to 200m with sufficient incrimentation to satisfy linear relationships. Distances greater than 200m can be easily obtained by certain instruments but manufacturers specifications state accuracies deteriorate beyond this and the correlation between this technology and normal EDM readings diminishes. Angle of incidence to the surface being monitored will need to be taken into consideration. In addition to this any interference to the line of sight will also need to be addressed when analysing results.

The site chosen for testing is an old section of closed off highway that has been realigned due to the advancements of a Brown Coal Mine. Permission has been granted to access this site for as long as required to complete testing and the site is free from any external sources that may have an effect on testing.

Actual field testing comprised of three different tests to satisfy the criteria mentioned above. Below is a detailed description on what was involved in the testing.

1. **Oblique angle testing-** To determine the effect that the angle of incidence/angle of reflection has on the distance read, observations starting at $0^o$ (Perpendicular to the line of sight) increasing in $5^o$ increments until the instrument fails to read or returns a distance outside of governing limits (tolerances set by the manufacturer). These oblique angular distance measurements were taken from distances 10m, 25m, 50m, 100m and 200m respectfully to satisfy error propagation over length of sight. This angular testing was carried out via the horizontal axis, vertical axis, and rotations of both axes. This will determine if there is any bias or misalignment of the reflectorless observations.

2. **Critical obstruction testing-** To determine if obstructions have any influence on the instruments ability to return an accurate distance measurement. Testing included the use of an 'obstruction' that was brought into line of the instrument that is observing distances to a known target and measure the offset to the line of sight when the obstruction starts to effect the distance read. This testing was done over distances 2m, 25m, 50m, 75m, 100m, 125m, 150m, 175m and 200m to determine if the divergence of the beam has linear properties. As per the first test, this obstruction testing will be undertaken utilising obstructions from top, bottom, left and right, to satisfy any bias or misalignment of the beam divergence.

3. **Minimal Approaches testing-** This test whilst not generally speaking a surveillance test was undertaken to determine the reflectorless capabilities for returning structural dimensions for engineering applications. Due to the increase in the number of total stations on the market that feature some form of direct reflectorless capabilities it is becoming easier to take distance readings to structures to determine dimensions for engineering purposes. Depending on the layout and

location of the structure to be ‘surveyed’ the ability to take precise measurements to the corners of this structure can be limited due to the inherent properties of the beam divergence of the instrument. This test incorporates an obstruction immediately behind the target set at a known distance that will imitate surrounding structures. Once the target has been sighted and the true distance determined the line of sight will be dialled off horizontally towards the edge of the target until the distance read becomes an averaged solution of the ‘true’ distance and that of the ‘structure’ behind. The offset measured to the structure edge will be recorded prior to interference of the reflectorless observation. This testing was undertaken at distances of 10m, 25m, 50m, 75m and 100m.

### 3.3.2 Design and construction of suitable testing apparatus

**Oblique Angle Testing Apparatus:**

The apparatus required for the oblique angle testing was designed to replicate a structural surface whilst being able to be force-centred onto a surveying tripod. This gives the ability to set known distances between the instrument and the surface measured. The target has been designed to be of a sufficient size to accommodate for instrument beam divergence. The target has also been built to provide accurate rotation in both the horizontal and vertical axis. This will enable the angle of incidence to be altered to emulate taking a distance reading to a given surface at an oblique angle. Built-in protractor like increments has been installed to precisely alter the rotation of the target in relation to the line of sight to the instrument.

The construction of the target is comprised solely of aluminium for its strength and lightweight properties. The target itself is 200mm by 200mm in size, not including the surrounding framework and rotates on two pins located halfway down each side. The target plate itself is made of 10mm thick aluminium that is centred on the horizontal axis of rotation, and has built-in attachment holes providing the option of attaching an additional target of different material.

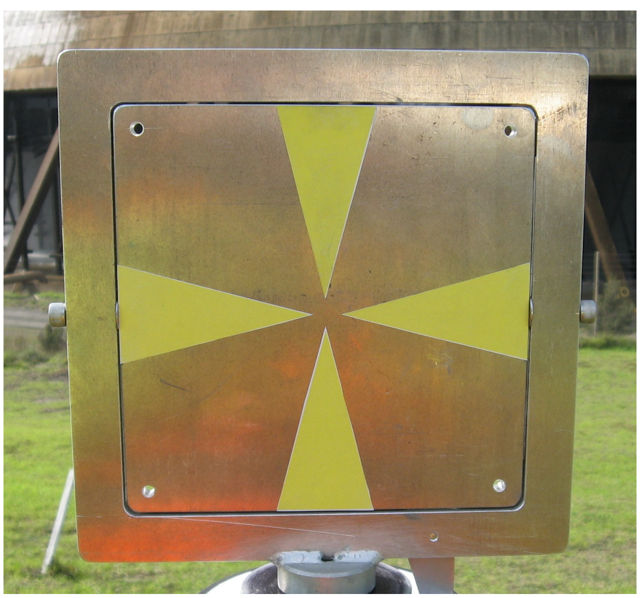


Figure 3.1 showing oblique testing apparatus set at perpendicular to line of sight

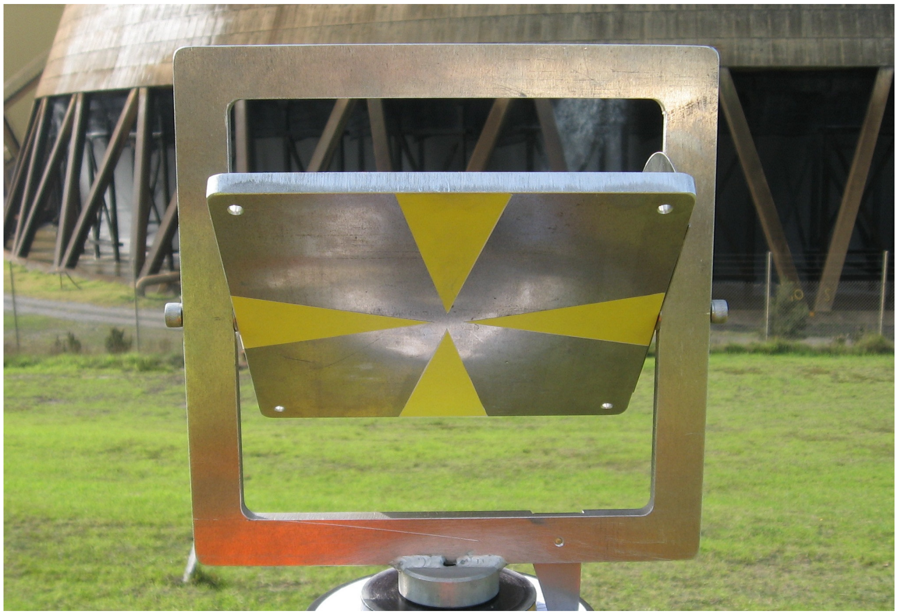


Figure 3.2 showing reflector target altering the vertical axis

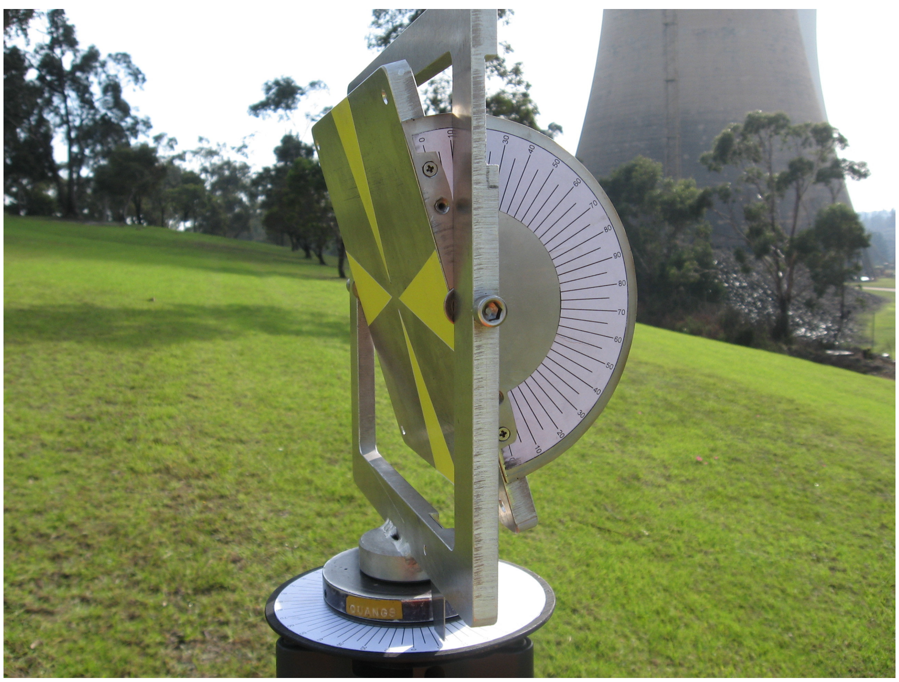


Figure 3.3 showing vertical axis adjustment scale set at 5˚ intervals

**Critical Obstruction Testing Apparatus:**

The apparatus required for the critical obstruction testing had to incorporate a variable 'shutter' that was to imitate an obstruction to the line of sight in a controlled fashion. This 'shutter' was required to be variable both horizontally and vertically.

The shutter has been designed to allow the offset to the line of sight to be determined via sliding the shutter towards the line of sight of the instrument to target. Figures 3.4 and 3.5 below show the chosen design of the critical obstruction apparatus.

Figure 3.4 showing critical obstruction apparatus set to vary horizontally

Figure 3.5 showing critical obstruction apparatus set to vary vertically

Material utilised in the construction of the obstruction shutter comprised primarily of wood, with laminated chipboard for the supporting surround and masonite for the actual shutter. Dimensions of the shutter are 125mm high and 340mm wide (when viewing Figure 3.5) and the shutter can slide the entire length of the white side supports.

The tribrach carrier, as seen in figures 3.4 and 3.5, can only be attached in one place on each axis, effectively force-centring the apparatus with each set up. A sighter arrow (seen in figure 3.4 as increments on the white support frame) is aligned with the reflector target set behind the obstruction, and then the shutter is brought online and the offset is recorded when the obstruction impacts on the distance read.

### 3.3.3 Selection of suitable reflectorless units

Initially testing of reflectorless capabilities was going to be directed solely at the Trimble S6 Total Station due to direct access to this instrument. Upon background research it was evident that other manufacturers of surveying instruments have utilised this new technology favourably and have available on the market instruments of similar capabilities to the Trimble S6.

Listed below are the reflectorless total stations that were utilised for testing:

- Trimble S6
- Leica Flexline TS09
- Topcon GPT9005A

All units undertook the oblique angle testing, with only the Trimble S6 utilised for Critical Obstruction and Minimal Approaches testing.

### 3.3.4 Objective 4: Identification of errors

Prior to any rigorous analysis of the reflectorless distance measurement results obtained all inherent errors relating to the methods of testing and the instruments undertaking the tests will need to be identified and where possible, eliminated. Index errors associated with the design of the target will need to be determined and taken into account when testing the instruments.

Each instrument tested will be subjected to a calibration on the local baseline with scale and index errors documented and accounted for. Atmospheric corrections for standard EDM observations can be easily applied based on accurate observations on the current atmospheric conditions. As part of the initial set up and instrument calibration, atmospheric simulations will be undertaken to determine the correlation between EDM atmospheric corrections and reflectorless corrections.

### 3.3.5 Objective 5: Analysing and Evaluating results obtained

Once all results are collected, they will need to be sorted and any outlying observations need to be discarded or reread to determine if the observation was exposed to survey error, or if indeed there may be an anomaly present in the data capture. Analysis of the data will result in graphs and tables comparing data, with statistics generated as to the quality of the data.

All analysed data needs to be considered when forming a conclusion on the viability of reflectorless technology, with any additional survey work carried out to rectify any data errors or anomalies. Lastly, final conclusions will be made and recommendations drawn from these conclusions.

## *3.4 Validity of results obtained and repeatability*

Data obtained from field testing has to have integrity relating to relevance to the testing criteria, comparability to conventional EDM distances and the ability to be compared simultaneously without any bias in the data or additional error brought on by varied field conditions or apparatus error. Testing apparatus that incorporates forced centring has been chosen to limit errors associated in plumbing surveying instruments relative to each other. Utilising the same reflective target for all testing scenarios has limited the error associated with varied field setups and any bias in the testing equipment will be inherited in all testing by all field instruments effectively cancelling out any random set up error associated with field testing.

## 3.5 Processing of Results

Field testing incorporates the use of the Trimble S6, Leica Flexline and Topcon GPT9005A for the oblique angle testing, with the Trimble S6 the chosen instrument for the critical obstruction and minimal approaches testing. Since the Trimble S6 instrument has been utilised in all testing this unit has been calibrated over a Department of Sustainability and Environment (DSE) approved EDM baseline for comparisons of the reflectorless measurements obtained relative to those of conventional distances. For graphical and analytical purposes each conventional EDM distance obtained from instruments tested will be adjusted to align with the distance measured by the Trimble S6 to account for any instrument index errors so that each instrument can be analysed jointly. The objective behind this testing is to analyse the performance of reflectorless measurements and not the inherent accuracy of the given instruments.

All surveying total stations are subject to cyclic and index errors that will impact the actual distance measurement obtained. If these intrinsic total station errors are negated then actual comparisons of the reflectorless measurements can be performed and analysed with respect to one another with a starting conventional distance that is true across all instruments.

## 3.6 Field Results - Oblique Angle Testing

Oblique angle testing was undertaken utilising the Trimble, Leica and Topcon total stations. As described in the project methodology distances chosen for field testing were as follows; 10m, 25m, 50m, 100m and 200 metres. Upon commencing field testing at 10m it was evident that the brushed aluminium surface of the testing apparatus resulted in inconsistent measurements over this small distance, resulting in the omission of 10 metre measurements from field testing.

Testing was undertaken at a closed section of old highway that was chosen for location convenience, suitable size and ease of access. All field testing was conducted with both the instrument and reflector target shaded to help control the affects of atmospherics and sun glare.

All field operation of the total stations tested was performed by the one operator to minimise systematic errors associated with operator work method. In addition to this, once testing of a particular instrument was performed a set of random distances and random angles of incidence in the horizontal and vertical axes were performed to act as a check on the results obtained.

## *3.7 Conclusion*

This chapter has discussed chosen field tests, potential test instruments and the associated testing apparatus utilised in field testing. Methodology relating to forced-centring and repeatable field scenarios along with ability to control atmospheric conditions has been detailed and determined a priority for field testing to be undertaken successfully.

# Chapter 4

# Field Testing and Results

## *4.1 Introduction*

The results outlined in this chapter provide detailed analysis of reflectorless measurements relative to traditional EDM distances along with comparison of comparable competitive instruments.

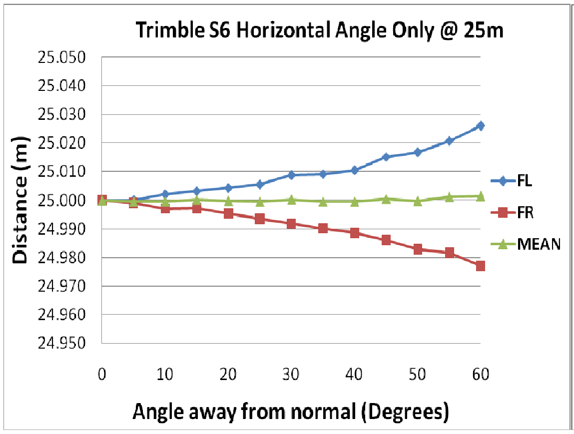
The aim of this chapter is to quantify results obtained to determine the validity of reflectorless measurements compared to traditional EDM distances, along with the final comparison of available testing instruments to determine if current technology has a significant impact on the best available measurement device.

