Upgrades and New Capabilities of the GFZ SLR Timing System

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Abstract

Currently the GFZ Potsdam timing system is based on a GPSDO receiver. Here we discuss its supplementation with a cesium standard equipped with a high performance tube. A station 'on time' point is designated to allow for traceability to UTC. Careful measurements have been made to separate the transmit delay from the overall system delay. In addition, software is being developed to monitor clock health, as well as generate timing data relating the station time to the laser pulse crossing of the system invariant point. The software is cross-platform and is designed to process normal ranging data being generated at the station. These improvements and measurements will allow Potsdam to participate in current and future missions that require one way ranging measurements, including T2L2, the ACES mission, and other transponder work.

Introduction

Advances in GPSDO technology have allowed many scientific laboratories have accurate timing sources with low cost. This consists of a crystal oscillator kept stable relative to UTC using GNSS signals. For the core ILRS missions, this is a proven and reliable technology; however for more specialized experiments an unsteered or high precision device may be necessary. This is the case for missions such as T2L2, one way ranging or ranging at interplanetary distances. In addition, one way ranging has a higher UTC accuracy requirement than standard two way ranging. These were issues that were addressed in the modification of the timing system. In addition to precision improvements, three objectives were pursued: the measurement of a one-way transmit delay, the definition of an on-time point for the station, and the monitor of the 1 PPS from the cesium in relation to UTC.

Timing System

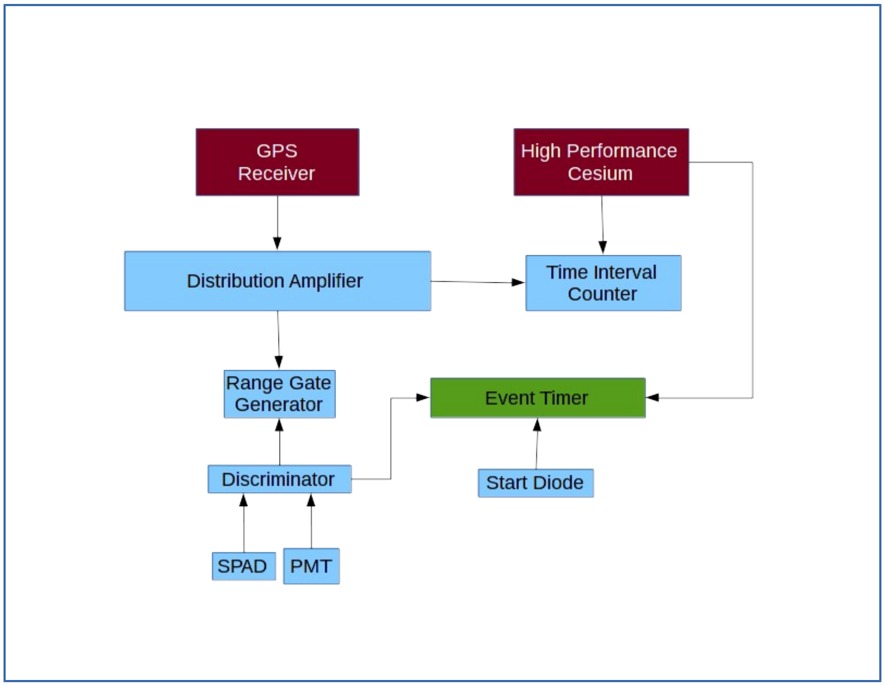
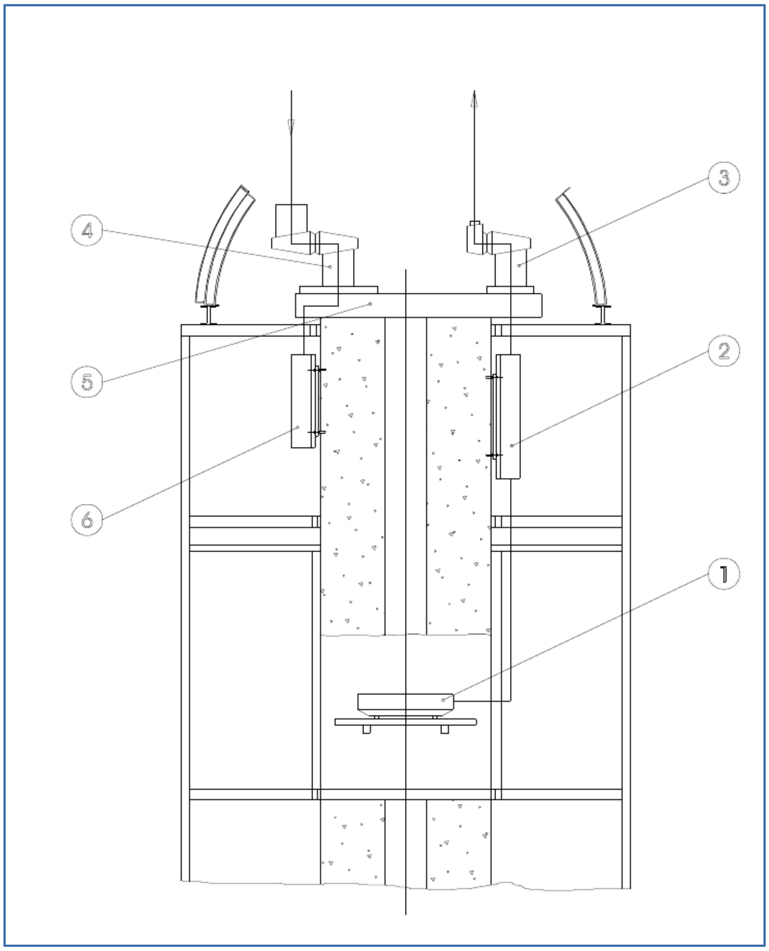


