DuoTone

Timing Diagnostics for the LIGO Detectors during S5

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The LIGO Length Sensing and Control (LSC) Data Acquisition System (DAQ)'s Analog-to-Digital Converter module (ADC) records the synchronized output of GPS/Atomic-Clock[1] time sources along with the Gravitational Wave channel in order to ensure accurate and direct diagnostics of data timing. We describe the basic idea behind this system and the associated DMT monitor (called DuoTone).

Accuracy of Digitalization of Analog Timing Signals:

A typical ADC digitizes analog signals by taking readings at the rising edges of clock pulses. There is no information recorded about the waveform between these moments. For example, an ADC that has an internal 16kHz clock takes one reading every 1/16384 seconds (approximately 61μs). Traditional analog timings signals are square wave type. Digitalization of such signals is inherently limited by the ADC's internal clock. In our case, the timing of the rising edge of the square-wave signal will be somewhere in between two subsequent readings that are 61μs apart (Fig-Top). Therefore, in the digital world, steep edges are not good choices for timing as opposed to the analog world.

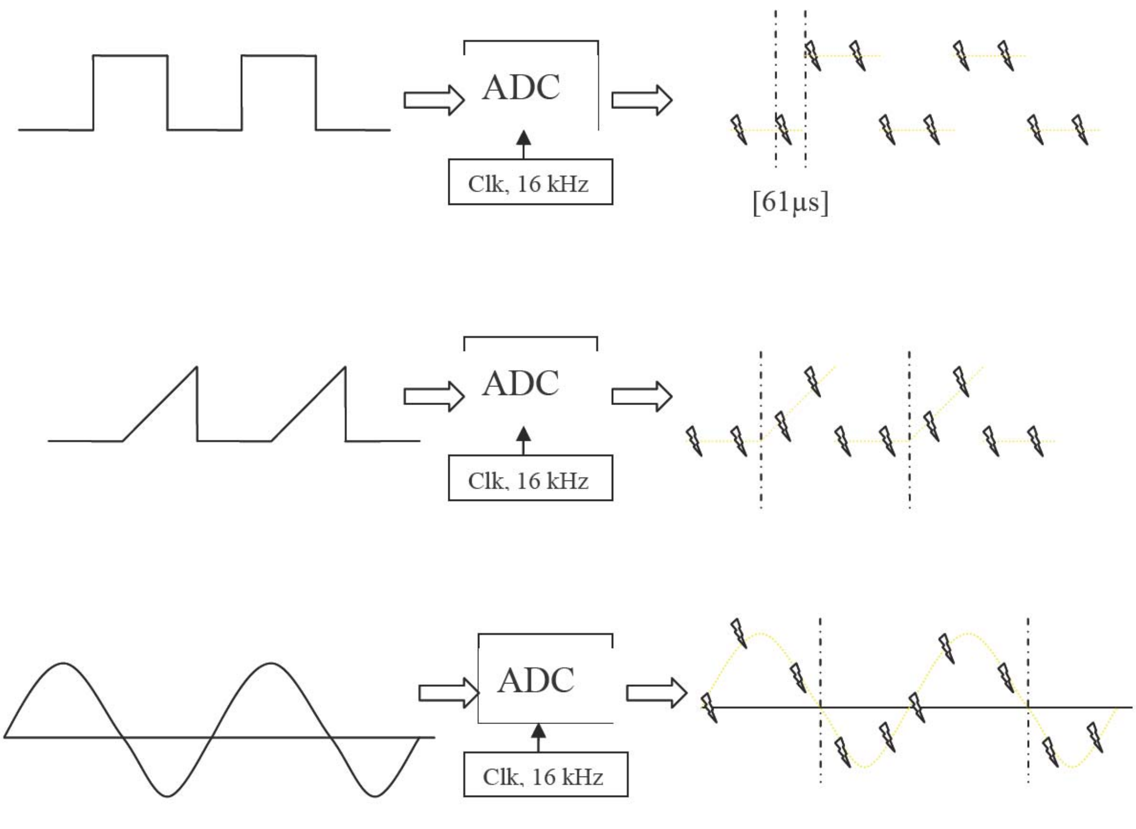

Figure 1 Timing signal types

[1] We will use GPS in this document to refer to a local, long term and accurate time source for brevity. In practice this can mean GPS or Atomic (Caesium) clocks.

There are techniques to overcome this limitation. LIGO uses two of them: (a.) using a (not too steep) GPS synchronized ramp signal and (b.) relying on GPS synchronized sinusoidal signal(s).

In case of a ramp signal, where multiple ADC samples are taken during the duration of the ramp, it is possible to determine the starting point of the ramp (where the signal starts rising) from the baseline and a fit to the sloping part of the ramp. The practically achievable accuracy can be better than 1µs for non-noisy channels and by observing sequential readings (Fig-Mid) it can also be somewhat improved.

