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Timing system test at the second engineering run (E2) at LHO

Szabolcs Márka, Daniel Sigg, Akiteru Takamori

Abstract: *We conducted two classes of tests during the E2 engineering run at Hanford. We continuously monitored the timing accuracy of the DAQ time stamp relatively to the timing signal provided by the LIGO Timing board, which is based on the GPS second tick. This measurement is capable of measuring delays modulo one second. The results indicate that we can measure the timing of the DAQ tick with an uncertainty in the order of 100 ns, which is comparable to the accuracy of the GPS clock itself and much less than the required accuracy of the ADC clock of 1ìs. However, occasionally we observed sudden, large jumps (up to 60ìs) between the DAQ tick and the GPS second tick timing. We associated these jumps with system reboots and this assumption was recently validated. To extend our capability to detect timing problems we propose to incorporate IRIG-B timing signals into the frames.*
To measure end-to-end timing accuracy, we had two partial shifts when we injected sine waves with varying frequencies into the four test masses. We used both analog and digital excitation channels. We measured the phase shift between the injected wave and the response. Due to statistical uncertainties the results varied by about 100ìs between the two shifts executing the exact same measurements. We concluded that we have to repeat these measurements with fewer points and much longer measurement times to get into the desired <10ìs range.

Introduction

We completed two classes of tests during the E2 engineering run at Hanford. One was capable of measuring the timing accuracy of the DAQ time stamp relatively to the timing signal provided by the LIGO Timing board, which is based on the GPS second tick. The other class of tests was designed to measure the end-to-end timing accuracy, with sine waves injected with varying frequencies into the four test masses.

We used the signals provided by the LIGO timing board and monitoring software running on one of the DMT machines[1] to measure the delay in every second during the full stretch of the run. We were capable of measuring delays modulo one second. The LIGO timing boards are equipped with a 1PPS/RAMP output to allow the calibration of the DAQ timing from the inputs of filter boards to the DAQ time stamp. The 1PPS is a 1ms square pulse with a rising edge precisely aligned with the GPS second tick. The RAMP is a 1 ms (~16 points at 16384 Hz sampling rate) long, steep ramp, which starts exactly at the GPS tick (rising edge of the 1PPS). A snapshot of the two signals is shown on Figure 1.

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[1] Thanks to John Zweizig for his help with DMT usage and his great contribution to our software!