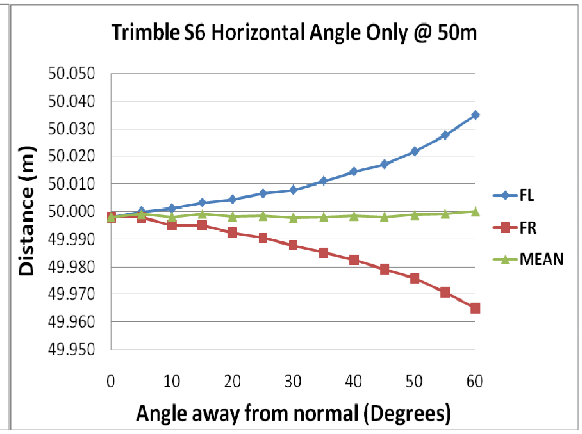
## *4.2 Oblique Angle Testing: Horizontal Angle of Incidence*

The following figures graphically display the relationship between the actual field distances measured with the angle of incidence to the reflector target. Each instrument has been shown independently with readings on both instrument faces and a mean of both faces to determine if collimation and sighting errors influence the resultant distance.

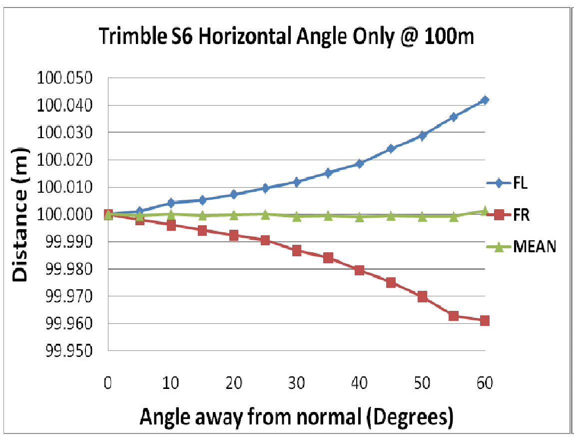
The figures will cover rotations in the horizontal, the vertical and combining both axes to replicate scenarios found in a field survey. Measurements have been taken at 5˚ intervals up to 60˚ from normal (perpendicular to the line of sight).

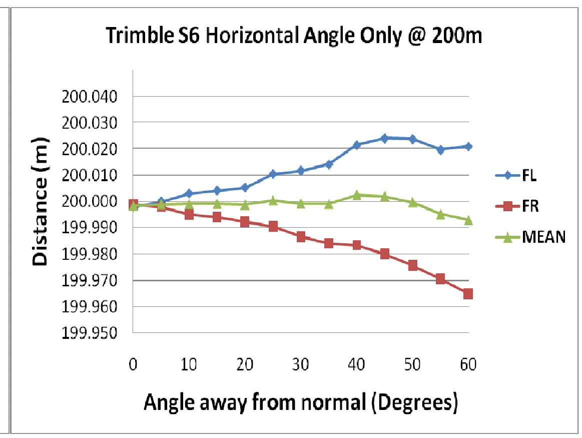
### 4.2.1 Trimble S6 Rotating Horizontally




Figures 4.1 and 4.2 Horizontal axes Trimble S6 @ 25m and 50m respectively



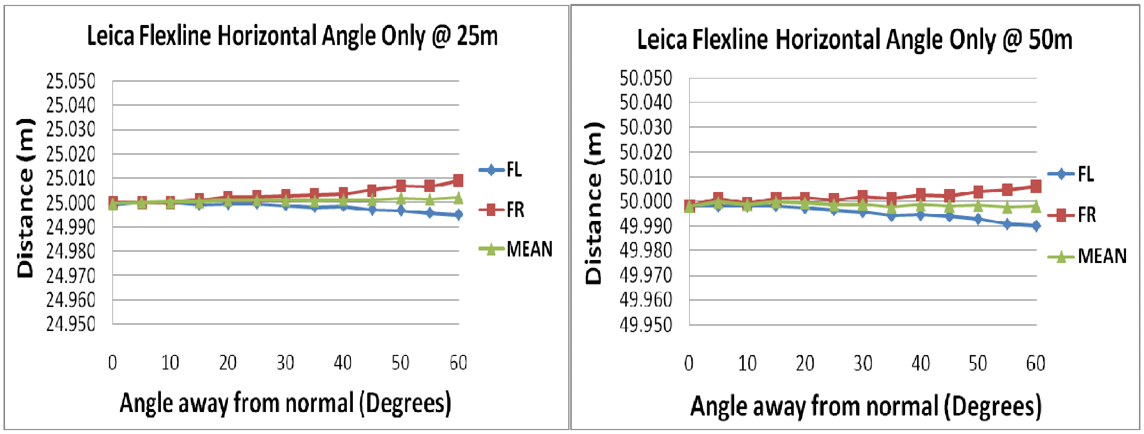




Figures 4.3 and 4.4 Horizontal axes Trimble S6 @ 100m and 200m respectively

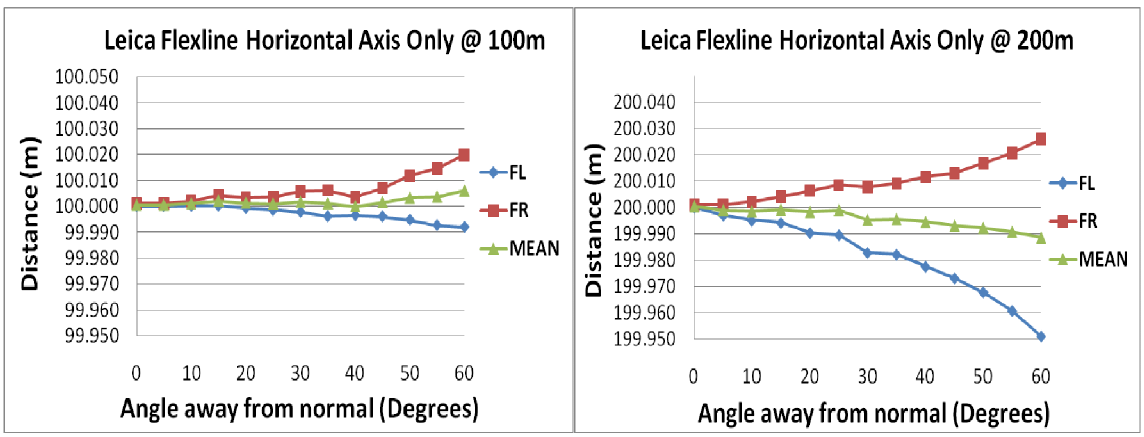
Analysing the results of the Trimble S6 varying the angle of incidence in the horizontal plane concludes that there is a significant face error associated with this instrument. The mean of both face readings returned the correct distance within manufacturer's specification (See Appendix B for details) to that of the conventional EDM distance obtained. In Addition to this it is apparent that there is little relationship between the distance to the target and the measurement error returned, even though the magnitude of the face error increases proportionally with distance, the resultant mean returns the correct distance.

At 200m distance between instrument and target the resultant distance falls outside the manufacturer's tolerance of ±3mm + 2ppm, this only occurs at angles greater than 50˚ from normal.

### 4.2.2 Leica Flexline Rotating Horizontally




Figures 4.5 and 4.6 Horizontal axes Leica Flexline @ 25m and 50m respectively

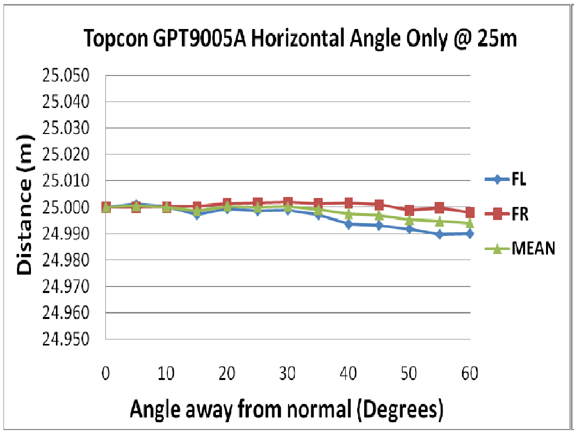


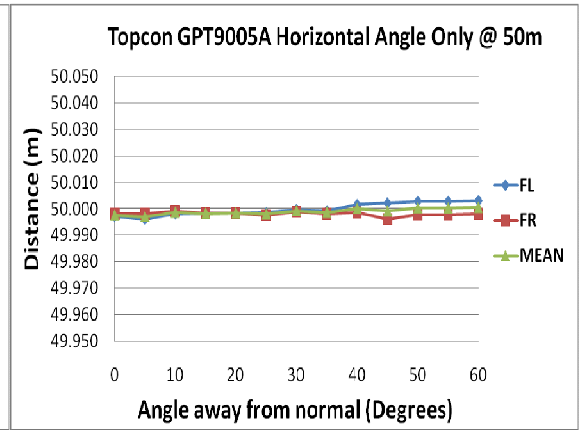

Figures 4.7 and 4.8 Horizontal axes Leica Flexline @ 100m and 200m respectively

As per the Trimble total station the Leica Flexline exhibits face errors proportional to distance with the mean of both faces returning an acceptable result within tolerance up to a distance of 50m. At 100m the results marginally exceed the instruments reflectorless tolerances of ±2mm + 2ppm (See Appendix C for details of instrument tolerances), and at a distance of 200m the Leica is outside its manufacturer's tolerance by a factor of 3. Keeping the angle of incidence below 45˚ will allow distances up to 100m to be obtained accurately but distances of 200m need to have the angle of incidence kept below 30˚.

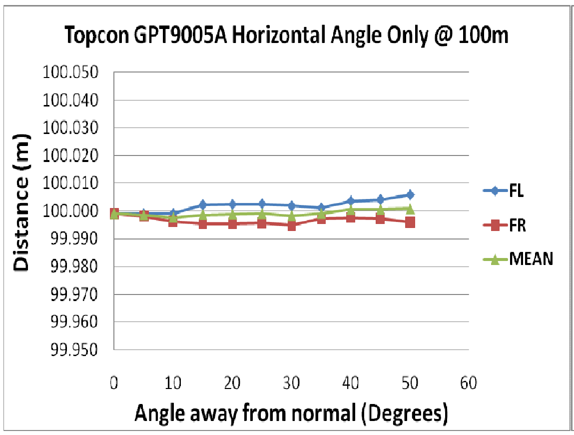
The face errors of the Leica instrument are significantly less than those of the Trimble instrument, possibly indicating greater coincidence with the instruments crosshairs.

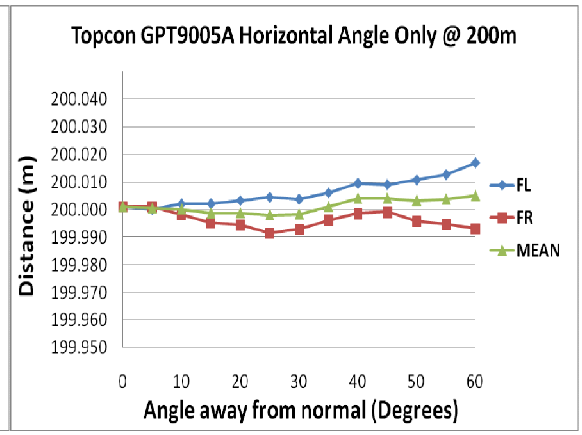
## 4.2.3 Topcon GPT9005A Rotating Horizontally




Figures 4.9 and 4.10 Horizontal axes Topcon GPT9005A @ 25m and 50m respectively



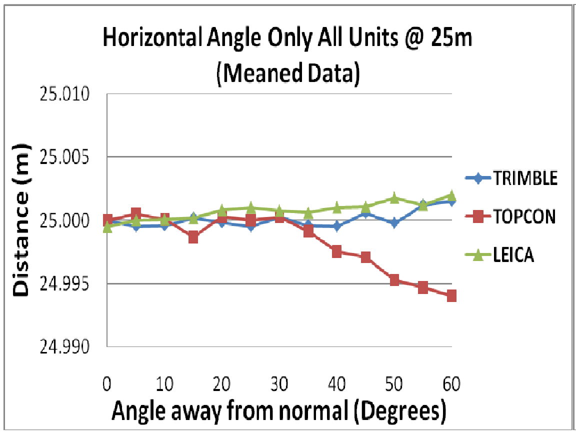



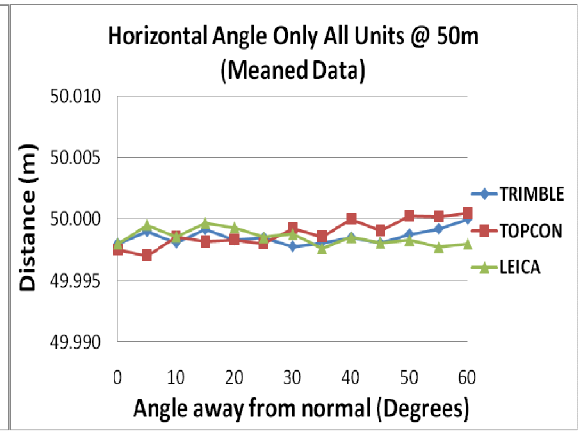

Figures 4.11 and 4.12 Horizontal axes Topcon GPT9005A @ 100m and 200m respectively

The Topcon instrument performed a little differently than the Trimble and Leica in that the face error was marginal and the resultant meaned data was within the quoted manufactuerer's tolerances of ±5mm (See Appendix D for details) for fine mode for all distances except at 25m. The Topcon total station utilises two independent modes for obtaining reflectorless distances, non-prism fine and non-prism long range with quoted tolerances of ±5mm and ±10mm +10ppm respectively. At a distance of 100m the Topcon instrument was still set on its fine setting, which would not return a distance when the angle of incidence was increased past 50˚. Long range mode was than utilised for the testing of 200m, returning distances at 60˚ from normal, but with an increased error.

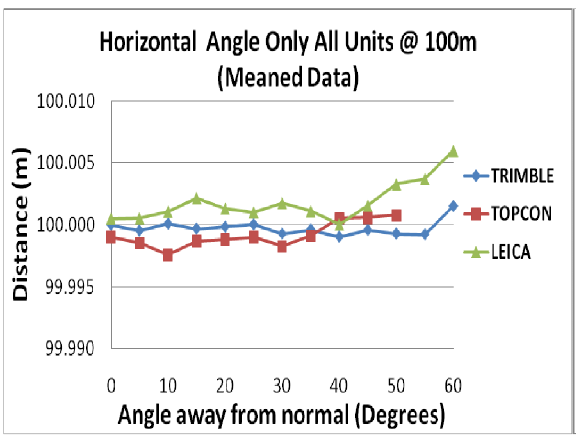
On analysing the results obtained at the 25m distance it is evident that the reflective properties of the testing apparatus may have hindered these results. This may be due to the instrument receiving too strong a signal or the polished aluminium surface reflecting sporatic signals.

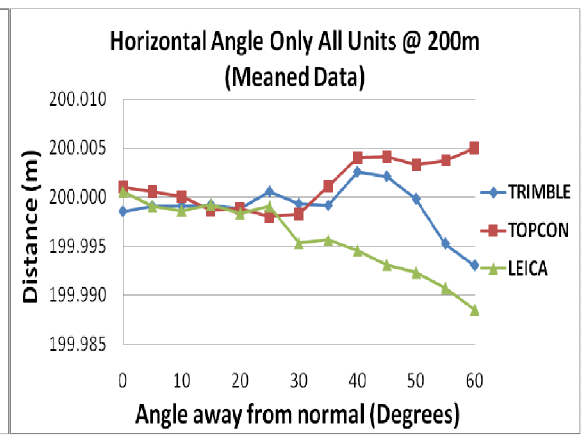
### 4.2.4 Averaged Datasets all Units: Horizontal Angle of Incidence




Figures 4.13 and 4.14 Horizontal axes all units @ 25m and 50m respectively




Figures 4.15 and 4.16 Horizontal axes all units @ 100m and 200m respectively

Analysis of combining the face left and face right observations proves that the resultant meaned data aligns extremely well with the actual EDM distance read up to oblique angles of 30˚. Summary of total station behaviour of oblique angle rotated in the horizontal are as follows:

- Topcon instrument at distance of 25m returned a result that indicates that the strong signal utilised by the instrument may have returned inconsistent results.