For a sinusoidal signal (of well known frequency), it is possible to determine the phase (Fig-Bottom), with similar accuracy.

Present timing diagnostic practice:

Except for the LSC system, timing diagnostics of present LIGO data streams rely on several ramp signals[2] (GPS synchronized, 1Hz rate). Ideally each ADC board should have one of these channels. In practice it is only done for the most important boards (~3-4 per interferometer).
The ramp signals are ~O(1ms) long and start/terminate sharply. Therefore they are good approximations for a '[Dirac comb]'. The [Fourier transform] of a Dirac comb is also a Dirac comb. This means that if there is a cross talk between channels, a Dirac comb (1Hz spacing) will contaminate the neighboring channels' frequency spectrum. By S5 we have reached the sensitivity that this contamination was unacceptable for the gravitational wave channel in the LSC.

Therefore the new LSC timing diagnostics is based on a different principle, where only a small set of frequencies can be contaminated by crosstalk[3]. The gravitational wave data stream's timing must be tracked for ~O(1µs) and timing problems bigger than 0.5s are

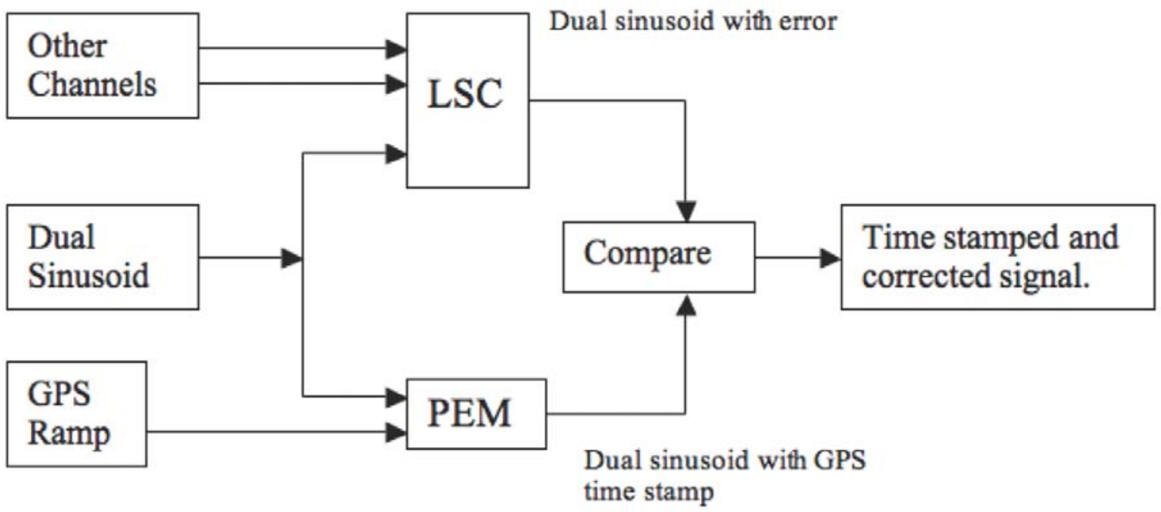

Figure 2 Block diagram of DuoTone signal flow.

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[2] See TimeMon documentation for further information.

[3] This contamination is desirable as it also allows us to track and record the time evolution of the crosstalk to the gravitational wave channel.

diagnosed through different tools (e.g. IRIG-B). These constraints allow us to use only two (GPS and phase synchronized) sinusoids with frequencies 1Hz from each other (DuoTone, Fig.2). Currently we use 960Hz and 961Hz signals; 960 is a harmonic of 60Hz to further preserve GW signal frequency space. The phase of these sinusoids can be determined in the digital domain. The only coincident zero crossing (per second) clearly and unambiguously marks the GPS 1PPS second tic in the data, therefore allows us to determine the relative time shift between the time stamps of the data and the absolute GPS time.

Unfortunately, currently the sinusoids are not hardware synchronized to the GPS time[4] therefore a software synchronization step is necessary. The DuoTone DMT monitor also takes care of this. The dual sinusoid signal is generated by the DMT arbitrary waveform generator (AWG). This signal is split and one copy goes into the LSC ADC. The other copy goes into the Physical Environmental Monitoring System (PEM) ADC. The PEM ADC also has a GPS synchronized (1PPS, 1Hz) ramp signal. Since the ramp signal is not in the LSC crate, it cannot pollute (easily) the other channels on LSC. By propagating the PEM ramp based timing to the PEM DuoTone sinusoid we can obtain the absolute timing of the AWG's DuoTone signal. This information and the coincident zero phase position of the DuoTone signals in the LSC is then used to determine the absolute timing of the LSC GW data.