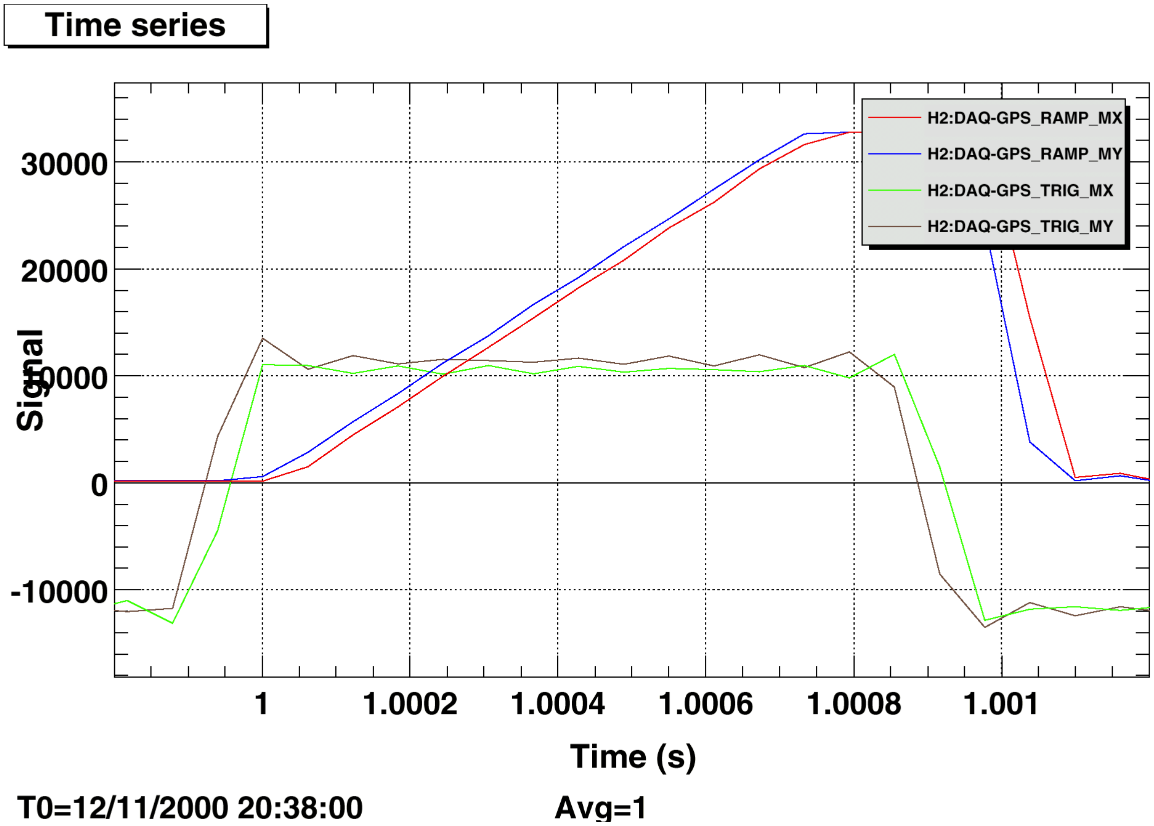

Figure 1. *An example of the RAMP and 1PPS (TRIG) signals recorded by the Diagnostic Test Tool. The small "wiggles" in the signal are due to the anti-aliasing filters.*

The RAMP signal makes it possible to determine the exact time of the GPS second tick relative to the time stamp: the crossing of the base line and ramp relative to the full second time stamp is the offset. Both, mid-stations and the data collection units in the 1x5, 1x22 crates in the LVEA have timing cards and acquire RAMP and TRIG.

To measure the end-to-end timing accuracy, we had two partial shifts where we injected sine waves with varying frequencies into the four test masses. We used both analog and digital excitation channels. Analog frequency synthesizers (SR345) were used at the mid stations, while we took advantage of the digital excitation engine for the input test masses. As expected, the digital injection produced much narrower lines in the power spectrum. The frequencies, measurement intervals and channels used for the measurements are listed in Appendices. We measured the phase shift between the injected wave and its response at the anti-symmetric port of the interferometer. The measurement errors were dominated by statistical uncertainties of order 100ì s; much larger than the overall requirement of 10ì s. In the future the measurement time has to be increased significantly.

DAQ timing results

We monitored the ramp signals from both mid stations and from the LVEA. Figure 2 shows the measured delay for the span of the entire E2 run.