- The Leica Flexline proved effective in returning a result well within quoted tolerences upto 50m but distances 100m and greater returned unacceptable results. This is due to the Leica having the heightest quoted accuracy of the instruments tested.

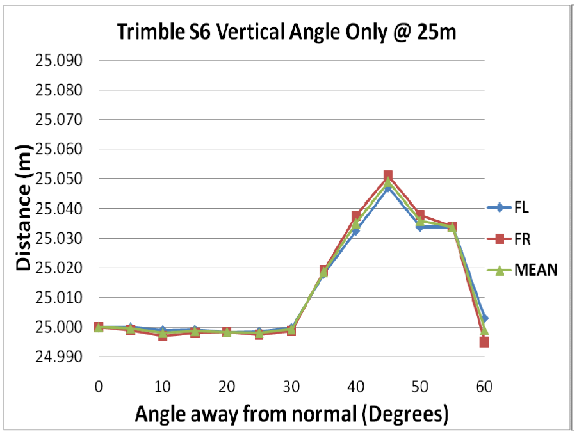
- The Trimble unit returned consistent results, with only the 200m distance failing its quoted tolerance and this was at an angle 50˚ away from normal.

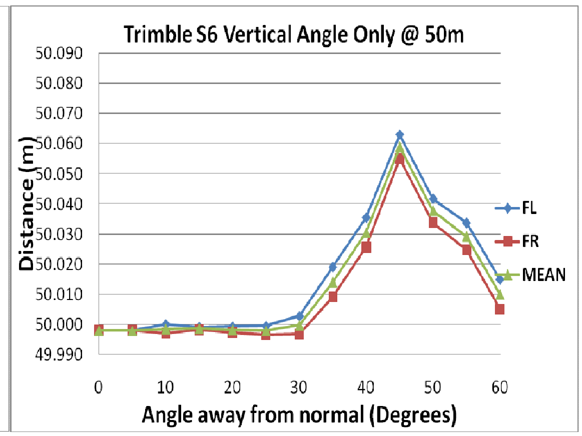
- Changing the Topcon reflectorless mode to 'Long Range' did not significantly affect the accuracy of the measurement.

## *4.3 Oblique Angle Testing: Vertical Angle of Incidence*

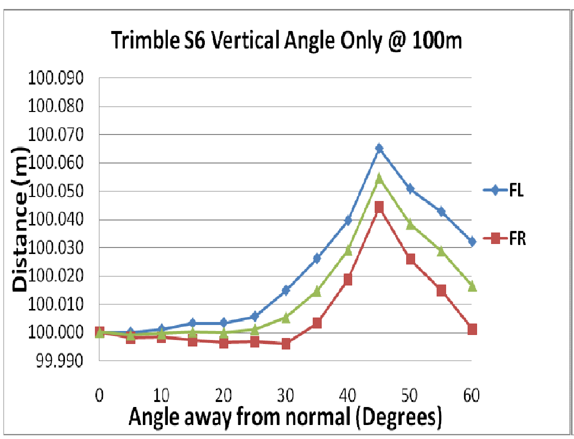
The following figures show the relationship between the actual field distances measured with the angle of incidence of the reflector target rotating vertically. Measurements have been taken at 5˚ intervals up to 60˚ from normal.

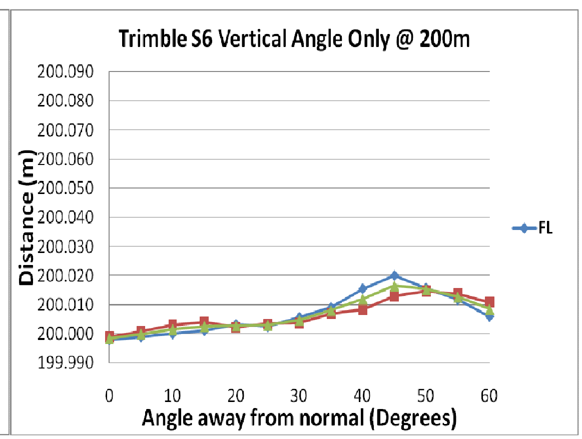
### 4.3.1 Trimble S6 Rotating Vertically




Figures 4.17 and 4.18 Vertical axes Trimble S6 @ 25m and 50m respectively




Figures 4.19 and 4.20 Vertical axes Trimble S6 @ 100m and 200m respectively

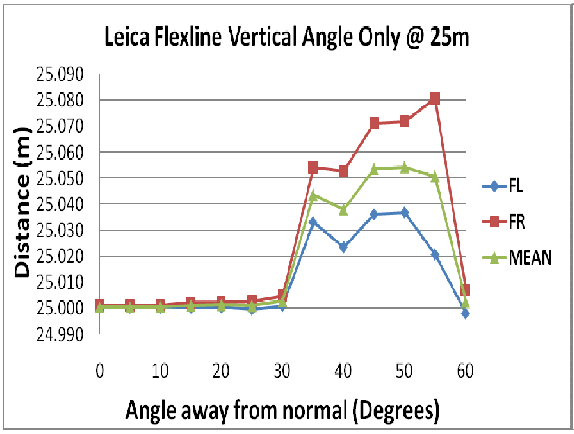
From the results obtained by rotating the target through the vertical axis it is evident that at approximately 30˚ from normal the distance measured increases significantly past the manufacturer's tolerances to an unacceptable level.

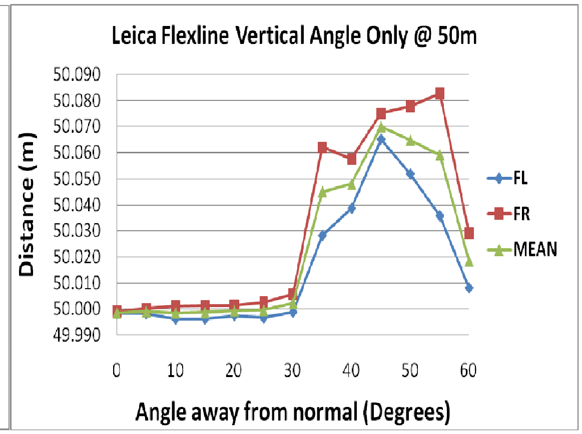
This increase in the measured distance occurs at all distances measured with a noticable decrease at the 200m distance measurement. The target material itself may be subject to reflections onto the target frame and tribrach carrier. The face errors present in these results are significantly smaller than those encountered in the horizontal angle, which is expected.

Since the beam divergence is elongated in the vertical axis with the Trimble S6 (Refer to Appendix B for details of beam divergance properties), with a magnitude of 8cm per 100m it is possible that the 200m measurement was incorporating the framework of the target into its distance calculation.

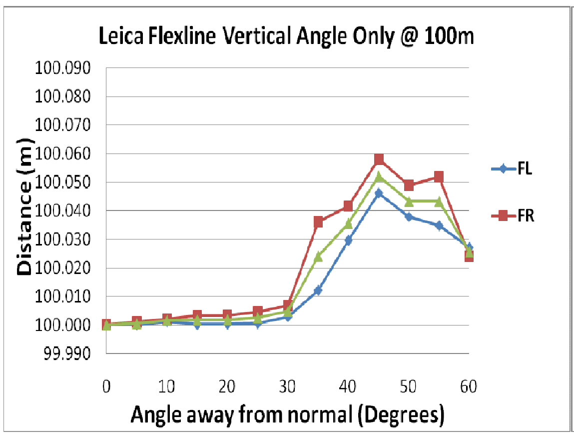
Similarily to varying only the horizontal angle there appears to not be a relationship between distance read and magnitude of error.

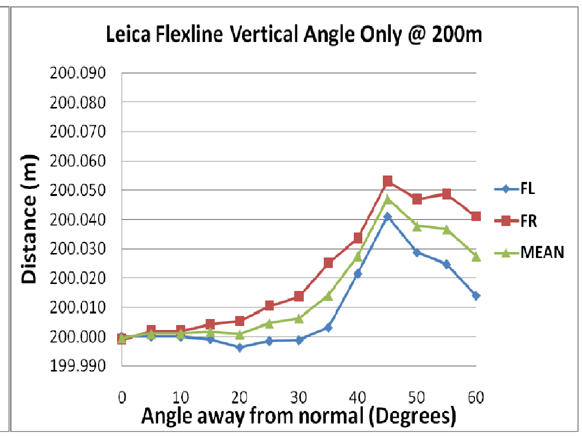
## 4.3.2 Leica Flexline Rotating Vertically




Figures 4.21 and 4.22 Vertical axes Leica Flexline @ 25m and 50m respectively



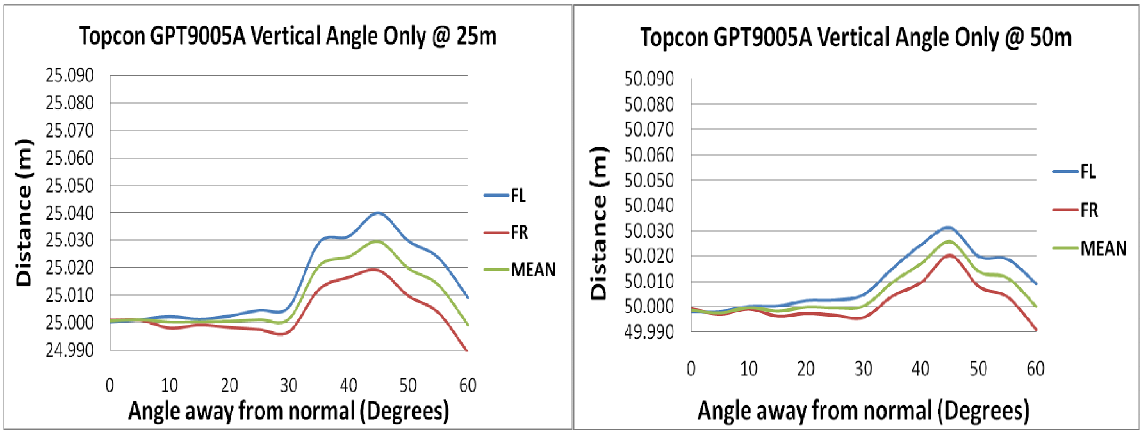

Figures 4.23 and 4.24 Vertical axes Leica Flexline @ 100m and 200m respectively

Varying the vertical angle for the Leica Flexline resulted in a similar outcome to that of the Trimble S6, with significant discrepancy occuring at angles greater than 30˚ from normal. Unexpectantly the face errors present in the Leica data are greater than those exhibited by the Trimble unit, since the horizontal axis testing indicated the Trimble S6 to possess a greater face error.

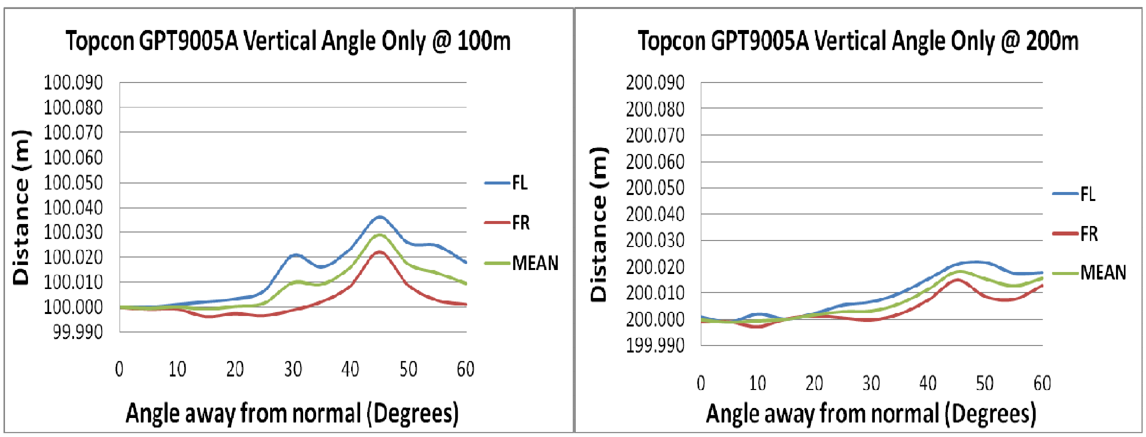
The profile of each distance shows a distinct peak in the measurement followed by a smaller trough. This may indicate some reflections distorting the output distance.

Of note, the data provided up to 30˚ with the exception of the 200m measurements show results well within the instruments quoted tolerances.

### 4.3.3 Topcon GPT9005A Rotating Vertically



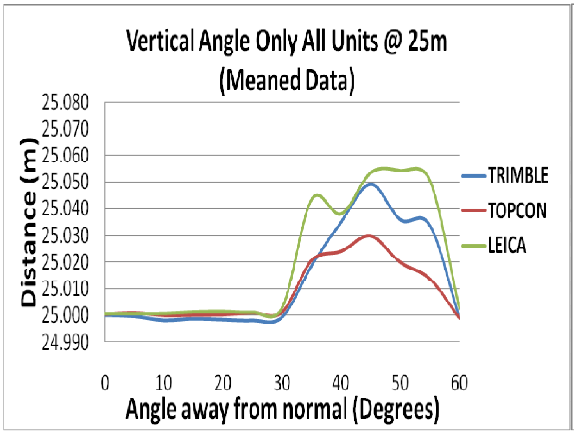
Figures 4.25 and 4.26 Vertical axes Topcon GPT9005A @ 25m and 50m respectively

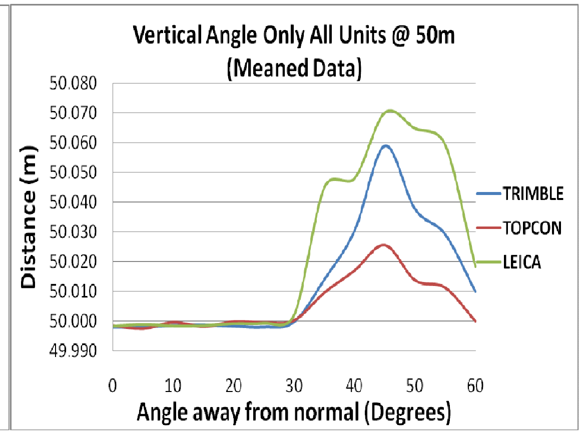


Figures 4.27 and 4.28 Vertical axes Topcon GPT9005A @ 100m and 200m respectively

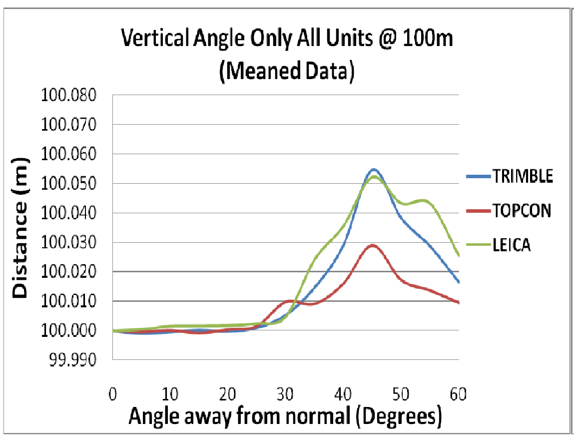
Similarily for the Topcon instrument the vertical angle of incidence has a distinct discrepancy in the distance measured once the angle is greater than 30˚ from normal. The Topcon unit which showed the smallest face error in the horizontal angle proved similar to the Leica unit in the vertical, returning a significantly larger reading, especially at smaller distances. The Topcon's largest variance from the correct distance occurs at 45˚ from normal, producing a graph of similar shape and scale to the Trimble S6.