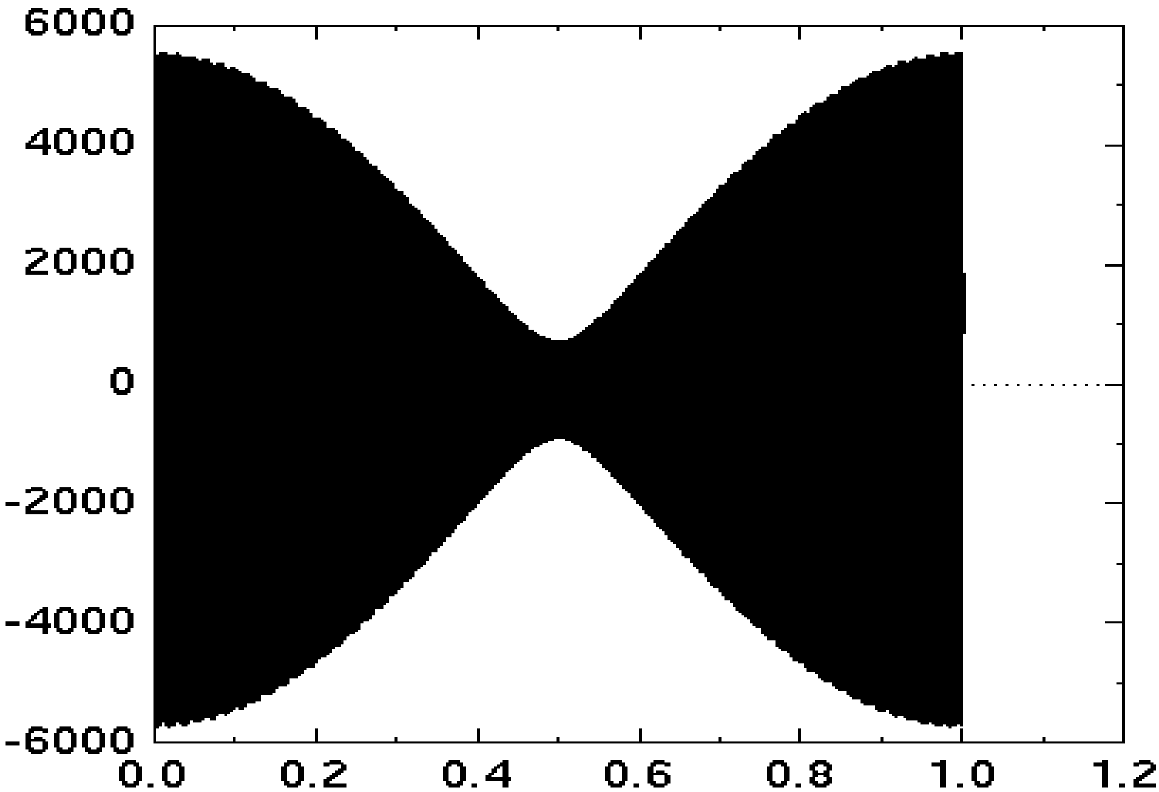

Figure 3 Envelope of a DuoTone signal (x axis is Time [s] and y axis is ADC counts).

[4] While a hardware solution already exists, it is only scheduled to be implemented after S5.

Output:

The DuoTone DMT monitor's output can be found from the SPI page. The main output (besides the alarms, EPIC data, trends and WebView/DMTViewer plots) is a table for each detector. The information provided in this table is in the following form:

Measurement time[5]	Channel[6]	Timing Shift[7]	Meas.Time from NOW[8]
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[852578354]	H1:DMT-DUOT_ :	**-2.418 us**	(-62 s)
[852578307]	H1:DMT-DUOT_ :	**-2.395 us**	(-109 s)
[852578261]	H1:DMT-DUOT_ :	**-2.387 us**	(-155 s)
[852578217]	H1:DMT-DUOT_ :	**-2.388 us**	(-199 s)
[852578173]	H1:DMT-DUOT_ :	**-2.395 us**	(-243 s)

…

[5] The GPS time of the middle of the time interval from which the result in this row was derived.
[6] The channel name with the name of the interferometer (H1 = LHO 4K, H2 = LHO 2K, L1 = LLO 4K)
[7] This is the actual result. This is the mean discrepancy between the time stamp on the data and the absolute time for the interval of the measurement. Nominally, this value should always be within ± 10μs.
[8] For easier reference: The distance in time from the moment of the webpage creation to the actual measurement. Should not be longer than a few minutes… *(The web page is created by a stand-alone 'cron job'. If DuoTone stops working, this distance will keep increasing, as there will not be new results created.)*