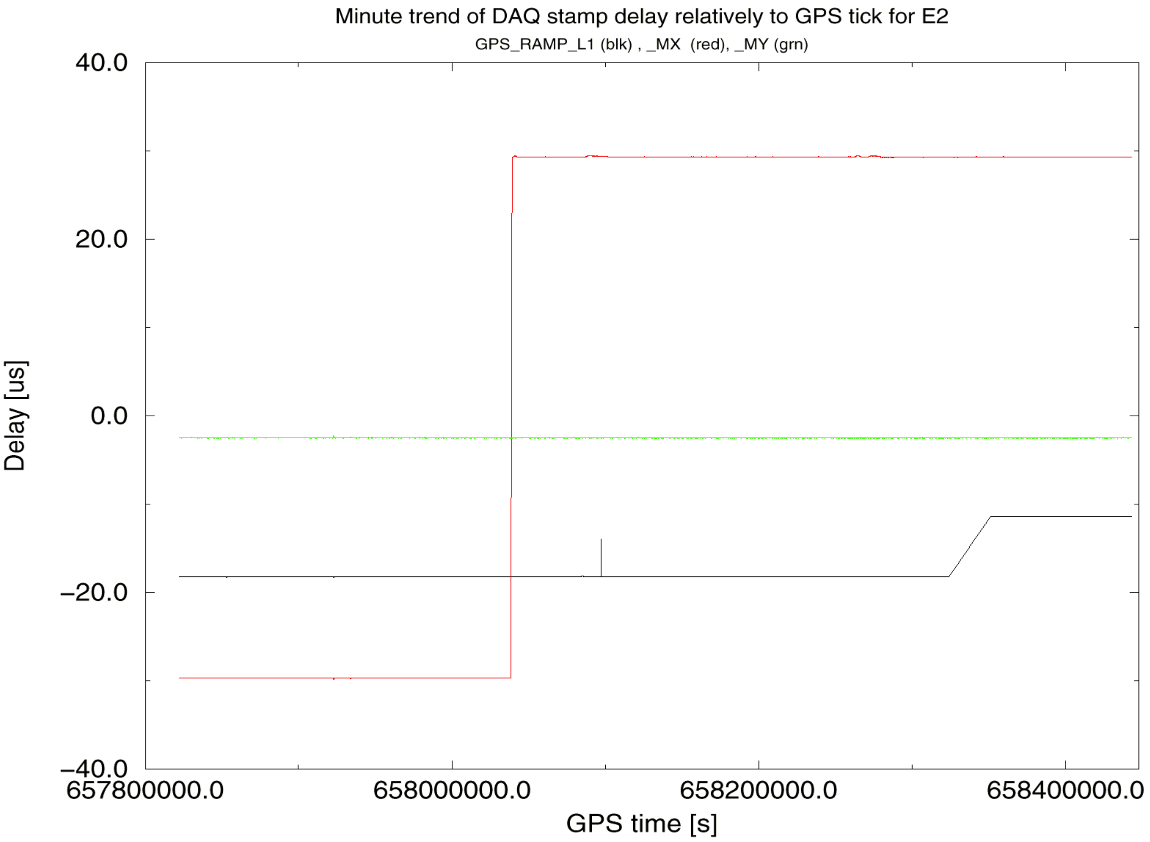

Figure 2. *Timing trend during the E2 run. The black curve shows the LVEA, the red shows the X mid station and the green shows the Y mid station time delay. The rare but significant jumps in the timing signals are due to system reboots. The slope in the black curve is due to missing data for that period. Note the occasional small ripples with amplitudes O(100ns), which are pronounced on the red curve.*

We observed rare, but large and sudden jumps in the delay times. The jumps are not correlated between channels and their size varies. We associate these jumps with rebooting the data collection units and assume that they indicate a problem with the initial setting of the timing board, but their exact cause still needs to be tracked down[2]. The jump in the red curve corresponds to a full cycle of the ADC clock, whereas the jump in the black curve only corresponds to a fractional cycle.

Figure 3 shows the distribution of delay times (1measurement/second) around their mean for the Y mid station covering the entire run. A very good Gaussian fit to the distribution gives ó=19 ns. The insert in Figure 3 shows a distinct and far reaching tail, which contains ~2% of the data points. This tail is unique to the Y mid station signal and not observable in the other measurements.

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[2] Recent experiments supported our “reboot” assumption, but the exact cause of the problem is still an open question.

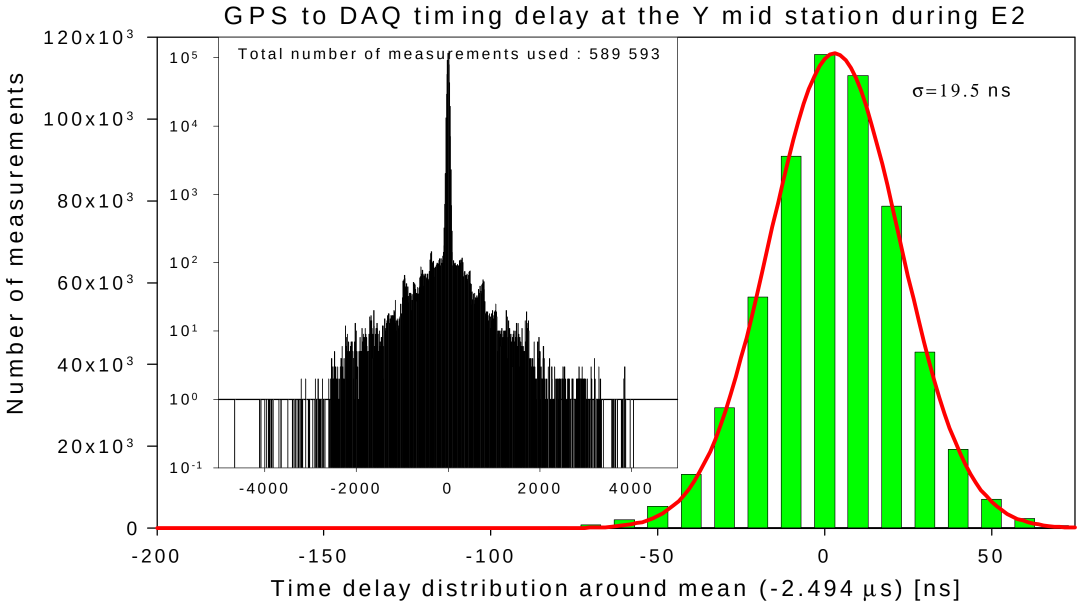

Figure 3. *Distribution of timing delays around their mean (Y mid station signal). The Gaussian fit gives ó=19 ns. Note that the insert has logarithmic scale on the Y-axis to emphasize the tails.*

