One Way System Calibration Techniques

Toby Shoobridge, David Benham
NERC Space Geodesy Facility
Herstmonceux, UK
Tooo@nerc.ac.uk

Abstract

It has always been necessary to make a two-way calibration to account for the delays in an SLR system. This is done by comparing the ranged measurement to a ground target of a known distance. With the current work in T2L2 and LRO it is now in addition necessary to provide as accurate an epoch as possible for the pulse as it passes the System Reference Point. Determining a one-way calibration for the transmit side delay proves difficult as the current two-way method cannot simply be divided so a new method is required. Our ongoing work to determine the transmit-side delay is presented. This includes measurements of the laser path from the start diode to the system reference point and the electronic delays in cables and equipment from the start diode to the epoch timer. The distance taken by the laser pulse path through the coudé path was measured using three techniques. The first used a laser rangefinder, more commonly used in building surveying. The second method was to make time-of-flight measurements of timed Hz laser pulses passing through the coudé and the third method used a combination of the telescope drawings and physical measurement. The laser rangefinder initially seems to have given the most repeatable and accurate result given that the manufacturers specify an accuracy of at worst 1.5mm over a 30m distance. The other independent methods will provide a good comparative check on this. The largest error contribution to the final result comes from the physical measurements made in the laser bed.

Aim and Necessity

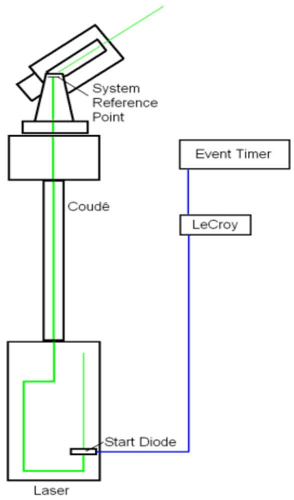
The aim is to measure the delay in the various components of the SLR two-way calibration in order to understand the Transmit-side delay.

It has always been necessary to make a calibration to account for the two-way delays in an SLR system. Now the proposed work in T2L2 and LRO requires as accurate an epoch as possible for the laser pulse as it passes the system reference point. This report describes the technique and results that have been developed to estimate the components of the various delays necessary to achieve this epoch correction at the level of a few ns.

Current System Calibration Technique

The standard range calibration value is determined as the sum of the Transmit and Receive-side delays by ranging to a fixed ground target at a known distance. Unfortunately this result cannot simply be separated into the parts we are interested in.

Transmit-side Delay



The Transmit-side delay is the sum of the times taken for the laser pulse to travel from the Start Diode to the System Reference Point and the propagation time for the Start Diode electronic pulse to travel through cables and electronic equipment to trigger the Event Timer. Described here are estimates of both these elements.

1. Measuring the Laser Path from the Start Diode to the System Reference Point

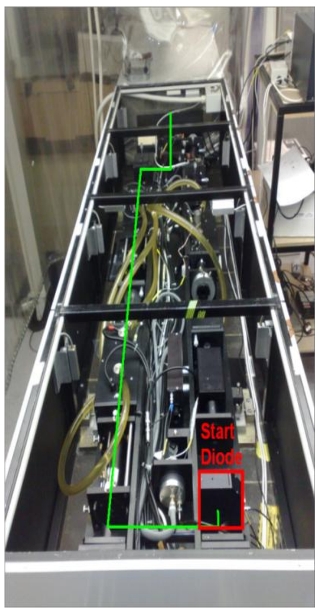
This was measured as two components, those being the optical delays in the laser bed (including the propagation effects of optics) and the Coudé path length.

a) Laser Bed

Physical Measurements were made with a rule along the Laser Path. The Effective increase in Path Length due to the Refractive Indices of Laser components was also calculated.