Figure 1: Simplified Timing Block Diagram

Figure 1 shows a simplified block diagram of the timing setup. Two timing sources are used, an Agilent 5071A Primary Frequency Standard with the high precision cesium tube option, and a 58503B HP GPS Time and Frequency Reference receiver. Precision timing is handled mostly with the cesium, with the HP unit used to keep track of the cesium's drift relative to UTC. The distribution amplifier is a custom build piece that was designed around the HP GPS and was found to be incompatible with the signals provided by the cesium. Future improvements would involve using the cesium as the primary source for distribution, with a GPS unit only monitoring the cesium 1 PPS relative to UTC. Under these limitations, a cesium 1 PPS and 10 MHz is provided to the event timer as the measurement critical device. The Allan deviation over an averaging time of 1000 seconds for this GPS unit is given as $\mathbf{5x10^{-11}}$. For the cesium, the same averaging time gives an AD of $\mathbf{2.7x10^{-13}}$, a significant improvement. [1] [2]

Measurement of the Transmit Delay

Standard two-way ranging relies on a calibration value in order to obtain the true time of flight of the laser pulse. The calibration value is subtracted from the raw measurement to account for delays in electrical and optical signal propagation. The method of measurement varies across SLR systems, but the value usually does not determine individual sources of delay, and includes delays in both the laser transmit path and the receive path. For one way ranging, the delay in the transmit path must be separated from the unused receive path (or vice versa). Specifically, we are interested in the location of the wavefront of a given laser pulse, relative to the invariant point of the telescope system, at the moment the start diode (SD) pulse is registered by the event timer. A photo diode (PD) is placed at a point that is easily referenced to the invariant point, and the time between the excitation of the PD and the signal input from the SD is measured.



1	laser
2	transmitter focal unit
3	transmitting telescope
4	receiver telescope
5	foundation
6	receiver focal unit

Figure 2: Geometry of the GFZ SLR telescope system[3]

Figure 2 shows the structure of the telescope system. The GFZ SLR system is unique in that it has a separate telescope and gimbal system for the transmit and receive paths. A consequence of this is that the invariant point of the system as a whole is halfway between the line joining the individual invariant points of the telescopes. This allows the PD to be placed directly at the system invariant point, since it is in free space.