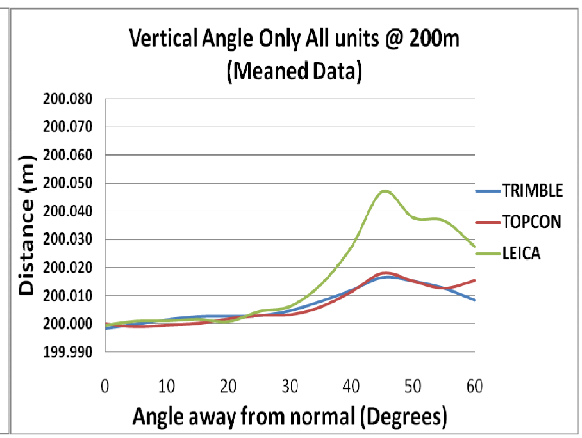
## 4.3.4 Averaged Datasets all Units: Vertical Angle of Incidence




Figures 4.29 and 4.30 Vertical all units @ 25m and 50m respectively




Figures 4.31 and 4.32 Vertical axes all units @ 100m and 200m respectively

Averaging the results of face left/ face right returns results that still observe unacceptable distances at angles greater than 30˚ in the vertical. Summarising the results yields the following:

- All units generally follow the same trend in varying the vertical angle
- Varying the distance did not proportionally increase the error, the error actually reduces as distance is increased with the Trimble and Topcon instruments
- Data obtained at angles of incidence greater than 30˚prove unacceptable

- Conversely, reading both instrument faces does not mitigate any error generated in the distance measurement

- External influences, including observations that are subject to additional reflections from an unwanted source, namely the reflector target frame and carrier may be contributing to the unexpected results obtained in the vertical angle

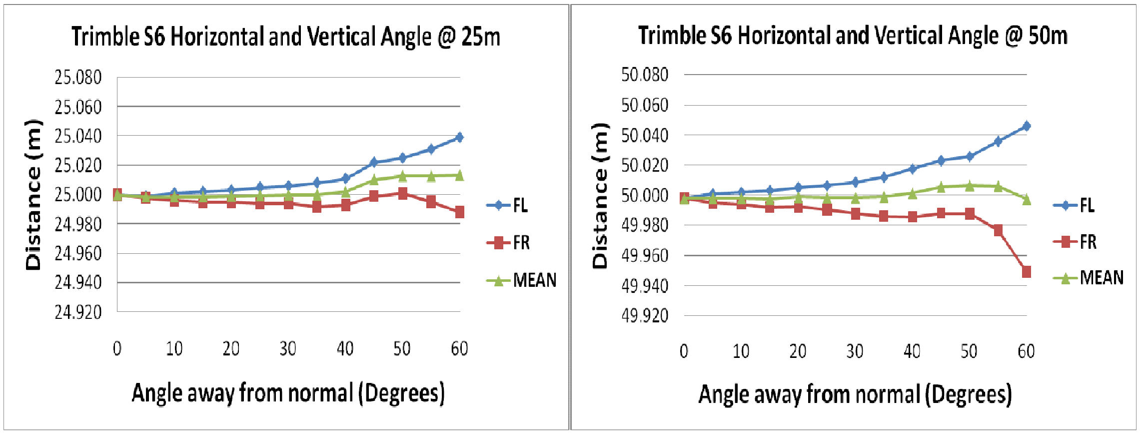
## 4.4 Oblique Angle Testing: Horizontal and Vertical Angle of Incidence

The following figures show the relationship between the actual field distances measured with the angle of incidence of the reflector target rotating both horizontally and vertically. With both the horizontal and vertical rotations completed it was decided to do testing of both together to see if the relationship is a combination of the horizontal and vertical error vectors, or a bias towards either the horizontal or vertical results.

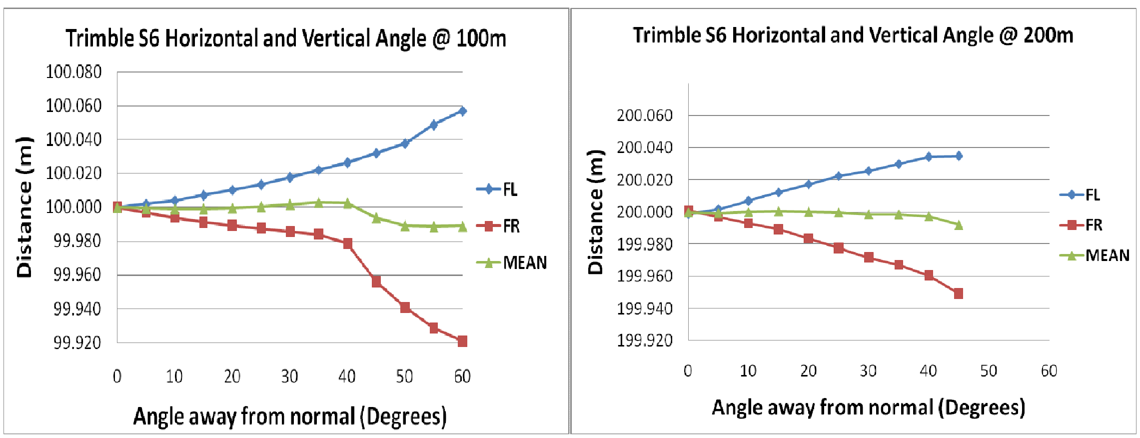
In real life surveying scenarios it is unlikely that the surfaces that are required to be located are directly square to the line of sight, or rotated in one axis only, they will mostly have a vertical and horizontal component in the geometry of the angle of incidence, making this test the most relevant to surveying conditions.

Measurements have been taken at 5˚ intervals up to 60˚ from normal, or until the instruments limits are exceeded.

## 4.4.1 Trimble S6 Rotating both Horizontally and Vertically




Figures 4.33 and 4.34 Combined axes Trimble S6 @ 25m and 50m respectively



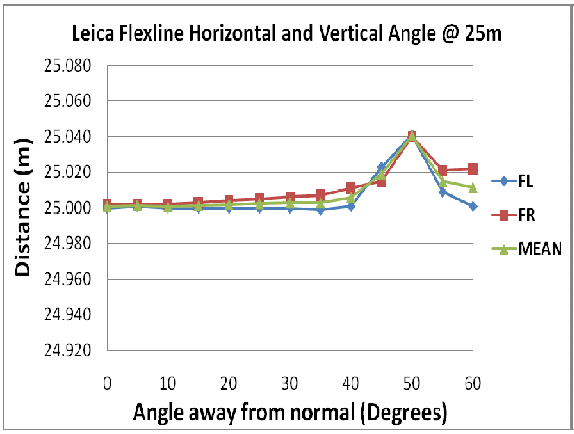

Figures 4.35 and 4.36 Combined axes Trimble S6 @ 100m and 200m respectively

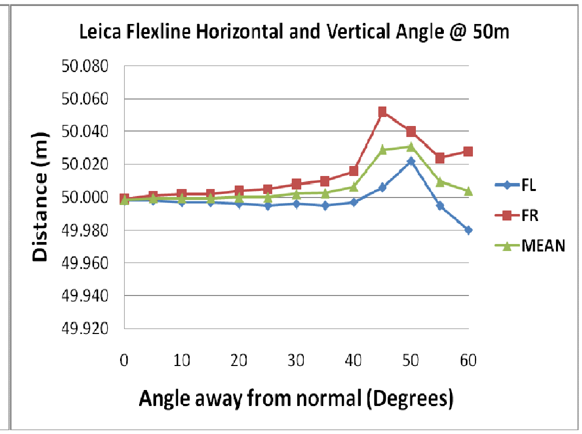
Results obtained from having the horizontal and vertical angles varied simultaneously shows errors in distance with similar properties to varying one axis at a time. Errors in distances read 100m and longer return a face spread similar to varying the horizontal angle only, whilst distances less than 100m show a dip around the 45˚-50˚ region similar to the vertical axis only, however at a lesser magnitude.

Averaging the face left and face right readings returns a distance error that is within manufacturer's specifications up to an angle of 40˚, angles greater than this returned a distance outside the tolerances of the instrument.

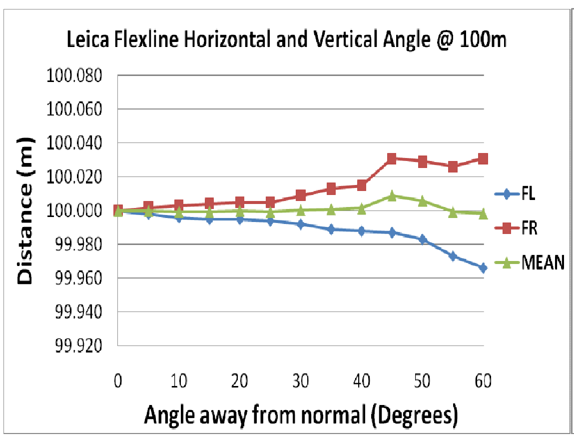
Measurements taken on face right seem to exhibit a greater variance than those on face left. At a distance of 200m to the reflector target the Trimble S6 could only read to an angle of 45˚ from normal. This shows that the combination of varying both axes has an effect on the instruments ability to return a distance, since this instrument was able to return a measurement on both horizontal and vertical axes separately up to 60˚.

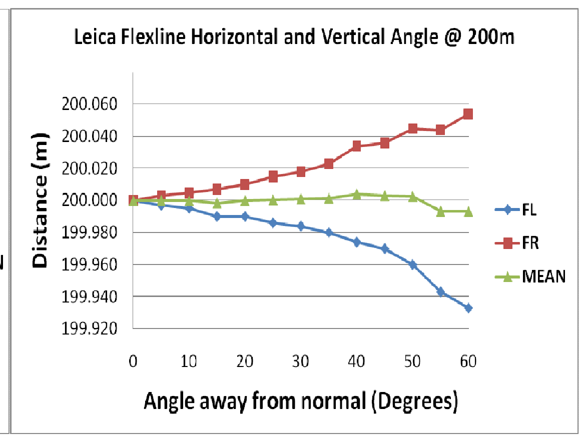
### 4.4.2 Leica Flexline Rotating both Horizontally and Vertically




Figures 4.37 and 4.38 Combined axes Leica flexline @ 25m and 50m respectively



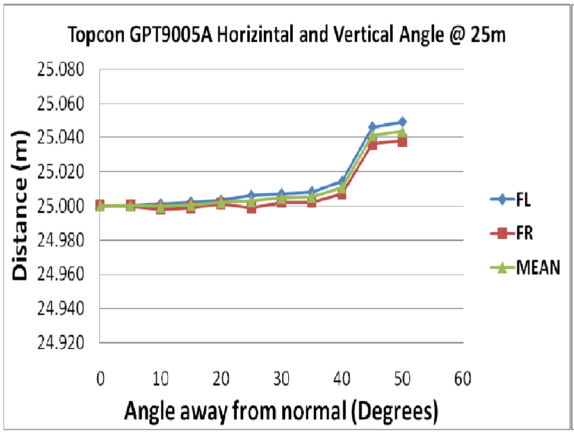

Figures 4.39 and 4.40 Combined axes Leica flexline @ 100m and 200m respectively

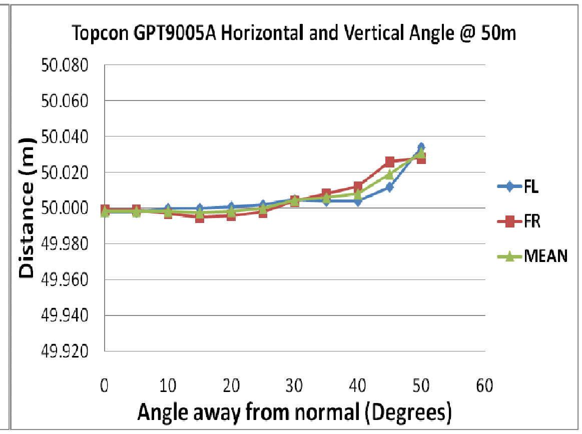
Analysing the Leica TS09 distance measurements with varying both axes simultaneously it is evident that the distance errors are significantly different for distances less than 100m as opposed to distances 100m and greater. Similarly to the Trimble S6 the results obtained from distances less than 100m follow a similar trend to varying the vertical axis only, whilst the longer distances return a value similar to horizontal axis rotation only.

Additionally the face errors present in the data show a significant increase at larger distances, this increase in face error at 200m is approximately twice the error than only rotating the horizontal axis exhibits.

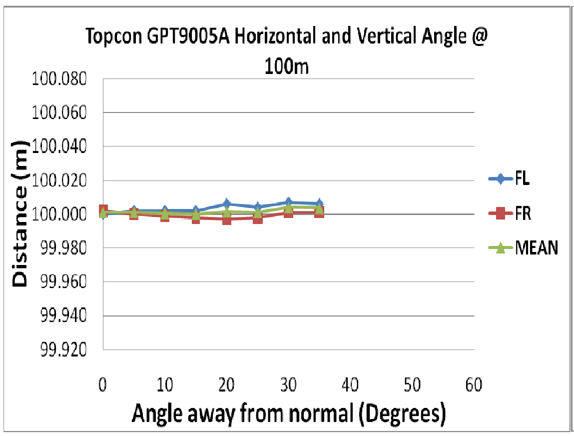
The distances obtained from averaging the face left/face right measurements are within manufacturer's specifications up to an angle of 40˚ for all distances measured, with the longer distances of 100m and 200m returning acceptable results up to and including the 60˚ measurements.

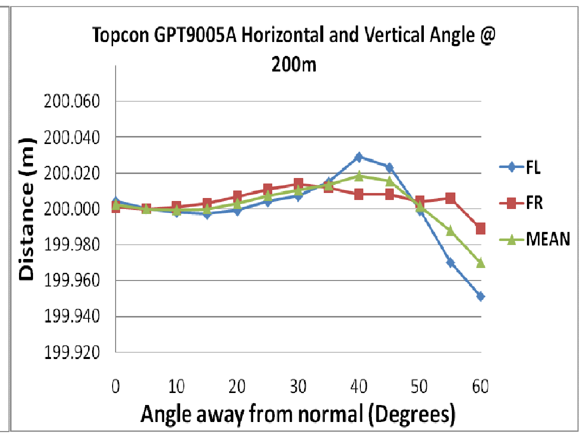
### 4.4.3 Topcon GPT9005A Rotating both Horizontally and Vertically




Figures 4.41 and 4.42 Combined axes Topcon GPT9005A @ 25m and 50m respectively



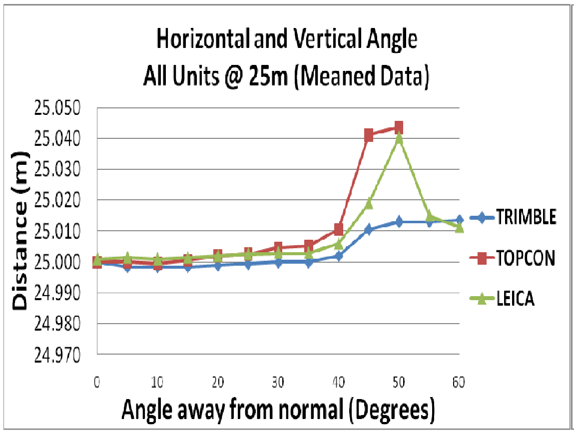

Figures 4.43 and 4.44 Combined axes Topcon GPT9005A @ 100m and 200m respectively

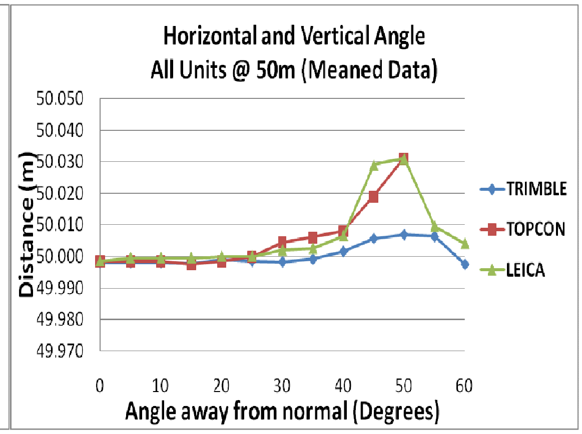
The Topcon instrument could not return a distance greater than 50˚ from normal on its non-prism 'fine' measurement mode. Non-prism fine mode setting has been utilised for all previous testing distances excluding the 200m readings and for consistency has not been altered.

