LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Photon Calibrators Upgrade Proposal

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1 Introduction

This document outlines several proposed upgrades to the existing Photon Calibrators. These proposals are based on recent efforts to understand the performance of the iLigo photon calibrators and considerations of how to best integrate them into eLigo and AdvLigo.

The proposed upgrades are:

1) Electronics upgrade
2) Optical layout upgrade
3) Power calibration and monitoring upgrade
4) Installation upgrade

1.1 Relevant documents

1) T070026-00-W **Status of the LIGO Photon Calibrators: February 2007** (http://www.ligo.caltech.edu/docs/T/T070026-00.pdf)
2) T070050-00-W **Comparison of photon calibrator results with the official calibration** (http://www.ligo.caltech.edu/docs/T/T070050-00.pdf)
3) The **photon calibrator section of the mLigo wiki** contains details of the proposed Pcal installation upgrade including pricing information (http://lhocds.ligo-wa.caltech.edu:8000/mLIGO/Photon_Calibrators).

2 Electronics upgrade

The Pcal electronics modules were originally mounted inside the Pcal box on the breadboard next to the optical components. The electronics boxes occupied approximately one third to one half of the space available for optical components. Incursions into the box to address electronics issues risked exposure to laser hazards and potential misalignment of optical components. The electronics are also a significant source of heat, especially the AOM driver. We recently found that the LHO MidX Pcal box operating temperature was about 11 deg. F above ambient, presumably due to the electronics modules. After removing the electronics modules, the only heat-generating components inside the Pcal box will be the AOM, the laser, and the power monitor.

We propose moving the laser power supply and controller, the AOM driver, and the Ligo-built Pcal electronics module which contains the PD pre-amplifier and the Pcal drive signal conditioner outside of the Pcal box. The laser power supply needs to be located close to the Pcal box because limitations in the thermo-electric cooler drive electronics preclude cable lengths over several feet without modifications at the manufacturer (~$500.00 for each unit). To avoid the cost and delays associated with sending the units back for modification, we propose mounting the laser supply to the *outside* of the Pcal box. The cable between the supply and the laser will utilize a DB9 bulkhead connector on the Pcal box.

The other modules, the AOM driver and the Ligo-built electronics, can be mounted more remotely, e.g. on the floor of the VEA or in an electronics rack. Two cables are required for the Laser

Safety/Personnel Access system (LS/PAS): one from the Pcal box lid interlock to the LS/PAS panel and one from the LS/PAS panel to the external interlock phone jack connector on the back of the laser power supply.

The electrical connector modifications to the Pcal box have already been made to the LHO Xend Pcal box, the mounting details for the laser power supply have been designed, and the implementation and testing should be completed by June 1, 2007.

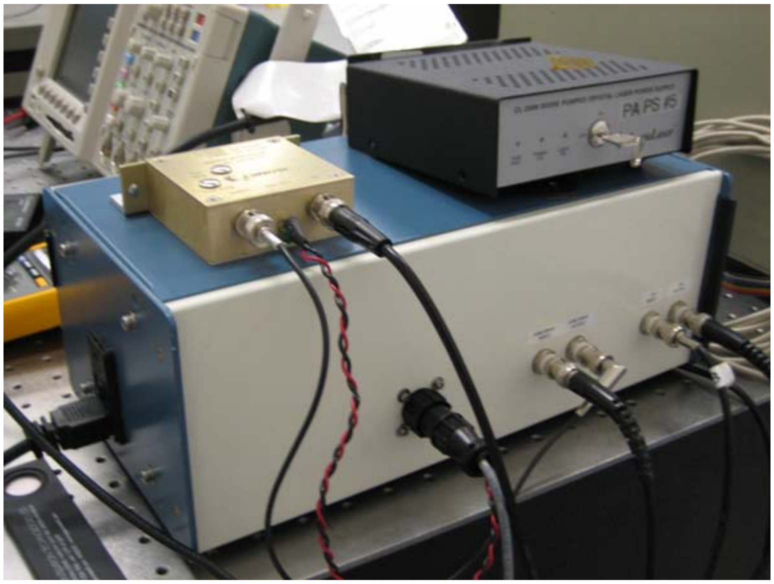

Figure 1 **Pcal electronics modules. The large white and blue box houses the signal conditioning amplifiers. The AOM driver is gold box on top at the left. It uses the lower box for heat sinking. The laser power supply is on top on the right.**

Figure 2 **Pcal electrical feed-throughs in the upgraded configuration. The internal power sensor output utilizes the isolated BNC bulkhead connecter on the upper left. The AOM drive input utilizes the isolated SMA**

feed-through on the upper right. The door interlock (two wires only) and the laser power supply to head interface are via 9-pin D connectors. The power for the internal PD utilizes the 4-pin CPC connector at the bottom. This would not be required with the proposed power sensor upgrade, which utilizes a photodetector operating in photovoltaic mode, if the current amplifier is mounted externally.

3 Optical layout upgrade

Utilizing part of the space gained by removing the electronics modules, we have reconfigured the optical path to accomplish several goals. Among these are optimization of beam parameters to improve diffraction efficiency in the AOM, modematching to optimize spot size on the ETMs, accommodation of multiple output beams, implementation of an alignment laser (laser pointer) upstream of final steering mirrors via a flipper mount, and placement of the PD in order to minimize exposure to scattered light.

