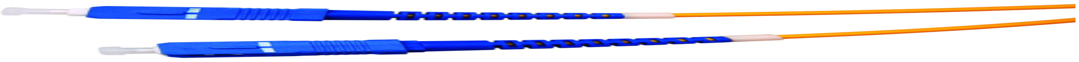

LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
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# aLIGO Timing System Checks During O3A

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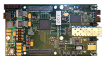
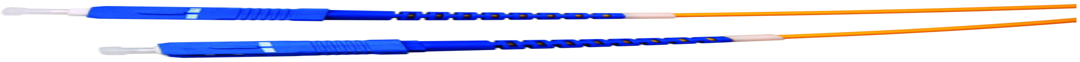




## Abstract

Advanced LIGO (aLIGO) data is recorded by a data acquisition system (DAQ) that is driven entirely by the GPS-backed aLIGO Timing Distribution System. Several independent clocks' 1PPS signals are used in timing diagnostics studies as witness signals. At each site, a Microsemi 4310b Cs-III Cesium-standard atomic clock checks for transient or short-term timing problems (see LIGO-T1700298 for details), and two CNS Clock II GPS clocks and a GPS-backed NTP server check for long-term/absolute timing problems.

We measured the time delay between aLIGO Timing Distribution System 1PPS and the aforementioned Timing Diagnostic System's CNS Clock II GPS clock's and a GPS-backed NTP server's 1PPS signals for the first half of aLIGO's third observation run (O3A). We also checked the atomic clock's calibration during O3A. We also performed checks throughout O3A which can be found in LIGO-T1900671 on the DuoTone time delays, which probe timing performance on the sub-microsecond level, and the IRIG-B outputs at both sites for all Open Public Alert candidates.

## 1. Introduction

The aLIGO Timing **Distribution** System is a custom timing solution that provides end-to-end timing signal integrity at the hardware level, ensuring absolute synchronization across all aLIGO sites to the GPS time standard (and UTC) below the required tolerance.

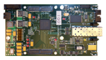
Auxiliary to the timing distribution system, there are **diagnostic** features which rely on a heterogeneous set of independent clocks to continuously measure the ***Timing Distribution System***'s accuracy and performance on different time scales. These diagnostic features and independent clocks are functionally distinct from the Timing Distribution System, and collectively are called the aLIGO ***Timing Diagnostic System***. The Timing Diagnostic System checks, among other things, guarantees that the Timing Distribution System is synchronized to GPS time. One of the main functions of the Timing Distribution System is to mark the start of each second with a voltage pulse ("One Pulse Per Second" or "1PPS"), which can be compared to independent Timing Diagnostic System reference clock 1PPS signals to verify that the Timing Distribution System's 1PPS is consistent within specifications.

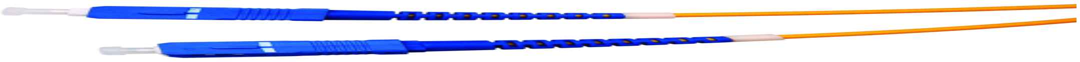
One of the reference signal types used at each site are CNS Clock II GPS clocks that provide long-term consistency measurements. These measurements can pinpoint local problems related to the GPS receiver or distribution system, however the GPS space segment is not tested by them.

## 2. Timing System Performance prior to O3

During LIGO's third observation run (O3), the **Timing Distribution System** performance – regarding CNS Clock II GPS clock, a GPS-backed NTP server Time Difference, and the atomic clock drift  - was well within specification during all observing time segments.

### a. NTP servers and CNS II clocks





The GPS-backed NTP server in the Mass Storage Room (MSR) at the Corner Station at Hanford showed variations from mean of less than ±70ns vs. the **Timing Distribution System** 1PPS signal at all times. (Figure 1: Timing Difference between the NTP Server and the Timing System's internal 1PPS signal at LHO during O3A). The CNS II clocks, located at end stations X and Y, showed variations of ±80ns from the mean time difference at all times (Figure 2: Timing Difference between Y End CNS II GPS Clock and the Timing System's internal 1PPS signal at LHO during O3A, respectively).