Addition to Effective Air Path for Various Refractive Indices												
Description	thick (mm)	er (mm)	ang (deg)	path (mm)	er path (mm)	ref index	er ref ind	lighttime (ps)	er time (ps)	eff airpath(mm)	er airp (mm)
45 deg Quarts Rotator Polarizer	4	0.05	0	4.000	0.050	1.5067	0.0001	20.089	0.252	6.027	0.076
Compensating Wedge x 4	4.4	0.1	56	5.269	0.120	1.5067	0.0001	26.465	0.603	7.939	0.181
Rod x 2	202.3	0.1	0	202.300	0.100	1.83	0.01	1234.030	7.353	370.209	2.206
Lens x 4	9.1	0.05	0	9.100	0.050	1.5067	0.0001	45.703	0.254	13.711	0.076
	0	0.05	0	0.000	0.150	1.7812	0.0001	0.000	0.891	0.000	0.267
Energy Monitor Splitter	1	0.05	45	1.132	0.057	1.5067	0.0002	5.688	0.285	1.706	0.086
Eyesafe (n/a)	0	0.05	0	0.000	0.050	1.5	0.03	0.000	0.250	0.000	0.075
KDP Doubler Crystal	20.4	0	0	20.400	0.000	1.49	0.03	101.320	2.040	30.396	0.612
Start Diode Splitter	1	0.05	45	1.132	0.057	1.5067	0.0001	5.688	0.285	1.706	0.085
Total Glass	242.2	0.5		243.334	0.633			1438.982	12.214	431.695	3.664
Amp Inclusive Length (mm)	2347.000	0.25									
Amp Air Path (mm)	2103.666	0.883									
Amp Effective Total Air Path (mm)	2535.360										
Time Amp Air Path(ps)	7012.219	5.887									
Time eff Airpath(ps)		24.4273005									
Amp Time(ps)	7012.219	ps									
error	30.314	ps									

Calculation of effective increase in laser path length due to propogation effects of various optics



The 10 Hz Laser showing the laser path and position of Start Diode

b) Laser Path

Three methods were employed to measure the Coudé Path:

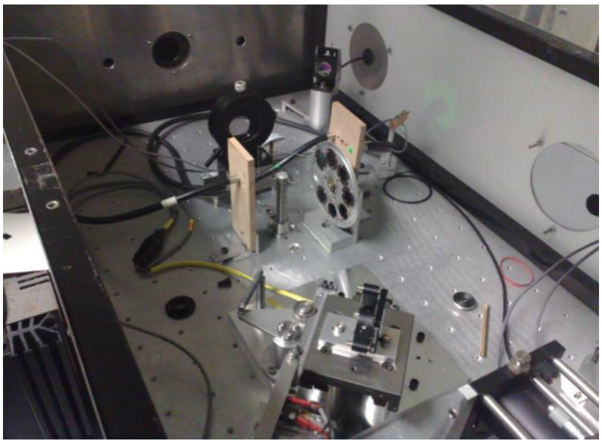
i) Physical Measurements and Technical Drawings

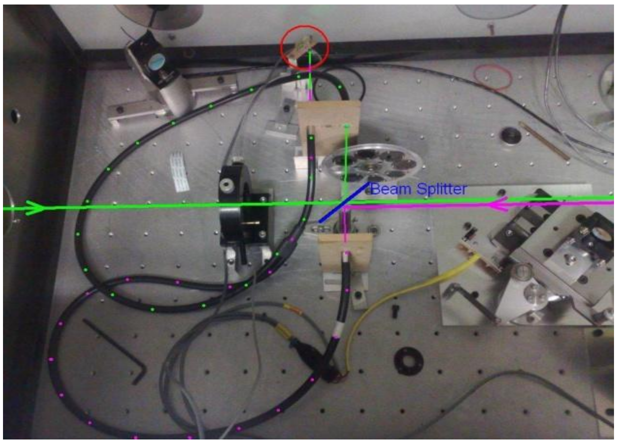
The original technical drawings of the telescope were used to calculate the Coude Path from the telescope base to the System Reference Point. The measurement from the telescope base to the Coude entrance was made using a tape measure and level. This simple method was used primarily as a useful comparison for the other methods.