The results indicate that the Topcon instrument has the least face error present out of all three instruments tested, and results up to and including the 100m measurements show consistent data that is within manufacturer's tolerances up to an angle of 35˚ from normal. Distances returned at greater angles than 35˚ indicate erratic behaviour, especially at the 200m measurements; this may indicate some reflector interference similar to that of the vertical axis errors only.

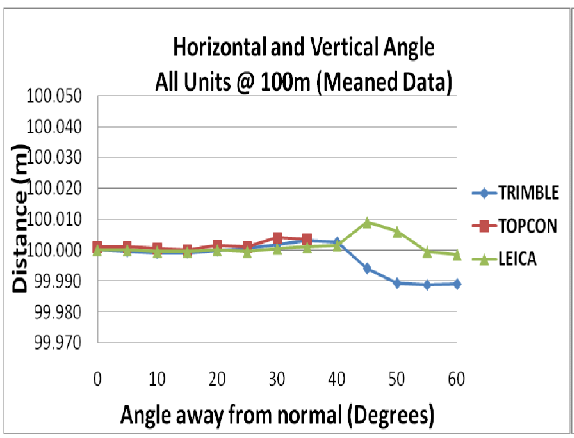
The erratic results of the 200m distances may be to the instrument being set on non-prism 'coarse' mode, but no additional testing was performed to confirm this.

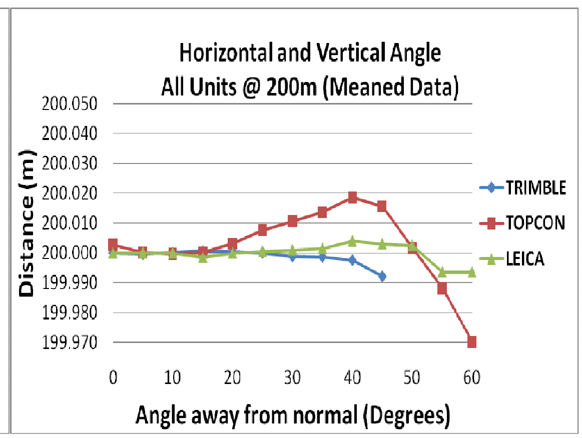
### 4.4.4 Averaged Datasets all Units: Horizontal and Vertical Angle of Incidence




Figures 4.45 and 4.46 Combined axes all units @ 25m and 50m respectively




Figures 4.47 and 4.48 Combined axes all units @ 100m and 200m respectively

Averaging the results of face left/ face right returns similar distances for all units at angles below 35˚ with the exception of the 200m results of the Topcon instrument.

Summarising the combined horizontal and vertical axis rotations yields the following observations:

- Data measured at angles greater than 35˚ return unacceptable results

- The Trimble and Leica instruments exhibit similar properties to both the individual reuslts of the horizontal and vertical rotations

- The accuracy mode on the Topcon unit can have a significant influence on the instruments ability to return a result

- Measurements obtained by combining the horizontal and vertical axes simutaneously indicate that the resultant distance is affected by error components from both axes, and is not just a addition of error in horizontal plus error in vertical

## 4.5 *Critical Obstruction Testing*

Critical obstruction testing as defined in section 3 is attempting to control the process of bringing an obstruction into the line of sight of the reflectorless measurement. This process will identify the approach limitations of obstructions and their proximities to either the instrument, or the surface measured. Critical obstruction testing was undertaken utilising the Trimble S6 total station.

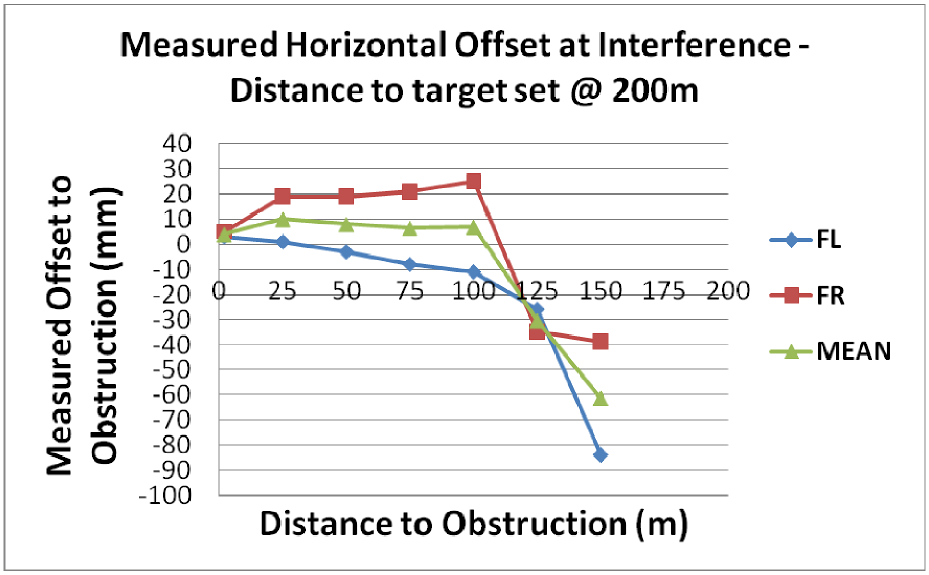



Figure 4.49 Trimble S6 Critical obstruction testing - horizontal

Figure 4.49 illustrates the relationship between the Distance to the obstruction and the offset the obstruction has in relation to the line of sight. The distance to the reflector target was set at a true 200m distance from the instrument via EDM with this distance checked and confirmed by reading with reflectorless without any obstruction present. The obstruction has then been placed at measured distances away from the instrument (X axis) and the shutter has then been moved toward the line of sight and the offset (Y axis) has been recorded when the known distance (200m) is affected by the obstruction. A negative value on the Y-axis indicates that the line of sight to the target is effectively passing through the shutter and the shutter is ineffective to obstruct the measurement.

By analysing the profile of the averaged data (green) it is evident that the obstruction shutter can get to within approximately 10mm to the line of sight before the distance read shows interference by returning an incorrect distance. The results indicate that there is no direct relationship between measured offset and chainage of the obstruction relative to the instrument up to distances 100m away.

Results obtained when the obstruction is set at distances greater than 100m show significant differences in offset measured when compared to distances less than 100m. Data obtained at these distances effectively 'ignore' the obstruction and read correct distances to the target directly through the obstruction. When the obstruction was set at 150m from the instrument the shutter had to be placed approximately 60mm (Averaged on both faces) across the line of sight before the distance to the target was corrupted. Attempting to set the obstruction at 175m resulted in the obstruction not able to have any influence on the distance generated, as the instrument effectively read through the obstruction at all offsets (Looking through the total station only the edges of the target could be seen with the shutter obstructing the view) still the correct distance was obtained. Testing with the shutter set to alter in the vertical axis returned similar results.

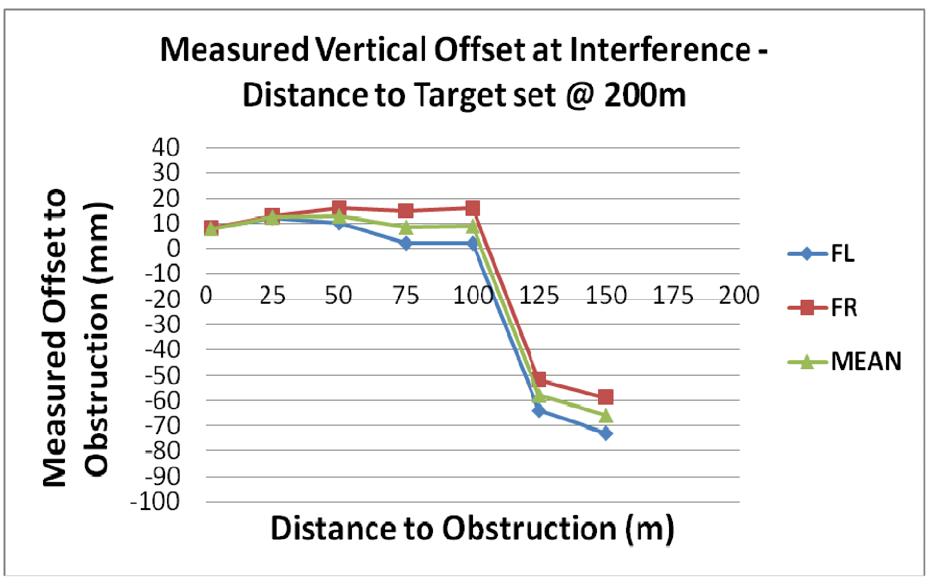



Figure 4.50 Trimble S6 Critical obstruction testing - vertical

Summarising the results of the critical obstruction test conclude:

- The face error present in both horizontal and vertical tests indicate the reflectorless measurements may not be coincident with the instruments crosshairs
- There does not seem to be a direct relationship with the magnitude of the offset with the distance to the obstruction (when the shutter effectively obstructs)
- Obstruction distances greater than 100m ignore the obstruction and can effectively see through it, proving the testing apparatus has limitations
- The size of the testing apparatus and the material selected may have influenced the 'shutters' ability to obstruct the distance to the target
- Further testing required to fully analyse the obstruction relationship with a larger apparatus that has the same reflective properties of the target

## 4.6 *Minimal Approaches Testing*

Minimal Approaches testing required measurements to be taken directly to the surface of the reflector target (apparatus as per the oblique angle testing) that is set at a known distance with an obstruction placed at a nominal 150mm immediately behind the reflector target. The Obstruction for the testing was a sheet of polished steel that had similar reflective properties to the reflector target.

As described in section 3, the minimal approaches testing required the crosshairs to be dialled off the centre of the target towards the nominated edge, recording the offset to the target edge when the reflectorless distance is affected by both the reflector surface and the surface directly behind. This procedure was performed on a horizontal edge (Side) and a vertical edge (Top) recording measurements on both instrument faces. Figure 4.51 below shows the reflector target with a steel sheet obstruction directly set up behind, this setup was repeated at distances of 10m, 25m, 50m, and 75m increments.

Figure 4.51 Showing Trimble S6 sighting reflector target with steel obstruction

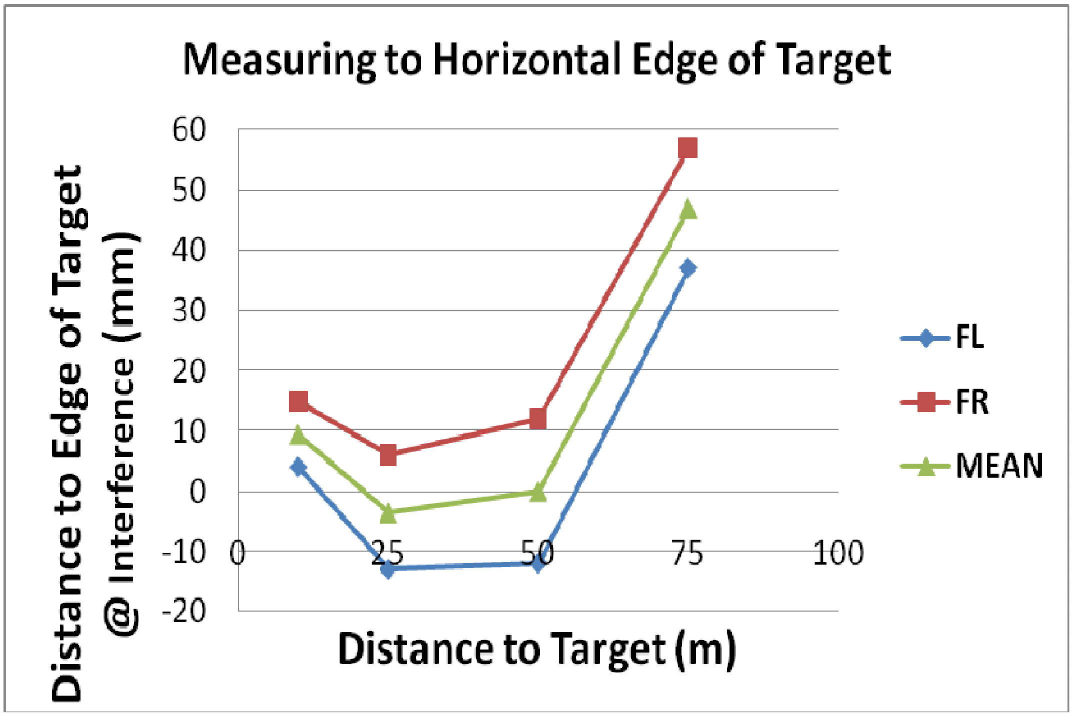


Figure 4.52 Trimble S6 Minimal Approaches testing - horizontal

Analysing the data present in figure 4.52 indicates that at distances greater than 50m reflectorless measurements cannot get to within approximately 50mm to a surface edge without risk of getting interference by structures directly behind.

The beam divergence specifications of the Trimble S6 DR300+ (Refer to Appendix B for further details) state a 40mm horizontal and 80mm vertical spread of the beam per 100m, resulting in a spread of approximately 20mm horizontal and 40mm vertical @ 50m. Therectically since testing is approaching an edge from one side this means that measurements to within 10mm of a horizontal edge (side) and 20mm of a vertical edge (top) should not spread past the edge and reflect on a background surface. The results up to 50m agree with this, but measurements taken at 75m fall well outside these constraints with an offset (meaned both faces) recorded of 46mm, with stated manufacturer's beam divergence of 30mm @ 75m.

Results obtained when approaching the vertical edge (top) of the reflector target indicate that at a distance of 75m the minimal offset (meaned both faces) before getting any obstruction from behind is 36mm, just outside instrument specifications of 30mm @ 75m. Results obtained from distances 50m and less are similar to results obtained approaching the horizontal edge, and are within instrument specifications for beam divergence tolerances.

Analysing figure 4.52 shows face left results at 25m and 50m to be negative, meaning the crosshairs of the instrument were dialled off the instrument by approximately 10mm and still returned the correct distance without interference from the background obstruction. This indicates that the reflectorless measurements may not be coincident with the instruments crosshairs; this is strengthened by the face that face error was present in the measurements.