Similar fits can be applied to the delay distribution of the other two signals (before and after the jumps). The fits give ó=26 ns for the X mid station before, ó=28 ns for the X mid after the jump (Figure 4) and ó=21 ns for the LVEA before the jump.

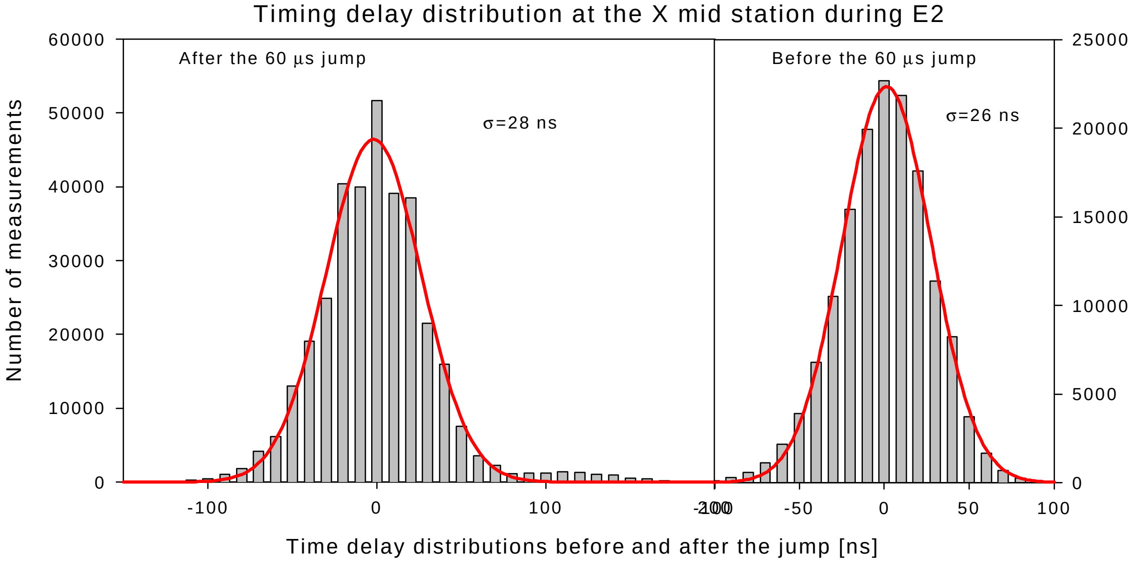

Figure 4. *Timing delay distributions at the X mid station before and after the jump. Note that the tail around 100 ns is only present in the distribution after the jump. This tail is due the more frequent ripples which can be seen in Figure 1.*

The accuracy of the measurement is already comparable to the inherent accuracy of our GPS receivers (see Appendices) and it is far better than the required 1ì s.

Conclusion and future needs

It is clear from the DAQ timing measurement that we are able to monitor the timing with a relative accuracy of O(100ns), which is comparable to the inherent accuracy of our GPS receivers. Systematic errors are believed to be small but need further investigation. However, we observed sudden occasional jumps (<60ìs) between the DAQ time stamp and the GPS second tick due to system reboots. We also observed that the signal from the Y mid station frequently contains glitches, which can reach as far as 4 ìs in certain cases. These problems make constant monitoring and further testing necessary. We also believe that it is necessary to monitor the timing of the LSC/ASC analog-to-digital converters and we recommend that RAMP/1PPS are added to these crates. To extend our capability to detect timing problems we propose to incorporate IRIG-B and NTP timing signals into the frames; this would allow us to test if the second time stamps are correct.

The timing monitor running on the DMT has proven to be useful. It will become a permanent monitor, which continuously checks the timing accuracy and which will raise an alarm if the timing is to far off. We will improve the error detection capability and also investigate the advantage of using additional IRIG-B and/or NTP decoding algorithms in the code.