The NTP server at the Corner Station at Livingston showed variations from mean of less than ±110ns vs. the **Timing Distribution System** 1PPS signal at all times (Figure 3: Timing Difference between the NTP Server and the Timing System's internal 1PPS signal at LLO during O3A), with most values within ±60ns. The CNS II clocks in the X station showed variations of less than ±90ns from the mean time difference at all times (Figure 4: Timing Difference between X End CNS II GPS Clock and the Timing System's internal 1PPS signal at LLO during O3A).

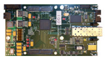
*Note: Data is only plotted during segments when the detectors were in observing mode (DQ Flag: L1:DMT-ANALYSIS_READY:1), and the segments with no points plotted in Figures 3 and 4 correspond to times when LLO was not in observing mode.*

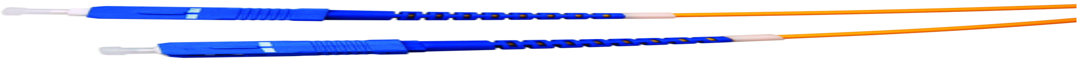
*Note: Plots for the CNS II GPS Clock at the Y End station at LLO and at the X End station at LHO will be included in a later revision of this document (relevant channel names: L1:SYS-TIMING_Y_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_2; DQ Flag: L1:DMT-ANALYSIS_READY:1 and H1:SYS-TIMING_X_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_3; DQ Flag: H1:DMT-ANALYSIS_READY:1)*

### b. Atomic Clock Drift

The Cs-III 1PPS signal has very low jitter, with a base Allan deviation of 5.0e-14 (source: Microsemi Cs-III fact sheet). This means that short timescale variations from the mean in the time difference between the TDS and Cs-III 1PPS signals can be interpreted as jitter in the TDS 1PPS signal. Over time, though, the Cs-III 1PPS will tend to drift linearly away from the TDS 1PPS. This happens because the Cs-III 1PPS signal is not synchronized to Global Positioning System (GPS) time via satellite connection, whereas the TDS 1PPS is. Consequently, any difference between the Cs-III period and 1 second (as measured by GPS) will be compounded over time. **It must be noted that this long-term linear drift is expected behavior, and that it does not hinder in any way the use of the time-difference timeseries in measuring jitter in the TDS 1PPS signal.**

Nonetheless, maintaining a small average time difference makes it easier to plot and measure jitter, and it is therefore important to recalibrate the Cs-III clock every few months to minimize the drift rate. This is accomplished by first finding the drift coefficient by taking a line-of-best-fit over multiple months of time difference data (starting at the most recent calibration). The residual of this line is the TDS 1PPS jitter, while the slope of the line is the drift coefficient.

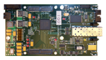


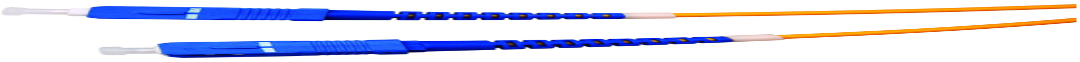


At LHO, the drift coefficient was measured as -1.3e-14 (Figure 5: Atomic clock drift at LHO during O3A). At LLO, the drift coefficient was measured as 2.3e-14 (Figure 6: Atomic clock drift at LLO during O3A). The observed drift behavior was gradual and piecewise-linear (as expected) and would not interfere with the short-timescale phase noise measurements that the Cs-III is used for. The calibration is sufficiently good that the shorter timescale (likely environmentally caused) piecewise-linear drift of the Cs-III clock is larger than the long-term drift. Further calibration was thus not performed, as it would likely amount to over-fitting and would not produce a qualitative improvement in long-term drift.

## 3. Conclusion

The time differences measured by the **Timing Diagnostic System**'s CNS II GPS clocks during the first half of O3 indicate that the **Timing Distribution System** performance did not suffer from problems. Additionally, the time differences measured by the Cs-III cesium clocks indicate that the **Timing Distribution System** performance did not suffer from short-term or transient problems.