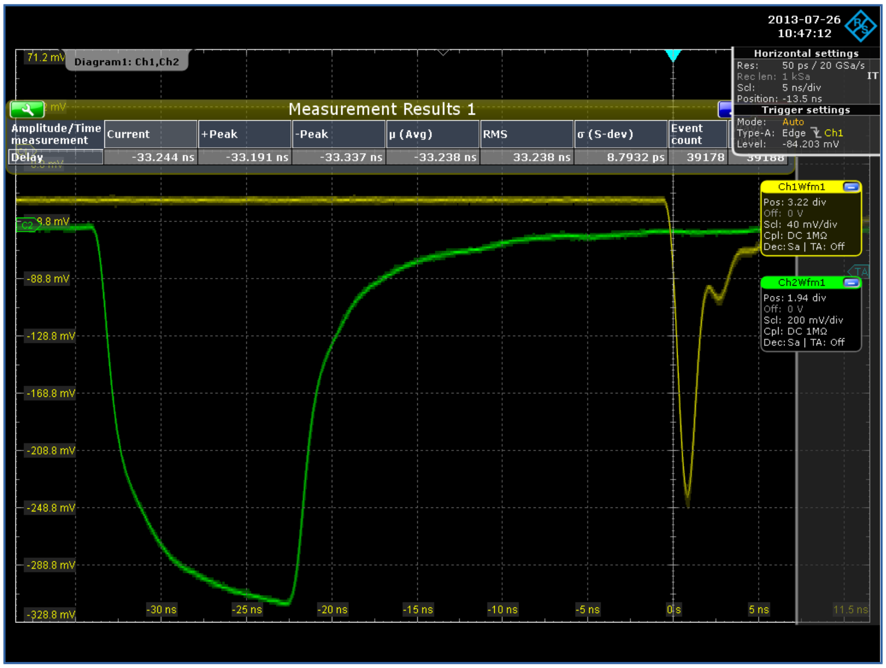


Figure 3: SD to PD Measurement

Figure 3 shows a typical SD to PD measurement in its raw form. The green pulse is from the SD, while the yellow pulse is from the PD placed at the invariant point. The final value for the measurement takes into account the delays from the cable connecting the PD to the oscilloscope, as well as other connecting cables between the interfaces. The precision of the measurement is affected by the fall time of the various diodes used. In this measurement, a silicon diode was used at the invariant point with a measured fall time of 766 ps. A faster diode would yield a more precise measurement.

	Average	Standard Dev.	Sample Size	
PD Cable Delay (ns)	92.327	0.013	7727	
SD Cable Delay (ns)	5.083	0.009	39879	
SD to PD Direct Measurement (ns)	-33.238	0.009	62659	
PD Peak to Peak (mV)	220.76	5.738	12287	
PD Fall time (ns)	0.766	0.022	12877	
SD-ET Trigger Uncertainty (ns)	0.053			
ND Glass Delay (ns)	0.009			
Distance between invariant point in telescopes (ns)	6.926			
STDDEV of Measurements				0.018
SD – PD Corrected (ns)				53.998
Delay from TX INV cross to SD (ns)				**50.535**

Table 1: Measurement Results

Measurements were also performed on the trigger level of the event timer. The specific one used is the

Model A032-ET Riga event timer. Pulses of varying amplitudes were used to narrow down the trigger threshold. This measurement is reflected in Table 1, under “SD-ET Trigger uncertainty”.

ND filter glass was used in front of the photo diode to get acceptable optical signal levels. This is shown in Table 1.

The measurement with all corrections accounted for shows a 53.998 ns delay from the SD pulse on the input of the event timer to the triggering of the PD. However, for one way measurements, the total system invariant point cannot not used, because this takes the unused receive path into account. The invariant point of the transmit telescope must be used instead. As a consequence of the calibration measurement technique, the distance between the invariant points of the two telescopes is known very precisely. Halving this light distance and subtracting from the corrected measurement gets the final value of **50.535** ns. Using this value allows a one way laser pulse to be referenced to an event recorded by the event timer.

Definition of the On-Time Point

Generally for precise measurements it is a good idea to define a point in the timing signal sequence that can be called the “on-time point”, that is, the 1 PPS point at which measurements are referenced. The choice of point is not unique to a system, and several good candidates can be available, as long as it is stable and consistent. This is much more critical for one way measurements where an absolute reference to UTC is needed. For our purposes, the first output of the cesium is designated as the on-time point.