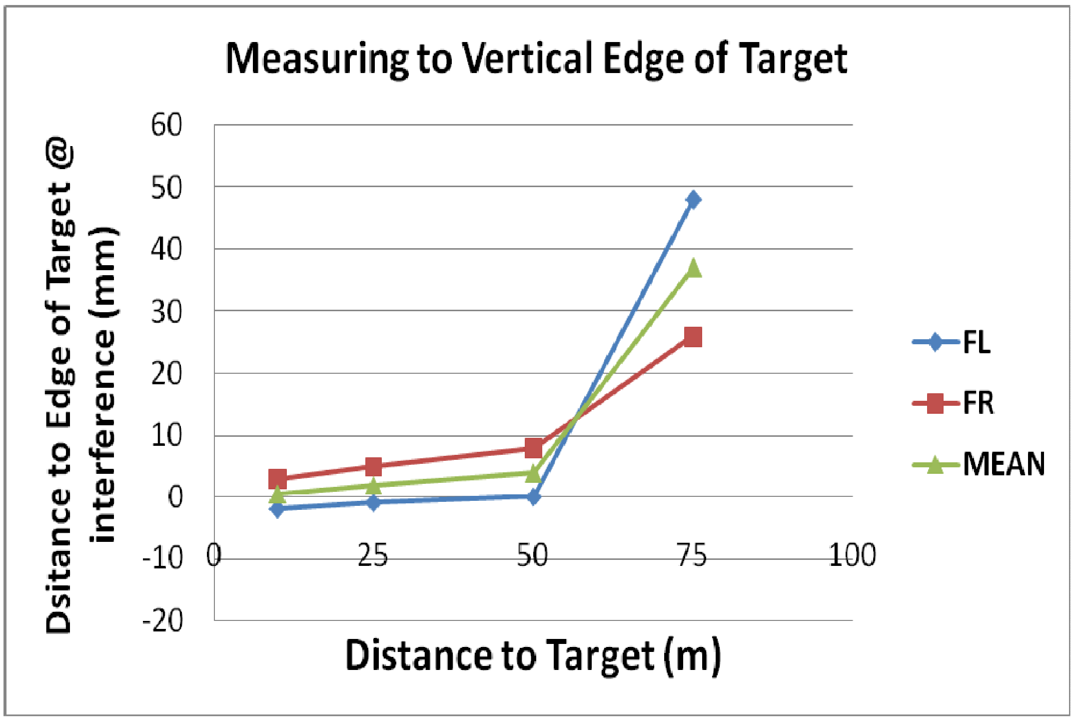



Figure 4.53 Trimble S6 Minimal Approaches testing - vertical

Summarising the results of the minimal approaches test conclude:

- Distances 50m and less return measurements that fall within quoted manufacturer's specification and tolerances for beam divergence, and indicate that at these distances measurements can be taken to close proximity (10mm) of an exposed surface edge with confidence

- Distances greater than 50m return results outside manufacturers specification for beam divergence and indicate that background obstruction can interfere with distance measured

- Measurements were attempted at 100m to try and identify measurement trends, but the results obtained were inconsistent and not used for processing

- Face left measurements at 25m and 50m to a horizontal edge provided negative offsets, meaning the crosshairs were sighted off the edge of the target and still returned the correct distance

## 4.7 *Problems Encountered in Field Testing*

Overall field testing undertaken went smoothly with no inherent major problems, with only minor alterations in the process of performing and booking the results occurring. Other minor problems that were encountered were:

**Oblique Angle Testing:**

- Results obtained at 10m were inconsistent and were not included in the analysis of the data obtained
- Atmospheric conditions, namely sun glare seem to have minor effects on distance measurements, even with both instrument and reflector target shaded
- Topcon instrument needed to be set to non-prism long range mode to return useable results over 100m

**Critical Obstruction Testing:**

- Apparatus utilised in this testing had short comings on distances greater than 100m
- Material selection of testing apparatus needed to match testing target for repeatability
- More testing is required to fully analyse obstructions to the line of sight of reflectorless observations

**Minimal Approaches Testing:**

- Distances greater than 75m were not attainable due to inconsistent results
- At 75m testing needed to be repeated to obtain reliable results as the spread of data was significant

## *4.8 Conclusion*

The proceeding chapter has summarised and detailed field testing undertaken to satisfy aims and objectives set out in the methodology. Field testing incorporated three separate tests, Oblique Angle, Critical Obstruction, and Minimal Approaches testing. Results obtained from these tests identified that under ideal and controlled conditions, reflectorless measurements can be very accurate and can provide results well within the particular instruments quoted tolerances.

# Chapter 5

# Analysis and Discussion

## *5.1 Introduction*

The following chapter will analyse and discuss results obtained in chapter 4 in greater detail. Field testing results will be evaluated against true EDM distances, comparisons on how instruments performed individually, along with how obstructions can interfere with results obtained.

## *5.2 Oblique Angle Testing*

Primary field testing undertaken in this research project was based on testing total station reflectorless measurements under varying angles of incidence. As shown in chapter 4 instruments utilised for this test included the Trimble S6, Leica Flexline and Topcon GPT9005A.

As illustrated in chapter 3 Oblique Angle testing was undertaken utilising an apparatus that can accurately vary the angle of incidence to the line of sight of the total station in both axes. This apparatus was utilised due to its ability to control the angle of incidence accurately under repeatable situations.

Distances measured in field testing were limited to 200m. This was due to the repeatable nature of the testing and distances greater than 200m would bring in additional sighting errors and the aim of this research was to analyse reflectorless distance measurements and not total stations directly.

Evaluating results obtained for Oblique Angle testing indicate the following characteristics present in all instruments tested.

**Rotating Horizontal Axis Only:**

Having the horizontal axis rotated at 5˚ increments up to 60˚ from normal to the line of sight provided results for all instruments tested that generally align with manufacturer's accuracy specifications. Analysing the results obtained by varying the horizontal angle of incidence provided the following observations:

- Significant face errors are present with the Trimble S6 exhibiting the greatest face error spread
- Generally all instruments tested provided face errors that increase proportionally with distance to the reflector target
- Generally all instrument s tested provide face errors that increase proportionally with increasing the angle of incidence
- Averaging the face left/face right observations provided a meaned data set that agreed with the true distance under most circumstances
- The profile of the meaned data indicated that there is no direct relationship with the length of the distance read to the size of the error (relative to the true distance)

Overall results indicate that distances can be obtained accurately at oblique horizontal angles if both instrument faces are read and ideally if horizontal angles are kept below 40˚ from normal.

**Rotating Vertical Axis Only:**

Having the vertical axis rotated (rotating the top of the reflector target towards the instrument) return significantly different results to the rotations in the horizontal. Interestingly the averaging of the face errors unlike the horizontal rotations did not eliminate error and return a correct distance. At approximately 30˚ from normal all instruments tested exhibited a 'spike' increasing the distance significantly past all manufacturers' quoted tolerances. On analysing this anomaly it may be due to the construction of the testing apparatus obtaining a reflection on itself in the vertical.

Possibilities why the testing apparatus may influence distances obtained when rotating the vertical component is due to the fact that the construction of the test apparatus (refer to figure 3.2, in chapter 3) includes the use of a solid aluminium frame that surrounds the centre target face. This frame rotates with the target face when varying the angle of incidence horizontally and stays flush with the target face, thus not distancing itself from the target surface cancelling out any chance of stray reflections from the framework. When rotated vertically the framework stays rigid and the reflector target face rotates (tips towards the instrument) thus in a sense becoming a separate object from the target face and stray reflections maybe possible. Figure 5.1 below shows how the testing apparatus rotates vertically.

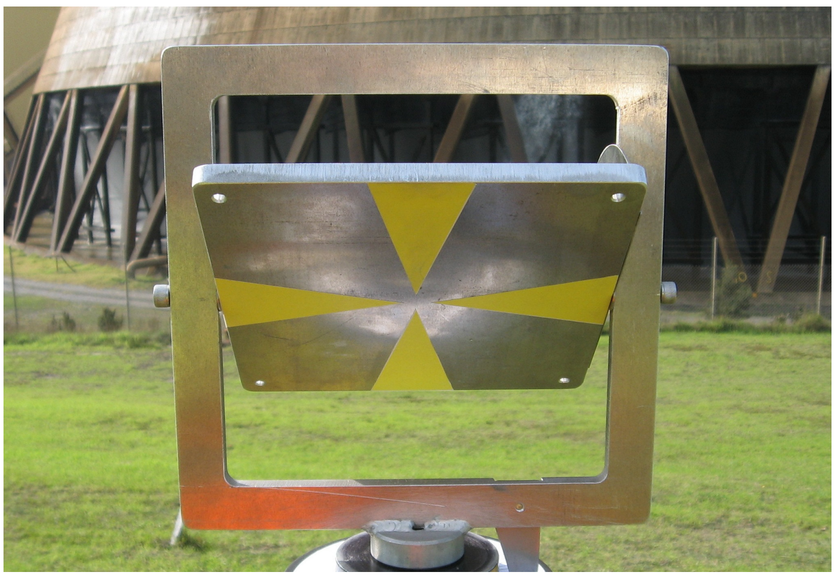


Figure 5.1 Showing testing apparatus rotating vertically

In addition to the target frame potentially influencing the distance measurement, the testing of the target face rotating with the top towards the instrument (refer to Figure 5.1) may also potentially increase the chance of reflections onto the target carrier and tribrach directly below the testing apparatus. Independent testing of rotating the reflector target backwards (the top of the target face dipping away from the instrument) returned similar results to those of rotating towards. This testing was performed at the same stage as rotating the target face towards the instrument but was only used as a quick check, and consequently these results whilst they agreed with rotating towards the instrument cannot be accurately analysed because they were not undertaken over all angles and all distances, but as a gross check.

Unlike rotations in the horizontal, the vertical axis testing resulted in instrument face errors for the Trimble S6 to be significantly less, with the Leica and Topcon instruments increasing their face errors in the vertical axis.

Angles rotated up to 30˚ from normal to the line of sight produced distances for all instruments tested to agree with manufacturer's quoted tolerances, with results at 60˚ from normal also generally agreeing with quoted tolerances.

**Rotating Horizontal and Vertical Axes:**

Results obtained from rotating the horizontal and vertical axes simultaneously exhibit properties similar to both separate axes, with face left/face right spread consistent with horizontal axis and 'spike' data between 30˚ and 50˚ comparable with vertical axis rotation.

This testing aligns most favourably with scenarios found in surveying as geometry of the angle of incidence in most field conditions will inherently by variable. The magnitude of the errors present in the range of results between 30˚ and 50˚ is similar to that of the rotation of the vertical axis only but at a smaller scale.

Prior to testing it would seem obvious that the combination of both axes rotating would result in errors larger than those present in a singular axis rotation, but upon testing this was not the case. Combined axis rotations indicate that the errors associated with varying the angle of incidence returns acceptable results within quoted tolerances for angles up to 30˚ as per individual axis rotations.

Of note the Topcon instrument, which returned consistent results for both the individual axis rotations retuned a distance error that fluctuated significantly past 30˚ from normal. The Topcon non-prism fine mode of reflectorless measurement also would not return a result for distances greater than 100m and the long range mode needed to be used which results in quoted accuracy of ±10mm +10ppm. This quoted tolerance for this instrument is not comparable to either the Trimble S6 or Leica Flexline, both of which have tolerances of ±3mm +2ppm and ±2mm +2ppm respectively.

## *5.3 Critical Obstruction Testing*

Critical Obstruction testing was undertaken solely by the Trimble S6 due to equipment availability.

Analysis of the results obtained from the critical obstruction testing indicate that whilst results obtained for obstruction distances below 100m yield useable data, the shortfalls of the critical obstruction apparatus used for testing effectively make results obtained redundant.

Initial analysis of data obtained from setting the obstruction apparatus at short distances (Below 100m) indicated that a general trend offset of 10mm to the line of sight was attainable before the obstruction started to influence the distance measured. Another trend that was present in the data was that the face error was slightly increasing as distance increased, indicating non-coincidence of the reflectorless laser to the instruments crosshairs.

Once distances over 125m were tested it became apparent that the apparatus utilised for field testing was limited in its ability to 'obstruct' the line of sight and the instrument effectively read 'though' the obstruction. This apparent shortcoming of the field testing highlighted the potential for the shorter distances to have data that may not necessarily indicate the affects of an actual obstruction.

Shortcomings of the testing apparatus include both the size of the obstruction shutter as well as the material utilised in constructing the apparatus. The total station effectively measured through the obstruction to the target on the other side, this may indicate that the shutter was not wide enough to effectively obstruct the reflectorless signal (Refer to Chapter 3 for specifications on the testing apparatus). Additionally to this the construction material utilised for the obstruction shutter was wood, with the reflector target being made of aluminium. Ideally the reflective properties of the obstruction should have been similar to the testing target material for repeatable testing.

Critical Obstruction testing requires more testing to be undertaken, utilising a more suitable obstruction apparatus to fully analysis and evaluate the effects an obstruction has to the line of sight of a reflectorless measurement.

## *5.4 Minimal Approaches Testing*

Minimal Approaches testing was undertaken solely by the Trimble S6 due to equipment availability.

Results obtained indicate that beam divergence is significant to the ability to approach a surface edge, especially at distances greater than 50m. Manufacturer's of reflectorless total stations document the inability of reflectorless observations from locating features like building corners or proximity to building corners or edges due to the effects of beam divergence.

This test was undertaken to try and control the proximity to an exposed surface edge to determine if any relationship with distance and offset to edge was present.

Results indicate at longer distances (over 50m) the repeatability of the measurements obtained from the instrument prove that external sources for instance sun glare, appear to influence the results obtained even when instrument and target are shaded.

Overall Minimal Approaches testing is inconclusive and further testing may be required in an isolated environment free from external influences.

## *5.5 Conclusion*

Results analysed in this chapter indicate that the angle of incidence to the line of sight of reflectorless measurements can have a significant impact onto the distance measured. Oblique Angle testing also identifies that the horizontal and vertical geometry have different effects on the distance obtained and angles greater than 30˚ from normal can generate significant errors in distance, especially if the angle of incidence is altered in the vertical axis.

Instrument face error is also present in field testing results, and combining face left and face right observations is critical in obtaining the correct distance when oblique angles are present in the horizontal axis, especially for the Trimble S6 instrument tested.

Analysing results obtained in the Critical Obstruction testing prove that testing shortfalls, namely testing apparatus influenced field data obtained and further testing is required to fully analysis the impact an obstruction has to the line of sight of a reflectorless observation. In addition to this minimal approaches testing also provided data insufficient to fully analyse and further testing is required in controlling external influences to fully determine the impacts of beam divergence on the returned distance.

# Chapter 6

# Conclusions and Recommendations

## *6.1 Introduction*

This chapter will summarise results obtained from the investigation of this project. Conclusions will be drawn as to the effectiveness of reflectorless technologies to return accurate and repeatable measurements.

Additionally to this recommendations on the suitability of reflectorless measurements will be made, along with areas were further study and testing can be undertaken to build on this research.

## *6.2 Effectiveness of Reflectorless Measurements*

Research and field testing undertaken in this project have identified that reflectorless measurements under controlled conditions can return accurate and repeatable distances. Controlling conditions of angle of incidence, proximity to obstructions and geometry of control stations are inherent problems a surveyor faces day to day. Atmospheric conditions, namely sun glare seems to have a minor influence on reflectorless distance measured even when instrument and target are shaded. All these aspects need to be taken into account when reflectorless observations are required, and having an understanding that the distance obtained can be influenced by external influences should iterate the need for independent checking of all field work, especially distances obtained by reflectorless means.

## 6.3 Recommendations

From the investigation of this project, recommendations have been drawn to identify best practice methods for obtaining accurate and repeatable reflectorless distance measurements. The following procedures should be addressed to help mitigate any discrepancy that may arise in reflectorless observations:

- Always where possible perform face left and face right observations to mitigate any collimation and sighting errors inherent in the reflectorless measurement, and also the total station itself
- Always shade the instrument when accurate reflectorless observations are required
- Minimise the angle of incidence to the surface of the required object where possible, and angles greater than 30˚ from normal should be avoided
- Contrasting conditions due to sun glare can have an influence on the reflective properties of the surface measured and minimising these conditions is advisable
- If required surfaces need to be located at angles of incidence greater than 30˚, the data obtained should be held with less certainty, and any independent checks should be performed if possible
- Proximity to surface edges is significantly affected by beam divergence and instrument specifications as to the size of the reflectorless beam need to be taken into account when trying to obtain extremities of structures
- Any visual obstruction to the line of sight needs to be addressed before assuming it will not impact the distance measured

## 6.4 Further Research

Field testing undertaken in this research project was limited due to time and equipment availability and further testing could be undertaken to expand on the results obtained.

Significant testing has been undertaken in determining the impacts the angle of incidence has on the distance measured. Results found when varying the vertical axis indicate that all instruments tested return unacceptable results between the angle range of 30˚ and 60˚ where in the horizontal axis these results yield a much more acceptable result. This may indicate that the apparatus utilised in this testing influenced results obtained by generating stray reflections from the surround frame of the target. Further research could be undertaken to design and construct an apparatus that does not have a supporting frame to potentially interfere with the results, and further testing of this vertical axis can be performed to determine if apparatus used in testing influenced results obtained.

Oblique angle testing was initially going to include the use of different reflective surfaces for testing to determine if reflective properties had an effect on angle of incidence measurements. Further testing including different surfaces (Material, Roughness, Colour, etc.) could be undertaken to further analyse the geometry of angle of incidence and the impacts of reflective properties.

Results obtained with critical obstruction testing have proved insufficient and further work is required to determine the effects an obstruction has on the line of sight of a reflectorless measurement. Construction of a critical obstruction shutter that is of sufficient size and having the ability to change the reflective properties of the shutter may yield results consistent and repeatable for analysis.