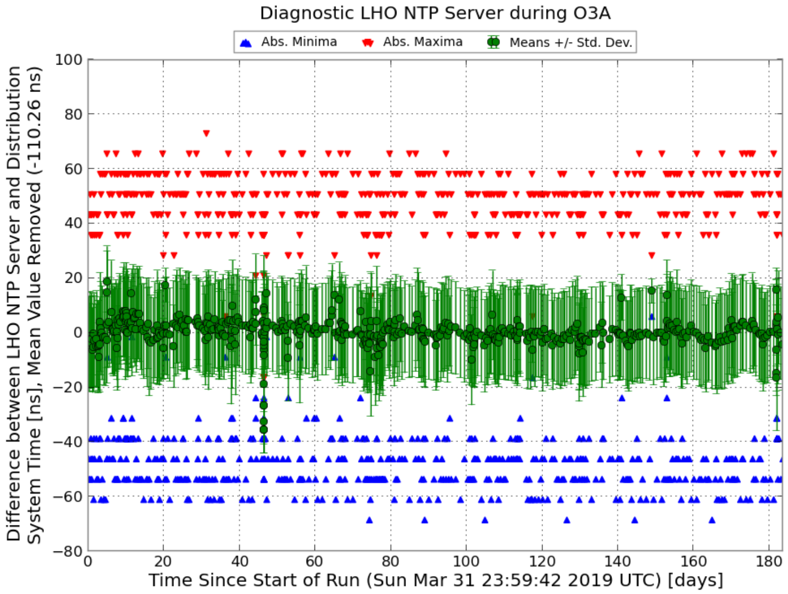


Figure 1: Timing Difference between the NTP Server and the Timing System's internal 1PPS signal at LHO during O3A. (EPICS channel name: H1:SYS-TIMING_C_MA_A_PORT_2_SLAVE_CFC_TIMEDIFF_3; *DQ Flag: H1:DMT-ANALYSIS_READY:1*)

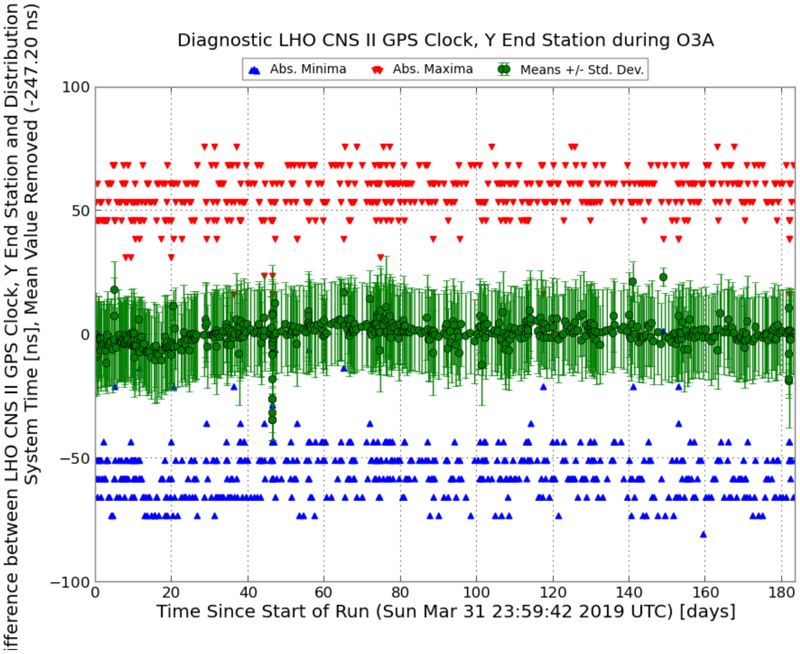
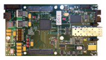
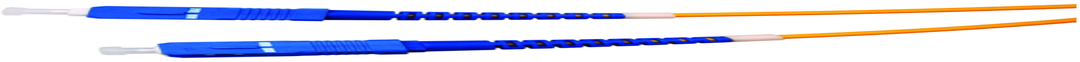