ii) Reflected 10 Hz Laser Pulse

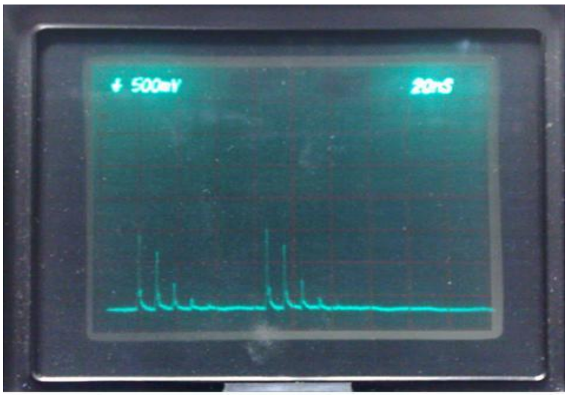
The Laser was fired through the coudé chain and reflected back via a mirror on the emitter as can be seen in these images.

Both the outgoing and returning laser pulses were used to trigger the same light-sensitive diode (circled in red) via the use of a beam splitter and a two-into-one fiber optic as shown below. The output from the diode was viewed via an oscilloscope. The time interval between the outgoing and returning pulse, estimated via the oscilloscope display, was used to calculate the laser path distance.





The two laser pulses and semi-trains can be seen clearly on the oscilloscope.

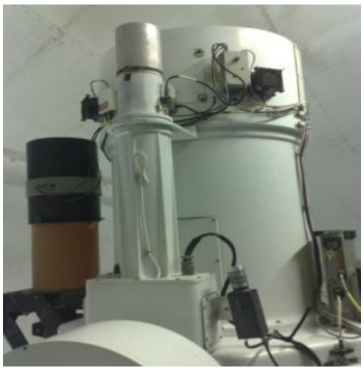


iii) Laser Rangefinder

A Bosch DLE 50 Laser Rangefinder, more commonly used as a building surveying tool, was used as a third method of measurement. The manufacturers state a typical accuracy of ±1.5mm over a 30m distance.

An adjustable mount was manufactured enabling the Rangefinder to be aligned to reflect correctly off all mirrors and measure directly the required coudé path length.

Having aligned the Rangefinder, the emitter was removed and replaced with a flat surface for the rangefinder to measure to. Measurements were taken with the telescope placed in varying azimuth positions to ensure no significant change in the measurement was present due to poor alignment for example. The process of alignment and measurement was repeated, and very good repeatability at the level of 1mm in the results was found.



Telescope complete with emitter.

Emitter removed and replaced with flat surface.

Results

a) Physical Measurements and Technical Drawings

8.411 m Error ± 20 mm

- Difficulty in Physical Measurement of Coudé below Telescope

b) Reflected 10-Hz Laser

8.388 m Error ± 30 mm

- Limited by accuracy in interpreting the Oscilloscope display
- Research more accurate ways of measuring timing between outgoing and returning pulses

c) Bosch Laser Rangefinder

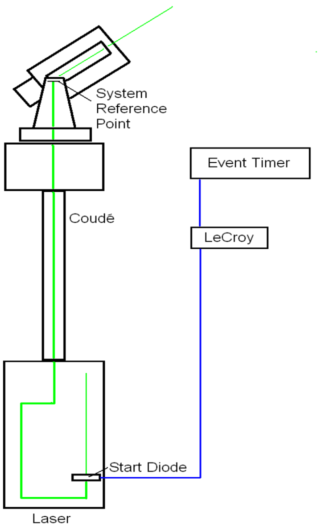
8.398 m Error ± 1.5 mm

- Most accurate and repeatable method

- All the results agree to within 25mm. The method we found to be best due to its accuracy and repeatability was that using the Bosch Laser Rangefinder; the result itself is also easily within the range of error of the other two methods.