Minimal approaches testing, whilst generating results sufficient to analyse, further testing could be undertaken to actively control atmospheric conditions by testing in a control environment for example indoors, where sun glare can be controlled. This may give the ability to test longer distances to determine minimal approach limitations and relationships.

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# Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

**ENG4111/4112 Research Project**

**PROJECT SPECIFICATION**

FOR: *Alan Hosking*

TOPIC: INVESTIGATION OF THE EFFECTIVENESS OF REFLECTORLESS TECHNOLOGIES ON STRUCTURAL

SURVEILLANCE MONITORING

SUPERVISOR: Mr. Glenn Campbell

SPONSORHSIP: SMEC Urban Pty Ltd.

PROJECT AIM: The aim of this project is to determine if reflector-less technology can provide accurate and repeatable distance measurements that can be utilised in structural surveillance roles solely, or in conjunction with conventional distance measurements.

PROGRAMME: Issue A, 6th March 2009

1. Research literature on reflector-less technologies utilized by total station manufacturers and their direct uses in movement monitoring.
2. Design an apparatus and field setup that can perform a variety of field measurements.
3. Calibrate testing procedures with conventional distance measurements to determine 'true' baseline distances.
4. Perform required field testing of the selected instrument
5. Analyse results obtained and compare to baseline readings
6. Submit an academic dissertation on the research.

As time permits:

7. Test different instrument of same make to establish repeatability of measurements and quality of testing procedures.
8. Test other reflector-less instruments to compare not only on the distances obtained, but the flexibility, effectiveness and limitations of each individual instrument.

AGREED (student) (supervisor)

____________________________ ____________________________

Date: / / 2009 Date: / / 2009

Assistant Examiner: ____________________________

# Appendix B – Trimble S6 Specification Datasheet


**KEY FEATURES**

MultiTrack™ technology offers the choice between passive and active tracking

MagDrive™ servo technology gives incredibly fast, smooth performance

SurePoint™ accuracy assurance automatically corrects instrument pointing

Upgradable from servo to Autolock® function to Robotic

Integrate GPS technology with GPS Search/GeoLock and the Trimble® I.S. Rover

100% cable-free instrument and Robotic rover

### MAGDRIVE SERVO TECHNOLOGY

The Trimble® S6 Total Station redefines instrument performance with unsurpassed integration of servos and angle sensors. The instrument's advanced error compensation provides fast, accurate measurements every time. With the smooth, silent servo motors of MagDrive servo technology, the Trimble S6 offers exceptional speed and accuracy.

### CHOOSE TARGET MODE: ACTIVE OR PASSIVE

The Trimble S6 will lock and track a wide variety of targets and conventional prisms to exceptional range. Additionally, surveyors can choose between passive and active tracking with the new Trimble® MultiTrack™ Target. Its flexibility expands opportunities in all surveying applications.

**Active Tracking with Target ID: Always find your correct target**

With the Trimble MultiTrack Target you will always find and lock to the correct target. Nearby reflective surfaces, including road signs, cars, warning vests and other on-site prisms, will not disrupt your surveys. Active tracking also offers longer range, and the 360 degree active LED rings ensure that your correct target is tracked from any angle.

**GPS Search target location**

GPS Search is a feature in Trimble Survey Controller™ field software that works with the Trimble MultiTrack Target to maximise Trimble S6 Total Station speed. GPS Search uses GPS positioning at the robotic rover to locate a prism anywhere, anytime, so that with a Trimble® I.S. Rover, or even a GPS card or Bluetooth® receiver, the Trimble S6 can lock onto the prism in just a few seconds.

### HIGH CAPACITY INTERNAL BATTERY WITH INTELLIGENT SYSTEM CHARGER

The Trimble S6 runs for six hours in Robotic mode on one internal lithium-ion battery, with no cables needed. The battery is intelligent, so you can quickly check how much power each battery contains.

With three batteries in the multi-battery holder, you'll spare yourself the task of changing batteries during your work day. Recharge your Trimble S6 and GPS system batteries in the same charger.

### SUREPOINT ACCURACY ASSURANCE

The Trimble S6 Total Station aims and stays ... through windy weather, vibrations, handling, and sinkage, by actively correcting unwanted movement. This technology, Trimble's unique SurePoint accuracy assurance, ensures accurate pointing and measurement every time. Reduce aiming error and avoid costly re-measurement for supreme confidence in your results.

### DIRECT REFLEX TECHNOLOGY

Direct Reflex (DR) technology from Trimble enables measurement without a prism even to exceptional distances. Hard-to-reach or unsafe targets are no obstacle for the Trimble S6. Measure quickly and safely without compromising accuracy.

### COAXIAL OPTICS, EDM, TRACKER, LASER POINTER

Whether measuring in Face 1 or Face 2, or aiming manually or with the tracker, with Trimble S6 what you see is what you measure. The Trimble S6 optics by Carl Zeiss are fully coaxial for full measurement confidence.

### INTEGRATED SURVEYING

Only a Trimble total solution offers field-proven optical and GPS integration from field to office. The Trimble controller of your choice connects without cables to your Trimble S6 or GPS system. It can be switched between sensors, collecting all data into one job file for seamless data transfer. Simply use the sensor that best suits your environment or job requirement.

# TRIMBLE S6 DR300+

## PERFORMANCE

| | |
|---|---|
| **Angle measurement** | |
| Accuracy (Standard deviation based on DIN 18723) | 2" (0.5 mgon) 3" (1.0 mgon), or 5" (1.5 mgon) |
| **Angle reading (least count)** | |
| Standard | 1" (0.1 mgon) |
| Tracking | 2" (0.5 mgon) |
| Averaged observations | 0.1" (0.01 mgon) |
| **Automatic level compensator** | |
| Type | Centered dual-axis |
| Accuracy | 0.5" (0.15 mgon) |
| Range | ±6' (±100 mgon) |
| **Distance measurement** | |
| Accuracy (S. Dev.) | |
| Prism mode | |
| Standard | ±(3 mm + 2 ppm) ±(0.01 ft + 2 ppm) |
| Tracking | ±(10 mm + 2 ppm) ±(0.032 ft + 2 ppm) |
| DR mode | |
| Standard measurement | ±(3 mm + 2 ppm) ±(0.01 ft + 2 ppm) |
| Tracking | ±(10 mm + 2 ppm) ±(0.032 ft + 2 ppm) |
| >300 m (656 ft) | |
| Standard measurement | ±(5 mm + 2 ppm) ±(0.016 ft + 2 ppm) |
| **Measuring time** | |
| Prism mode | |
| Standard | 1.2 s |
| Tracking | 0.4 s |
| Averaged observations[1] | 1.2 s per measurement |
| DR mode | |
| Standard | 1–5 s |
| Tracking | 0.4 s |
| Averaged observations[1] | 1–5 s per measurement |
| **Range (under standard clear conditions[2,3])** | |
| Prism mode | |
| 1 prism | 2500 m (8202 ft) |
| 1 prism Long Range mode | 5500 m (18,044 ft) (max. range) |
| 3 prism | 3500 m (11,482 ft) |
| 3 prism Long Range mode | 5500 m (18,044 ft) (max. range) |
| Shortest possible range | 0.2 m (0.65 ft) |
| DR mode (typically) | |
| Kodak Gray Card (18% reflective)[4] | >300 m (984 ft) |
| Kodak Gray Card (90% reflective)[4] | >800 m (2625 ft) |
| Concrete | 300–400 m (984–1312 ft) |
| Wood construction | 200–400 m (656–1312 ft) |
| Metal construction | 200–250 m (656–820 ft) |
| Light rock | 200–300 m (656–984 ft) |
| Dark rock | 150–200 m (492–656 ft) |
| Reflective foil 20 mm | 800 m (2,625 ft) |
| Reflective foil 60 mm | 1600 m (5,249 ft) |
| Shortest possible range | 2 m (6.56 ft) |

## EDM SPECIFICATIONS

| | |
|---|---|
| Light source | Pulsed laserdiode 870 nm, Laser class 1 |
| Laser pointer coaxial (standard) | Laser class 2 |
| **Beam divergence** | |
| Horizontal | 4 cm/100 m (0.13 ft/328 ft) |
| Vertical | 8 cm/100 m (0.26 ft/328 ft) |
| Atmospheric correction | –130 ppm to 160 ppm continuously |

## TRIMBLE S6 HIGH PRECISION EDM WITH DR

### PERFORMANCE

| | |
|---|---|
| Angle measurement | |
| Accuracy (Standard deviation based on DIN 18723) | 1" (0.3 mgon) |
| Angle reading (least count) | |
| Standard | 1" (0.1 mgon) |
| Tracking | 2" (0.5 mgon) |
| Averaged observations | 0.1" (0.01 mgon) |
| Automatic level compensator | |
| Type | Centered dual-axis |
| Accuracy | 0.5" (0.15 mgon) |
| Range | ±6' (±100 mgon) |
| Distance measurement | |
| Accuracy (S. Dev.) | |
| Prism mode | |
| Standard | ±(1 mm + 1 ppm) ±(0.003 ft + 1 ppm) |
| Tracking | ±(5 mm + 2 ppm) ±(0.016 ft + 2 ppm) |
| DR mode | |
| Standard measurement | ±(3 mm + 2 ppm) ±(0.01 ft + 2 ppm) |
| Tracking | ±(10 mm + 2 ppm) ±(0.032 ft + 2 ppm) |
| Measuring time | |
| Prism mode | |
| Standard | 2 s |
| Tracking | 0.4 s |
| Averaged observations[1] | 2 s per measurement |
| DR mode | |
| Standard | 3–15 s |
| Tracking | 0.4 s |
| Averaged observations[1] | 3–15 s per measurement |
| Range (under standard clear conditions[2,3]) | |
| Prism mode | |
| 1 prism | 3000 m (9,800 ft) |
| 1 prism Long Range mode | 5000 m (16,400 ft) |
| 3 prism | 5000 m (16,400 ft) |
| 3 prism Long Range mode | 7000 m (23,000 ft) |
| Shortest possible range | 1.5 m (4.9 ft) |
| DR mode (typically) | |
| Kodak Gray Card (18% reflective)[4] | >120 m (394 ft) |
| Kodak Gray Card (90% reflective)[4] | >150 m (492 ft) |
| Concrete | 80–150 m (262–492 ft) |
| Wood construction | 80–180 m (262–590 ft) |
| Metal construction | 80–120 m (262–394 ft) |
| Light rock | 80–120 m (262–394 ft) |
| Dark rock | 60–80 m (197–262 ft) |
| Reflective foil 20 mm | 600 m (1,968 ft) |
| Reflective foil 60 mm | 1200 m (3,937 ft) |
| Shortest possible range | 1.5 m (4.9 ft) |

### EDM SPECIFICATIONS

| | |
|---|---|
| Light source | Laserdiode 660 nm; Laser class 1 in Prism mode<br>Laser class 2 in DR mode |
| Laser pointer coaxial (standard) | Laser class 2 |
| Beam divergence Prism mode | |
| Horizontal | 4 cm/100 m (0.13 ft/328 ft) |
| Vertical | 4 cm/100 m (0.13 ft/328 ft) |
| Beam divergence DR mode | |
| Horizontal | 2 cm/50 m (0.066 ft/164 ft) |
| Vertical | 2 cm/50 m (0.066 ft/164 ft) |
| Atmospheric correction | –130 ppm to 160 ppm continuously |

# GENERAL SPECIFICATIONS

## GENERAL SPECIFICATIONS

| | |
|---|---|
| **Leveling** | |
| Circular level in tribrach | 8'/2 mm (8'/0.007 ft) |
| Electronic 2-axis level in the LC-display with a resolution of | 0.3" (0.1 mgon) |
| Servo system | MagDrive servo technology, integrated servo/angle sensor electromagnetic direct drive |
| Rotation speed | 115 degrees/sec (128 gon/sec) |
| Rotation time Face 1 to Face 2 | 3.2 sec |
| Positioning speed 180 degrees (200 gon) | 3.2 sec |
| Clamps and slow motions | Servo-driven, endless fine adjustment |
| **Centering** | |
| Centering system | Trimble 3-pin |
| Optical plummet | Built-in optical plummet |
| Magnification/shortest focusing distance | 2.3x/0.5 m–infinity (1.6 ft–infinity) |
| **Telescope** | |
| Magnification | 30x |
| Aperture | 40 mm (1.57 in) |
| Field of view at 100 m (328 ft) | 2.6 m at 100 m (8.5 ft at 328 ft) |
| Shortest focusing distance | 1.5 m (4.92 ft)–infinity |
| Illuminated crosshair | Variable (10 steps) |
| Tracklight built in | Standard |
| Operating temperature | –20 °C to +50 °C (–4 °F to +122 °F) |
| Dust and water proofing | IP55 |
| **Power supply** | |
| Internal battery | Rechargeable Li-Ion battery 11.1 V, 4.4 Ah |
| Operating time[6] | |
| One internal battery | Approx. 6 hours |
| Three internal batteries in multi-battery adapter | Approx. 18 hours |
| Robotic holder with one internal battery | 12 hours |
| **Weight** | |
| Instrument (servo/Autolock) | 5.15 kg (11.35 lb) |
| Instrument (Robotic) | 5.25 kg (11.57 lb) |
| Trimble CU controller | 0.4 kg (0.88 lb) |
| Tribrach | 0.7 kg (1.54 lb) |
| Internal battery | 0.35 kg (0.77 lb) |
| Trunnion axis height | 196 mm (7.71 in) |
| Communication | USB, Serial, Bluetooth®[7] |

## ROBOTIC SURVEYING

| | |
|---|---|
| **Autolock and Robotic Range[3]** | |
| Passive prisms | 500–700 m (1,640–2,297 ft) |
| Trimble MultiTrack Target | 800 m (2,625 ft) |
| **Autolock pointing precision at 200 m (656 ft) (Standard deviation)[4]** | |
| Passive prisms | <2 mm (0.007 ft) |
| Trimble MultiTrack Target | <2 mm (0.007 ft) |
| Shortest search distance | 0.2 m (.65 ft) |
| **Angle reading (least count)** | |
| Standard | 1" (0.1 mgon) |
| Tracking | 2" (0.5 mgon) |
| Averaged observations | 0.1" (0.01 mgon) |
| Type of radio internal/external | 2.4 GHz frequency-hopping, spread-sprectrum radios |
| Search time (typical)[8] | 2-10 s |

## GPS SEARCH/GEOLOCK WITH THE TRIMBLE MULTITRACK TARGET

| | |
|---|---|
| GPS Search/GeoLock | 360 degrees (400 gon) or defined horizontal and vertical search window |
| Solution acquisition time | 15–30 seconds[9] |
| Target re-acquisition time | <3 seconds |
| Range | Autolock & Robotic range limits |

## TRIMBLE I.S. ROVER

(Integrated Trimble GPS/GNSS and Trimble S6 robotic rover)

| | |
|---|---|
| Trimble S6 Robotic Total Station | |
| Trimble GPS/GNSS System | Any Trimble R8, Trimble R6, or 5800 system |
| Controller | Trimble TSC2 or Trimble CU |

A Trimble I.S. Rover comprising the Trimble R8 GNSS with the Trimble MultiTrack Target.

1. Repeats for defined number of measurements up to 99.
2. Standard clear: no haze, overcast or moderate sunlight with very light heat shimmer.
3. Range and accuracy depend on atmospheric conditions, size of prisms and background radiation.
4. Kodak Gray Card, catalog number E1527795.
5. Limited temperature range for high-precision ±(1 mm + 1 ppm): 0 °C to 40 °C (32 °F to 104 °F).
6. The capacity in –20 °C (–4 °F) is 75% of the capacity at +20 °C (68 °F).
7. Bluetooth type approvals are country specific. Contact your local Trimble Authorized Distribution Partner for more information.
8. Dependent on selected size of search window.
9. Solution acquisition time is dependent upon solution geometry and GPS position quality.



