CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Laser Interferometer Gravitational Wave Observatory (LIGO) Project

To/Mail Code:	
From/Mail Code:	Daniel Sigg Szabi Márka
Phone/FAX:	
Refer to:	LIGO-T030098-00
Date:	May 22, 2003

Subject: **Atomic Clock Proposal**

Summary:

We propose to install and integrate an independent timing system based on a caesium clock. The purpose of this system is twofold:

- Provide a diagnostics system to check and verify the current timing system which is based on GPS. And provide a NIST traceable calibration of absolute timing.
- Proof that we understand the arrival time of gravitational waves from an astrophysical point of view.

The equipment costs for this system are estimated to be 200k$.

Requirements:

The requirement of relating the arrival time of a gravitational wave at the vertex with the international timing standard is ±10µs. In the past the requirement of the clock was set to ±1 µs to allow for uncertainties in translating this time to the response of the interferometer. It is clear that one may relax the requirement on the clock as long as the overall uncertainty stays below ±10µs. We believe it is important to have both a primary system and an independent verification system that both deliver this accuracy. We feel strongly that it is not an option to miss a discovery just because of a relatively small timing error that has gone unnoticed.

An Illustration:

If one assumes a 1kHz signal and tolerates no more than a 20° phase mismatch between different detectors, the required timing precision has to be better than 50µs. Some people may argue that a 1kHz bandwidth isn't high enough, or that they would like to know the phase to better than 20°. This illustrates the ultimate need for a timing accuracy at the ±10µs level.

Current System:

The current timing is based on GPS master clocks that are located at every building. A quartz oscillator running at 2^{24}Hz is phase locked to the GPS 1pps signal and serves as the main clock signal for the ADC and DAC boards. Data are collected in segments of 1/16s length before they are assembled into 16 second long frames. Whereas the exact time mark is provided by the front-end hardware, the GPS master clock is also read out to provide the time stamps of the 1/16s long data segments. To monitor the accuracy of the sampling process a ramp signal several samples long that is precisely aligned with the GPS 1pps is read in on an auxiliary channel. To check the time stamp of the data we also read in an IRIG-B signal that is derived from the same GPS master clock. Furthermore, the LSC software incorporates several internal consistency check to make sure that there is enough time to process the data before the next sample arrives, to make sure that each and every sample is actually seen by the ADC, and to make sure the DSCs in mid and end stations are working in synchronization with the LSC. To transfer the timing information to the physical arrival time of gravitational waves one has to calibrate the time delay—either in the input chain or, because of the current amplitude/phase calibration procedure, in the suspension chain. It is envisioned that the most accurate timing calibration will be derived from the photon calibrator. Because it uses radiation pressure to apply a force to the ETMs, it is the most direct way to induce a displacement.

Proposal:

Whereas the current system is good enough to meet the requirements (eventually), it is rather difficult to proof. Since absolute and long term timing accuracy is of outmost importance for the pulsar analysis, we propose to implement a second independent timing system that is capable of verifying the current system at the design requirement level. This independent timing system would serve as both a diagnostics system to check the performance of the current system as well as a monitor system to continuously evaluate the timing accuracy during science runs. This new system should fulfill the following criteria:

- Establish an independent time base at the same accuracy as the primary system, i.e., somewhat better than ±10µs.
- Be available in all buildings so that both the input and output chains can be tested. One should also be able to synchronize the photon calibrator, so that a direct measurement of the optical and electronic delays can be performed.
- Be conceived as both **independent** and **sufficient** by the LSC collaboration and the astrophysics community at large.

Options:

There is basally one option that will deliver the required accuracy as well the desired independence: a caesium based atomic clock. The option of using WWVB has been discarded because it won't deliver the required accuracy. The option of using an ensemble of GPS clocks from independent vendors has been discarded because another GPS system will not be considered independent by most. Installing an atomic clock should remove any doubts about the timing accuracy once and for all.

Proposed System:

We propose to install a caesium master clock at each site that serve as the long-term timing standard. We also propose to acquire a portable rubidium clock at each site to synchronize the caesium clock to NIST and other GW observatories, to perform diagnostics at the outbuildings and to serve as a short-term backup if the Caesium clock needs service. The time signal is sent to the outbuildings over an optical distribution system. We intent to sent the timing signal to all outbuildings and to use it there to synchronize the photon calibrator and to compare it against the local GPS master clock.

Equipment		unit	ext.
Caesium clock, Datum CS plus	2	38k$	76k$
Portable rubidium clock, AR-51A	2	15k$	30k$
Optical distribution system (LHO/LLO)		39/25k$	64k$
Fiber cabling (single mode between LVEA/MSR)		3/2k$	5k$
Time-Interval Measurement (e.g., Agilent 53131A)	9	2k$	18k$
UPS (36h for caesium clock)	2	3k$	6k$
Total			199k$

cc:

commissioning group   revision technical review board

Document Control Center