2. Cables and Electronic Equipment

The delays in cables and electronic equipment comprise the Start Diode, LeCroy Discriminator, Event Timer and Cables.



a) Start Diode

A Beam Splitter is used in the path of the laser to direct a small percentage of laser light to the Start Diode. The Diode is placed 25.5mm from the Beam Splitter, the time taken for the laser to pass through this space was included. There is also a delay in the Diode circuitry which is yet to be determined. This delay may prove difficult to determine due to the effects in the variation of the laser energy that reaches it and its temperature.

b) Cables and LeCroy Measurement

The pulse provided by the Start Diode passes through two cables, a LeCroy distribution device and some electronics before triggering the start in the Event Timer. The delay produced by these components was determined by making a series of calibrations with and without the various components in the chain. The resulting difference in the calibration values demonstrates the actual delay produced by each item. This method could not be employed for the electronics leading to the Event Timer, this delay is yet to be determined or may remain unknown.

c) Event timer

The delays inherent in the use of the event timer are as yet un-measured, but are estimated to be small and likely less than 1ns. Further work will address this issue.

Total Delay between Start Diode and Event Timer

Start Diode

- To be Determined
- Beam Splitter to Diode 0.027 m

Cables

- Diode to LeCroy: 13.350 m
- LeCroy to ET: 2.791 m

LeCroy

- LeCroy currently in use: 3.609 m

Event Timer

To be Determined

Total: 19.776 m

The results found using this method were compared to the calculated expected delay. The signal propagation through a cable can be expressed as a percentage of the speed of light. An approximate figure found for the coaxial cable in use is 66%. This would broadly agree with the results found for the cables tested. For example, the results for the cable between the Start Diode and the LeCroy discriminator are shown below.

Physical Length	8.868 m
Effective Length at 66% light speed	13.436 m
Effective Length using calibration method	13.349 m

Total Transmit-side Delay

The transmit-side delay can now be given as the difference between the time the laser passes through the System Reference Point and the time that ET is triggered.

Subtract Laser Path Delay from Cable and Electronic Equipment Delay

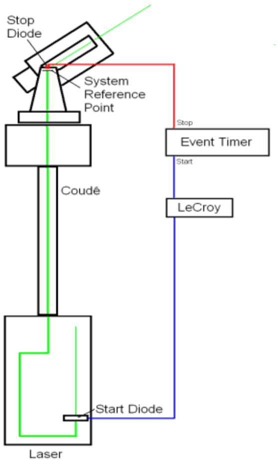
Transmit-side Delay = 19.77617 m - 13.49233 m
= 6.28383 m
= **20.946 ns** Error Estimate <1ns

So the Laser Pulse passes through the System Reference Point 21ns before the Event Timer is triggered. This result uses the electronic delays determined to date and the coudé path measurements made using the Bosch laser rangefinder.

Further Work

- More Tests on LeCroys and Cables
- Event Timer Delay
- Start Diode Delay
- Measure all Receive-side delays to close the loop and compare against our standard two-way calibration result
- Setup to enable measurement of Transmit-side delay as one measurement

Measuring the Transmit-side delay as one complete measurement.



Another method to measure the transmit-side delay as a whole would be to place a diode in the laser path, on or near the system reference point. The pulse from this diode could then be fed to ET stop in place of the SPAD stop pulse. This replaces the outgoing beam (beyond the System Reference Point), returning beam and Receive-side delays with a cable and diode. This relies on having a good understanding of the delay produced by the diode and cable used. This method would be ideal if it could be a permanent fixture to the system that could be setup to calibrate for the Transmit-side Delay on a regular basis, perhaps immediately before and after any LRO or T2L2 observations. It would also allow for quick calibrations to account for any necessary changes that may be made to the system.

Conclusion

We are working towards providing an epoch for the time the laser pulse passes through the System Reference Point, as necessary for LRO and T2L2. The current measurement gives a 21ns correction to the currently-recorded observational epochs, with estimated precision better than 1ns. However, the electronic delays in the Start Diode and event timer are still to be included.