We concluded that the sine response measurements have insufficient signal-to-noise ratios, we therefore have to repeat these measurements with fewer points and much longer integration times to get to the desired 10ìs accuracy range.

Appendix A: GPS tick to DAQ times stamp measurement data

Data and various plots from the timing accuracy measurement between the DAQ time stamp and the timing signal provided by the LIGO timing board can be found at: http://blue.ligo-wa.caltech.edu/engrun/E2/Results/EtoE_Timing/

Minute trend files for E2 DAQ timing measurements (compressed ASCII):

File name:	Start time (GPS & UTC)	End time (GPS & UTC)
Delay.821915_838475.log	657821915 Nov 9 16:18:25 2000	657838475 Nov 9 20:54:25 2000
Delay.838535_875045.log	657838535 Nov 9 20:55:25 2000	657875045 Nov 10 07:03:55 2000
Delay.875165_891667.log	657875165 Nov 10 07:05:55 2000	657891667 Nov 10 11:40:57 2000
Delay.906849_443068.log	657906849 Nov 10 15:54:00 2000	658443068 Nov 16 20:50:58 2000

Available plots for minute trend:

L1_Min_endofweek.ps
L1_Min_Full_Week.ps
L1_Min_magnified.ps
L1MXY_Min_FullWeek.ps
MX_Min_endofrun.ps
MY_Min_FullWeek.ps

Second trend files for E2 DAQ timing measurements (compressed ASCII):

File name:	Start time (GPS)	End time (GPS)	Gap duration
T_Sec.657825309_657838502.log	657825309	657838502	
T_Sec.657838503_657846266.log	657838503	657846266	
T_Sec.657846267_657864283.log	657846267	657864283	
Gap!	*657864284*	*657875103*	*10819 sec (~3 hours)*
T_Sec.657875104_657879721.log	657875104	657879721	
T_Sec.657879722_657906546.log	657879722	657906546	
Gap!	*657906547*	*657906813*	*266 sec (~4 minutess)*
T_Sec.657906814_657917487.log	657906814	657917487	
T_Sec.657917488_657997413.log	657917488	657997413	
T_Sec.657997414_658449255.log	657997414	658449255	

Appendix B: Alternative methods to obtain accurate time

We believe that there should be one or preferably more independent (from GPS and each other) ways to obtain absolute timing information, important for coincidence measurements between the sites.

To check the absolute timing without relying on the already available GPS clocks one can use standard IRIG-B signals, which are transmitted via radio signal and should be readily available at both IFO, albeit not necessarily from the same clock. To incorporate this timestamp into the frame data we can add IRIG-B signals to the data stream and recover the time information in software.

Another check can be done on the frame builder by comparing the time stamp of the data with the time from a network timeserver based on an accurate and GPS independent clock such as the NIST timeserver. Alternatively, the frame builder can just add a time of creation to the frame files with the DMT timing monitor comparing the two time stamps and raising an alarm if they differ.

Appendix C: Inherent accuracy[3] of our GPS clocks

There are multiple pieces to the GPS accuracy issue. First is the absolute accuracy of the GPS signal as it is received by the Motorola receiver that we use. This is specified by Motorola to be **+/- 200nsec**. This can be reduced to **+/- 45nsec** via a Position Hold upgrade. The better we know the position of the antennas the better we can calculate the time corrections. Position Hold averages over 10,000 seconds (about 3 hours) after turn on and will save a precise position from which the unit can make more accurate time correction calculations. The only better way would be a military KYK13 unit with Carrier Phase Tracking. This solution would require security clearances, armed guards and a substantial financial investment from our part.

There is a **+/- 50nsec** quantization error from the 10MHz clock in the Motorola receiver. This can and will be removed via a sawtooth correction.

In addition, a **+/- 60nsec** quantization error from the 2^23 Hz clock that JXI2 built into the board for LIGO. We needed a binary clock so that we would not get glitches or missing pulses in the clocks going to the ADCs and DACs. This could also be reduced with a sawtooth correction technique. The bottom line for the Master GPS Receivers is:

Absolute error is **(+/- 200nsec) + (+/- 50nsec) + (+/- 60nsec) = +/- 310nsec** at the present and it will be **(+/- 45nsec) + (+/- 50nsec) + (+/- 60nsec) = +/-155nsec** soon.

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[3] Thanks to Dale Oumiette for his help to collect the information presented in this section.