TRIMBLE AUTHORIZED DISTRIBUTION PARTNER

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www.trimble.com

Source: Trimble.com

# Appendix C – Leica Flexline Specification Datasheet

## Leica FlexLine
TS09 Total Station

### Leica FlexLine TS09 Total Station – Performance guaranteed

A true performance orientated Total Station that continually delivers regardless how demanding the task may be. Designed especially for mid-to-high accuracy applications. By including all FlexLine features from removable USB memory, *Bluetooth®* wireless technology, Emitting Guide Light to a complete range of application software, your TS09 guarantees maximum performance.

Whether you measure to prisms, or prefer direct measurements to objects, the choice is always yours. A selection of EDM options delivers exactly what you need.

With a FlexLine TS09 Total Station you have complete confidence of total performance for every application.

*Bluetooth®*, USB, Keyboard
- *Bluetooth®* cable-free connection
- USB memory stick for flexible data transfer
- mini-USB for fast data transfer
- Alpha-numerical keyboard for rapid entry

Electronic Distance Measurement
- Prism: 3500 m, 1 mm+1.5 ppm accuracy
- Non-Prism: 30 m FlexPoint
- Non-Prism: >400 m PinPoint – Power
- Non-Prism: >1000 m PinPoint – Ultra

Angular Accuracy
- 1", 2" or 3" angular accuracy
- Quadruple axis compensation to guarantee accurate and reliable angle measurement

- when it has to be **right**

Leica Geosystems

# Leica FlexLine TS09 Total Station –
## Performance guaranteed

| | | |
|---|---|---|
| **Angle Measurement (Hz, V)** | | |
| **Accuracy (Standard deviation ISO-17123-3)** | 1" (0.3 mgon), 2" (0.6 mgon), 3" (1 mgon) | optional |
| **Method** | Absolute, continuous, diametrical | |
| **Display resolution** | 0.1" / 0.1 mgon / 0.01 mil | |
| **Compensation** | Quadruple axis compensation (Setting On, Off) | |
| **Compensator Setting accuracy** | 0.5", 0.5", 1" | |
| **Distance Measurement with Reflector** | | |
| **Range Round prism GPR1** | 3'500 m | |
| **Range Reflective tape (60 mm x 60 mm)** | 250 m | |
| **Accuracy / Measurement time (Standard deviation ISO-17123-4)** | Standard: 1 mm+1.5 ppm / typ. 2.4 s, Fast: 3 mm+2 ppm / typ. 0.8 s, Tracking: 3 mm+2 ppm / typ. <0.15 s | |
| **Distance Measurement without Reflector** | | |
| **Range (90% reflective)** | | |
| **FlexPoint** | 30 m | |
| **PinPoint – Power** | >400 m | optional |
| **PinPoint – Ultra** | >1000 m | optional |
| **Accuracy / Measurement time (Standard deviation ISO-17123-4)** | 2 mm+2 ppm² / typ. 3 s | |
| **Laser dot size** | At 30 m: approx. 7 mm x 10 mm, At 50 m: approx. 8 mm x 20 mm | |
| **Data storage / Communication** | | |
| **Extended Internal memory** | Max.: 100'000 fixpoints, Max.: 60'000 measurements | |
| **USB memory stick** | 1 Gigabyte, Transfer time 1'000 points/second | |
| **Interfaces** | Serial (Baudrate 1'200 to 115'200)<br>USB Type A and mini B, *Bluetooth*® Wireless | |
| **Data formats** | GSI / DXF / LandXML / user definable ASCII formats | |
| **Emitting Guide Light** | | |
| **Working Range (average atmospheric conditions)** | 5 m – 150 m | |
| **Positioning accuracy** | 5 cm at 100 m | |
| **General** | | |
| **Telescope** | | |
| **Magnification** | 30 x | |
| **Resolving power** | 3" | |
| **Field of view** | 1° 30' (1.66 gon) / 2.7 m at 100 m | |
| **Focusing range** | 1.7 m to infinity | |
| **Reticle** | Illuminated, 5 brightness levels | |
| **Keyboard and Display** | | |
| **Display** | Graphics, 160 x 280 pixels, illuminated, 5 brightness levels | |
| **Keyboard** | Alpha-numerical keyboard<br>Second keyboard | |
| **Operating System** | | |
| **Windows CE** | 5.0 Core | |
| **Laserplummet** | | |
| **Type** | Laser point, 5 brightness levels | |
| **Centering accuracy** | 1.5 mm at 1.5 m instrument height | |
| **Battery** | | |
| **Type** | Lithium-Ion | |
| **Operating time** | approx. 20 hours¹ | |
| **Weight** | | |
| **Total station including GEB211 and tribrach** | 5.6 kg | |
| **Environmental specifications** | | |
| **Temperature range (operation)** | -20° C to +50° C (-4° F to +122° F)<br>Arctic Version -35° C to 50° C (-31° F to +122° F) | optional |
| **Dust & splash proof (IEC 60529)** | IP55 | |
| **Humidity** | 95%, non condensing | |
| **FlexField Onboard Software** | | |
| **Application programs** | Topography (Orientation & Surveying), Stake Out, Resection, Height Transfer, Construction, Area (Plan & Surface), Volume calculation, Tie Distance (MLM), Remote Height, Hidden Point, Offset, Reference Line, Reference Arc, Reference Plane, COGO, Road 2D, Roadworks 3D, TraversePRO | |

¹ Single Measurement every 30 seconds by 25° C. Battery time may be shorter if battery is not new.
² Range >500 m 6 mm+2 ppm

SWISS Technology by Leica Geosystems

TQM ISO 9001 / ISO 14001

**Total Quality Management – our commitment to total customer satisfaction.**

**Guide light (EGL):** LED class 1 in accordance with IEC 60825-1 resp. EN 60825-1

**Distance meter:** (PinPoint R400 / R1000): Laser class 3R in accordance with IEC 60825-1 resp. EN 60825-1

**Laser plummet:** Laser class 2 in accordance with IEC 60825-1 resp. EN 60825-1

**Distance meter:** (Prism Mode) Laser class 1 in accordance with IEC 60825-1 resp. EN 60825-1



Leica Geosystems AG
Heerbrugg, Switzerland
www.leica-geosystems.com

- when it has to be right

Leica Geosystems

**Source: Leica**-geosystems**.com**

# Appendix D – Topcon GPT9005A Specification Datasheet

**Faster, Smarter, Farther, Stronger - That's what the new 9-Series promises… and that's what Topcon delivers.**

Jobsite demands are constantly changing. Adopting and utilizing the very best technology innovations for your business enables you to increase your productivity and profitability like never before.

Robotic instrument technology and the significant performance advantages it can offer have changed the way topography and layout tasks are completed worldwide. Through Topcon's leadership and experience in optical instrumentation that spans more than 70 years, we have the know-how to design and build the very best Robotics systems available. Topcon is now on its 8th generation of robotic instrument technology.

With a modern, cable-free design, the 9-Series offers the most advanced robotic technology available. From Topcon, the world leader in optical total station technology. Our 9-Series robotic system features sophisticated technology unique to Topcon – our one-touch quick-lock feature that set the standard in Robotic target acquisition has taken another step forward, with X-TRAC 7. A superior technology solution for strong tracking and quick re-acquisition in challenging environments.

Available in 1, 3, and 5 second angle accuracies, you can select the instrument that best fits your requirements. The GTS-900A is prism required measurement technology. All GPT-9000A Series robotic systems offer reflectorless measurement superior to any other instrument available – capable of precision measurements at a mind-boggling 6,500 ft. (2,000m)!

Topcon's new 9-Series Robotic Systems: Superior Technology – Superior Design – Superior Performance and Value: only from Topcon, the World Leader in Precision Measurement Technology.

**9-SERIES**
Robotic Total Station System

TOPCON

## The new Topcon 9-Series combines advanced technology and modern design innovations.


### X-TRAC 7 Technology

- Strong Prism Tracking
- Fast Tracking
- Fast and Accurate Quick-Lock
- Intelligent RC-3 Power Regulation

### Advanced System Design

- Completely Cable-free instrument and rover
- Integrated graphical Windows color touch screen interface
- New, ultra-fast robotic servo technology

### Integrated Radio System

- 2.4 GHz Interference free Spread Spectrum Radio
- Integrated into side panel of the instrument
- Optional, radio module RS-1 for the FC-200 and FC-2500

### FC-200 or FC-2500 Field Controller

**FC-200:**

- Integrated Bluetooth® wireless technology
- 520 MHz Intel XScale® processor
- Optional RS-1 radio module

**FC-2500:**

- Integrated Bluetooth® wireless technology, WiFi
- Fast 624 MHz processor
- 256MB SDRAM, 2GB Storage
- Optional RS-1 radio module

### Completely cable-free system components:

- GPT-9000A/GTS-900A Robotic Instrument
- FC-200 or FC-2500 Graphical Field Controller
- RS-1 Radio System
- Lightweight 360° prism
- TopSURV 7 field controller software

## The Leader in Positioning Technology...

Topcon offers positioning products that deliver unparalleled site-wide performance and integration. Topcon's history of technological advances and our reputation for superior reliability means there's no other company positioned to provide you with a better "Total Positioning Solution."

From survey to inspection, Topcon dealers throughout the world provide innovative technology that gives surveyors, civil engineers, contractors, equipment owners, and operators the competitive edge by addressing such critical issues as increasing profits, quality craftsmanship, improving productivity, lowering operating costs, and enhancing jobsite safety.

Full positioning integration field-to-finish: That's the goal of Topcon. When it's time for you to step up to the next level, it's time to turn to Topcon.

## The Leader in Customer Satisfaction...

To ensure that your Topcon product maintains peak performance, your local Topcon dealer offers factory trained and certified service technicians. If service isn't available in your area, our factory offers a repair and return policy second to none.

### Offices Worldwide


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TOPCON
It's time.

**Topcon Positioning Systems, Inc.**
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**Specifications subject to change without notice**




P/N: 7010-2014 Rev. A Printed in U.S.A. 1/09


## Specifications

| | 9001A/901A | 9003A/903A | 9005A/905A |
|---|---|---|---|
| **ANGLE MEASUREMENT** | | | |
| Method | | Absolute Reading | |
| Horizontal | | 2 sides | |
| Vertical | | 2 sides | |
| Minimum Reading | 0.5"/1" (0.1/0.5mgon) | 1" / 5" (0.2/1mgon) | 1" / 5" (0.2/1mgon) |
| Accuracy | 1" (0.3mgon) | 3" (1mgon) | 5" (1.5mgon) |
| Tilt Correction | | Dual Axis | |
| Compensating Range | | ±6' | |
| **DISTANCE MEASUREMENT** | | | |
| Prism Mode | | | |
| 1 prism | | 9,840' (3,000m) | |
| 3 prism | | 13,120' (4,000m) | |
| 9 prism | | 16,400' (5,000m) | |
| Accuracy | | | |
| Fine 0.2mm / 1mm | | ±(2mm+2ppmxD*) m.s.e. | |
| Coarse 1mm | | ±(7mm+2ppmxD*) m.s.e. | |
| Coarse 10mm | | ±(10mm+2ppmxD*) m.s.e. | |
| Non-Prism Mode *(GPT-9000A Series only)* | | 4.9' - 820' (1.5m - 250m) | |
| NP Accuracy | | | |
| Fine 0.2mm / 1mm | | ±(5mm) m.s.e. | |
| Coarse 1mm / 10mm | | ±(10mm) m.s.e. | |
| Non-Prism Long Mode *(GPT-9000A Series only)* | | 16.4' - 6,500' (5.0m - 2,000m) | |
| NP Long Mode Accuracy | | | |
| Fine 1mm | | ±(10mm+10ppmxD*) m.s.e. | |
| Coarse 5mm | | ±(20mm+10ppmxD*) m.s.e. | |
| Coarse 10mm | | ±(100mm) m.s.e. | |
| **USER INTERFACE** | | | |
| OS | | Microsoft Windows® CE.NET 4.2 | |
| Processor | | Intel PXA255 400Mhz | |
| Screen | | Full Color Touch-screen | |

Topcon Positioning Systems is the worldwide leading developer and manufacturer of precision positioning equipment and offers the widest selection of innovative precision GPS systems, laser, optical surveying, and machine control products.

From open-field construction projects to isolated surveying sites and from rolling farmland to inner city utility projects, Topcon Positioning Systems provides innovative technology that provides a decidedly competitive edge to end-users.

The recognized innovative trend-setter in its industry, Topcon has focused on developing an array of integrated positioning and automation technologies to meet the constantly changing demands facing construction, surveying, agriculture, utilities and law enforcement industries worldwide.

Your local Authorized Topcon dealer is:



Source: Topcon.com.au

# Appendix E – Trimble S6 Calibration Certificate



**Job Identification:**Unit 4 090709ah

## EDM Calibration Certificate

This report has been generated by program Baseline Version 5.5.0.3, developed by the Western Australian Land Information Agency.

**Use of this application elsewhere should rely on baseline distances certified by the relevant authority.**

**Observation Date:** 9/07/2009
**Instrument Operator:** AH

**Computation Date:** 16/07/2009
**Computation Time:** 11:30:36 AM

### Equipment Details

**Instrument Owner:** SMEC Urban
**Owner Address:**
**EDM Instrument Make:** Trimble
**EDM Instrument Model:** S6 High Precision
**EDM Serial Number:** 92720408

**Reflector Make:** Wild
**Reflector Model:** GPR 1P
**Serial Number:** 000
**Reflector Constant:** -34 mm

### Baseline Details

**Name** Loy Yang
**Authority:** Geodetic Survey - SGV
**Authority Address:**Level 17, 570 Bourke Street, Melbourne 3000

**Location:** Bartons Lane, Loy Yang
**Last calibration Date:** 6/11/2008

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

The baseline distances should be traceable to standards specified by the Testing Authority.

### Instrument Correction (IC) in mm (to be added to the instrument reading)

**IC = 0.40 - 0.00386 D**

Where D = distance in metres

The reflector constant has been entered into the instrument

**CYCLIC ERRORS ARE INSIGNIFICANT**

| Calibration Parameters | Value | Uncertainty(95%) |
|---|---|---|
| Index | 0.40 mm | 0.81 mm |
| Scale | -3.86 ppm | 2.24 ppm |

The instrument correction has been determined from measurements in the range of 67 to 800 metres

**Job Identification:** Unit 4 090709ah

# EDM Calibration Certificate

This report has been generated by program Baseline Version 5.5.0.3, developed by the Western Australian Land Information Agency.

**Use of this application elsewhere should rely on baseline distances certified by the relevant authority.**

## Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is 4.00 mm + 20.00 ppm as described in terms of Recommendation No.8 of the Working Party of the National Standards Commision on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95 % confidence level. A coverage factor of 2 has been used for the uncertainty computations.

**Uncertainty of instrument correction : 0.81 mm + 2.24 ppm**

| Distance (metres) | Instrument Uncertainty (mm) | Minimum Standard (mm) | Comparison Test |
|---|---|---|---|
| 50 | 0.92 | 5.00 | PASS |
| 100 | 1.03 | 6.00 | PASS |
| 200 | 1.26 | 8.00 | PASS |
| 400 | 1.71 | 12.00 | PASS |
| 600 | 2.15 | 16.00 | PASS |
| 800 | 2.60 | 20.00 | PASS |

This instrument satisfies the National Standards Commission standards.

## First Velocity Correction (Atmospheric Correction)

$$\text{Correction} = \left( 280.00 - \frac{80.66\ P}{(273.15 + Td)} + \frac{11.27\ e}{(273.15 + Td)} \right) .\ \text{distance}/1000000$$

Where Td = Dry Temperature(Celsius), P = Barometric pressure(hectapascals)
e = partial Vapour Pressure (hectapascals)

The first velocity correction is based on a velocity of light of 299792458.00 m/s and on the refractive index formulae recommended by the International Association of Geodesy in 1999.

To obtain a regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to Work Instructions provided by the Testing Authority.

| | |
|---|---|
| Data entry by: ALAN HOSKING | Results checked by: |
| Position: SURVEYOR | Position: |
| Signature: [signature] | Approved Signatory: |
| Date: 16/7/09 | Date: |


16/07/2009 11:33:29 AM