Tracing and Monitoring Cesium 1 PPS to UTC

As the cesium is free running and not steered by GPS, it is important to monitor the drift of the generated 1 PPS output relative to UTC. The nature of a cesium clock means that no special calibrations will be necessary for the life of the cesium tube under normal operating conditions. However, random environmental processes can still cause a drift that could require the cesium to be re-synchronized to UTC. As the range gate is currently driven by the GPS signals, it is good practice to not let the GPS 1 PPS and the cesium 1 PPS become too far apart. For monitoring and logging purposes, software has been developed to allow the operator/station manager to ensure the health of the timing system. This is written in QT and was designed to work along side the ranging software developed for the station, with minimal computer resource use and little additional hardware. There are plans to expand this software to include timing stability analysis.

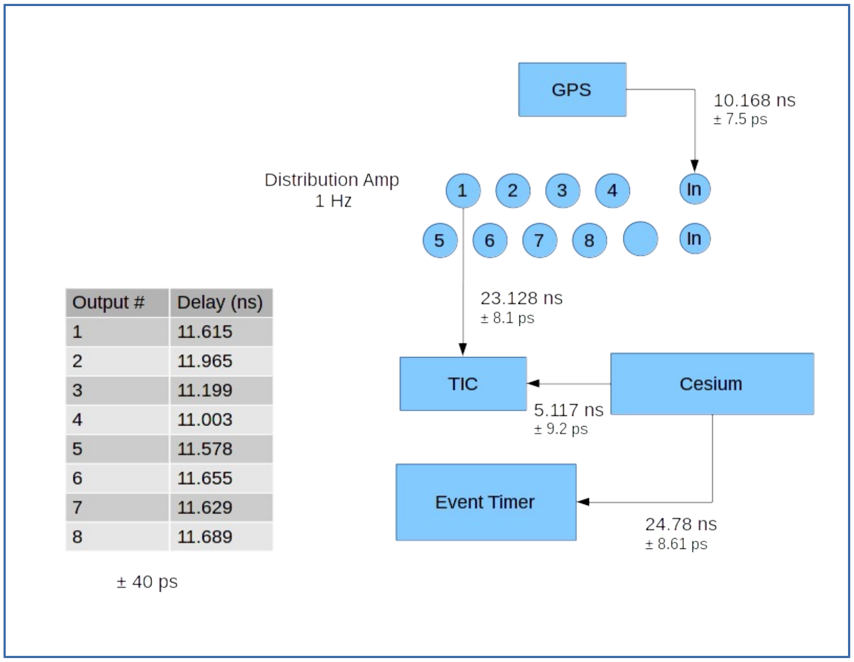


Figure 4: Tracing Cesium 1 PPS to UTC

Shown in figure 4 is the cable diagram for the UTC trace of the system on time point. Careful attention was paid to the custom distribution unit to determine differences in delay for different output. The table on the left shows the result of those measurements, some varying by as much as 1 ns. Using these measurements, we get a +**39.8 ns** difference between the GPS 1 PPS and the cesium 1 PPS. That is, if the 1 PPSs where perfectly synchronized, the TIC would read this value. The cable delay between the cesium and the event timer is also shown as **24.78 ns**, which can be accounted for in data processing if necessary. This completes the loop and allows event timer events to be accurately referenced to UTC while using the more stable cesium 1 PPS. Further refinement could be done to the measurement by an analysis of internal delays of the various equipment (the TIC for example), however this gives diminishing returns without more precise equipment, improvements to other subsystems (e.g. the detector), or improvements in atmospheric models.

Conclusion

Completing these measurements and analysis allows the SLR station at the GFZ to participate in current and future missions involving precise timing and one way ranging.

References

[1] "Agilent 5071A Operating and Programming Manual."
[2] "58503B GPS Time and Frequency Reference Receiver." [Online]. Available: http://www.symmetricom.com/media/files/support/ttm/product-manual/097-58503-13-iss-2.pdf. [Accessed: 27-Mar-2013].
[3] R. Neubert, L. Grundwaldt, G. Sesselmann, and M. Steinbach, "An innovative telescope system for SLR," in *Proc. SPIE 3865*, 1999.