Figure 2: Timing Difference between Y End CNS II GPS Clock and the Timing System's internal 1PPS signal at LHO during O3A. (EPICS channel name: H1:SYS-TIMING_Y_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_3; *DQ Flag: H1:DMT-ANALYSIS_READY:1*)





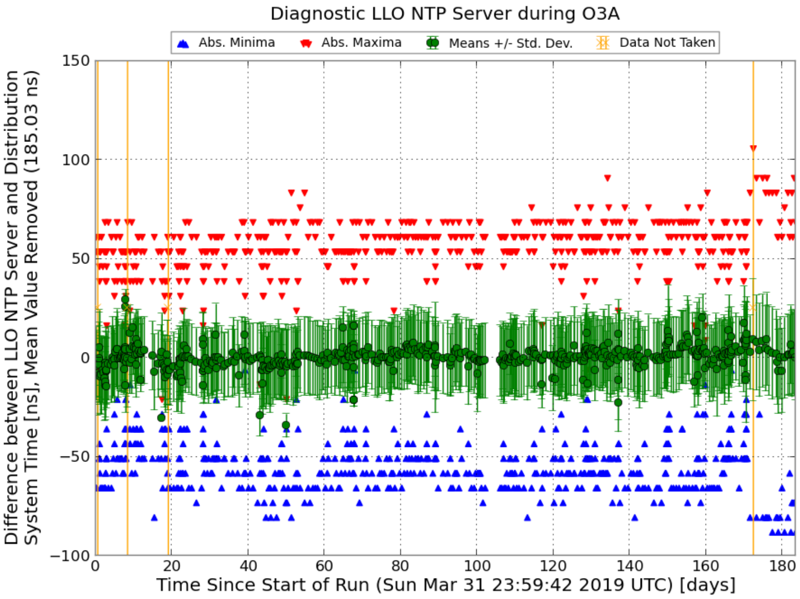


Figure 3: Timing Difference between the NTP Server and the Timing System's internal 1PPS signal at LLO during O3A. (EPICS channel name: L1:SYS-TIMING_C_MA_A_PORT_2_SLAVE_CFC_TIMEDIFF_2; *DQ Flag: L1:DMT-ANALYSIS_READY:1*)

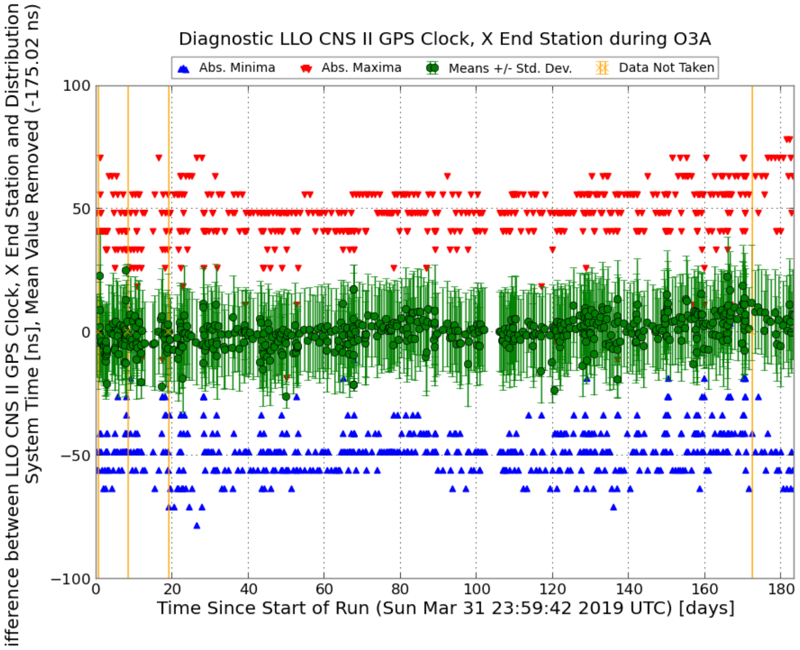
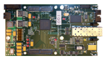


Figure 4: Timing Difference between X End CNS II GPS Clock and the Timing System's internal 1PPS signal at LLO during O3A. (EPICS channel name: L1:SYS-TIMING_X_FO_A_PORT_9_SLAVE_CFC_TIMEDIFF_2; *DQ Flag: L1:DMT-ANALYSIS_READY:1*)



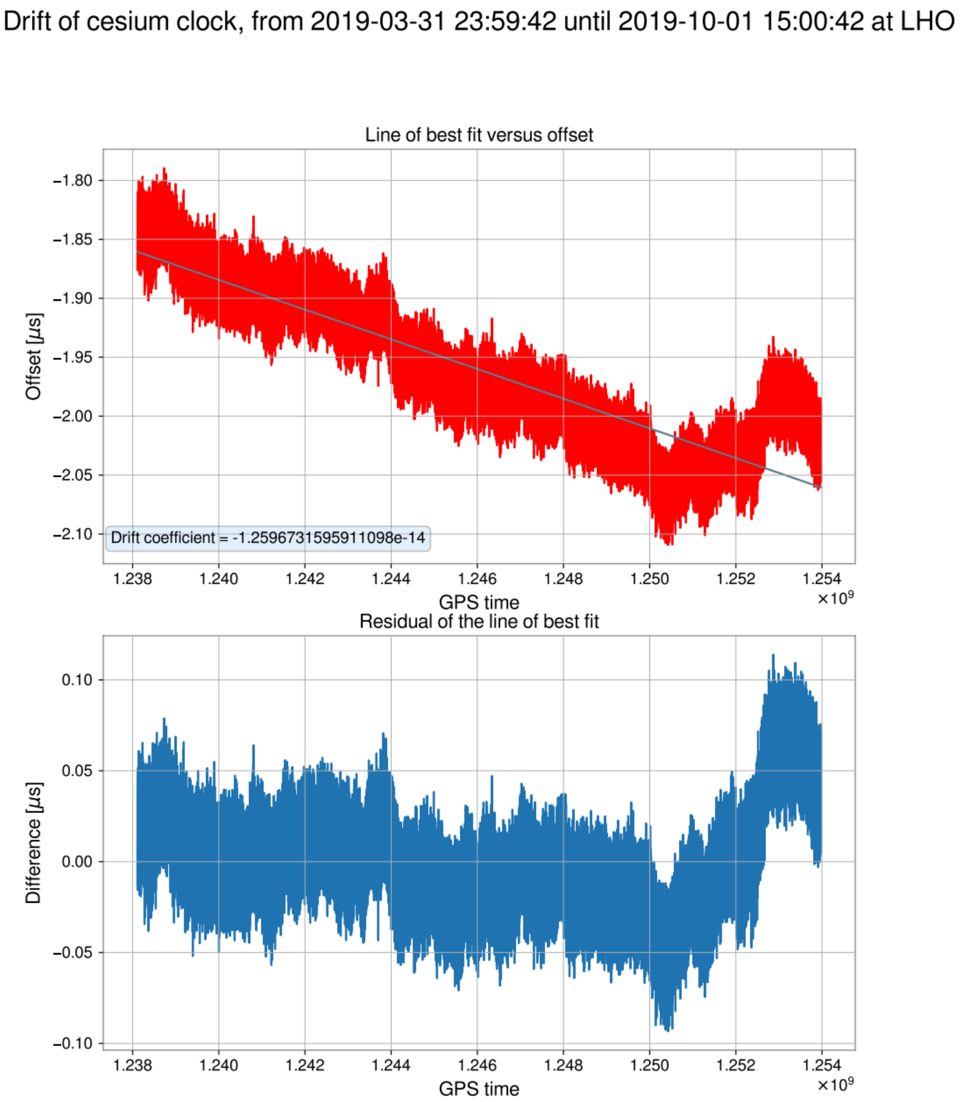
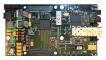


Figure 5: Atomic clock drift at LHO during O3A (EPICS channel name: H1:SYS-TIMING_C_MA_A_PORT_2_SLAVE_CFC_TIMEDIFF_1)



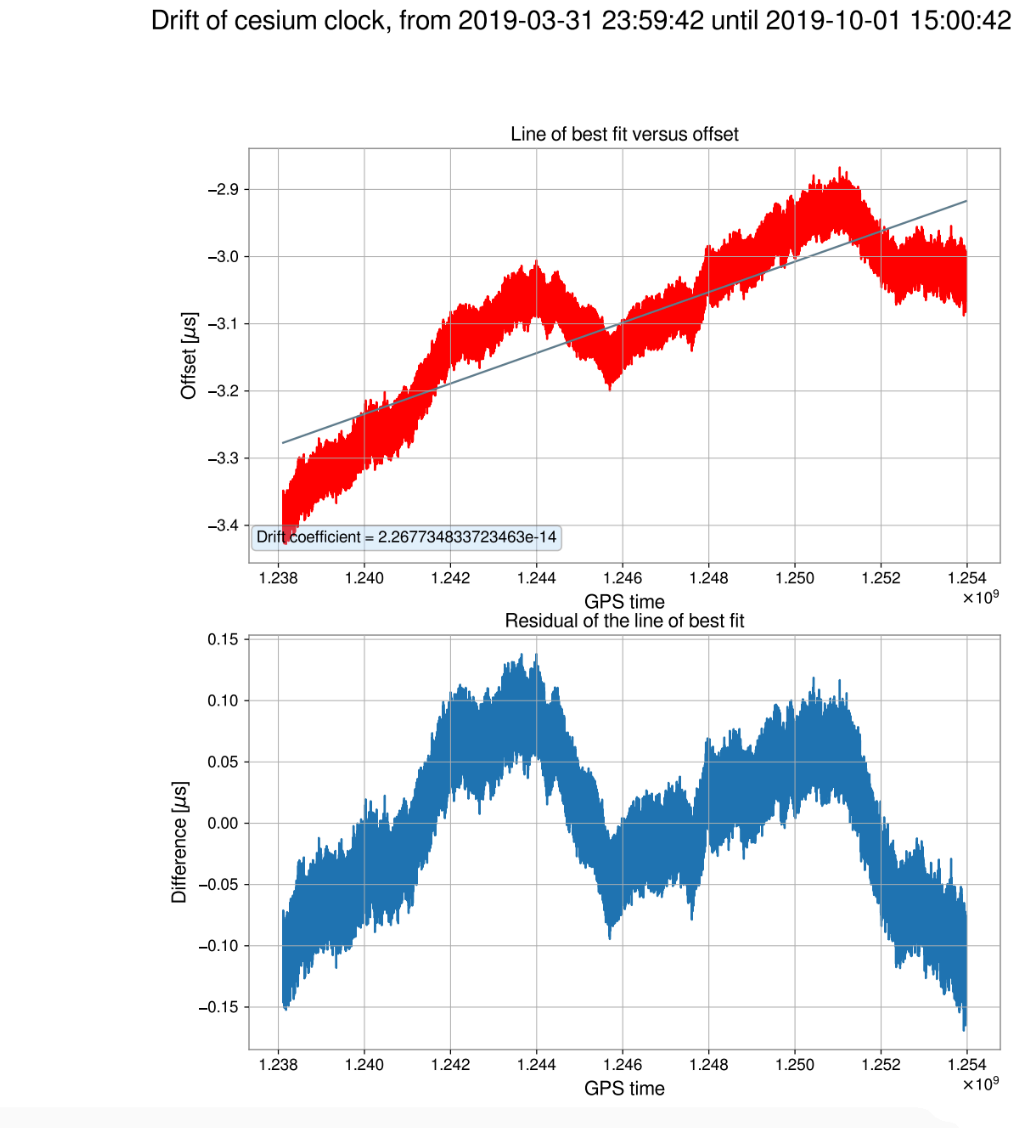


Figure 6: Atomic clock drift at LLO during O3A (EPICS channel name: L1:SYS-TIMING_C_MA_A_PORT_2_SLAVE_CFC_TIMEDIFF_1)