If we change to a different power sensor, e.g. an integrating sphere as proposed in the next section, the layout will likely need to be further reconfigured to accommodate the new sensor. We presently plan to run the Pcals in a two-beam configuration with the spots symmetrically displaced *vertically* from the centers of the ETMs. It appears that the two beams layout can work with typical mirror mounts. Iif we decide to utilize a four-beam configuration, custom mounts may be required due to space constraints inside the pcal box, field of view constraints, and the desire to minimize the Pcal beam space required on the LHO viewports. Viewport availability may become particularly tight at LHO when H2 will be converted to a 4-km-long interferometer and two interferometers will share one set of spool viewports.

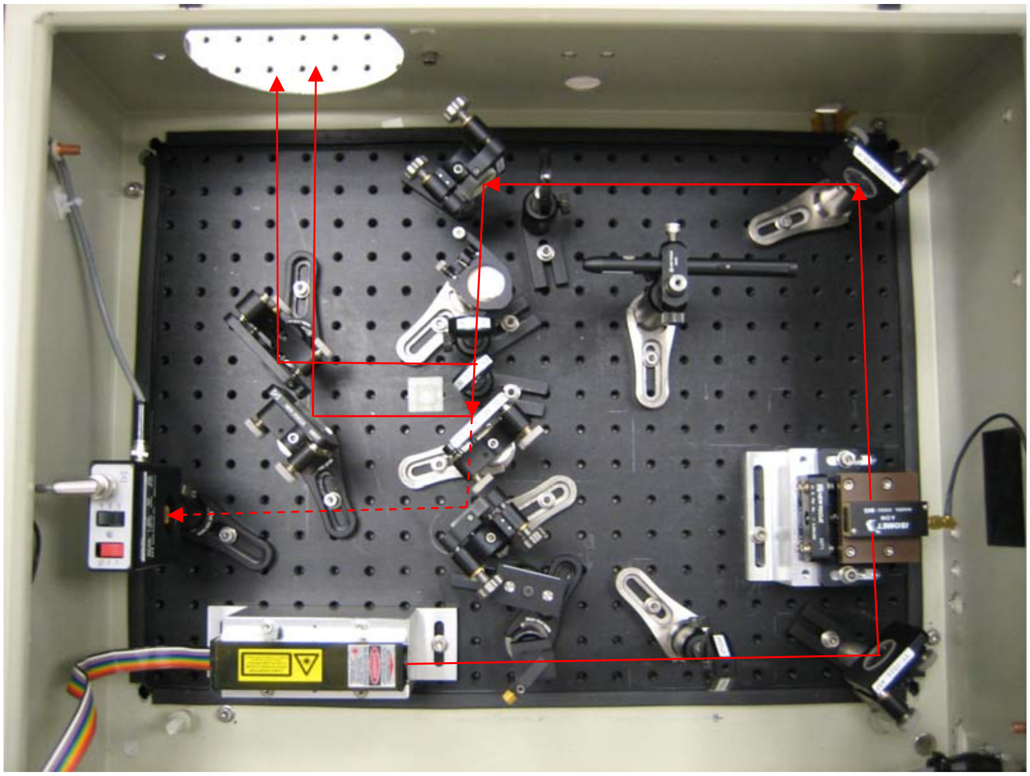

Figure 3 **Bird's-eye view of proposed layout upgrade. The two-beam output configuration is shown. The horizontally-polarized laser output passes through a polarizing beamsplitter cube before being focused into the AOM. The first order diffracted beam is then focused by a single spherical lens on the way to a 50%**

beamsplitter. The splitting ratio is fine tuned by adjusting the angle of incidence by rotating the splitter. The reflected and transmitted beams are then directed to the final steering mirrors that control the beam positions on the ETM. The PD would be replaced by an integrating sphere with an integrated PD if the proposed power monitoring upgrade is implemented. The laser pointer and flipper mount are for initial rough alignment of both beams.

4 Power calibration and monitoring upgrade

The principal source of error for the Pcals is absolute calibration of the modulated power levels incident on the test masses. The Pcals have utilized thermal power meters – calorimeters, from Scientech and Ophir - for measurements of the output power and calibration of the New Focus large-area PD mounted inside the box. Due the slow response of the thermal meters, the calibrations have been performed via DC offsets in the amplitude of the 80 MHz drive level to the AOM. We have encountered a number of difficulties with the thermal meter measurements. We suspect that some are related to positioning of the external sensor.

We propose to upgrade both the external power meter and the internal sensor to integrating spheres with fast germanium photodetectors. The internal sensor (integrating sphere and PD) will sample approximately 1-10% of the laser light. The integrating spheres should eliminate most of the errors associated with placement of the sensor head. Because the scattered light inside the sphere illuminates the whole surface of the PD, non-uniformities of PD response are also minimized. With proper selection of the integrating sphere size, surface material, and PD size and mounting location, the same sensor should be suitable for both the external sensor that will be used for calibration and the internal sensors that will constantly monitor a fraction of the laser output.

We propose purchasing the new sensors from a company such as Labsphere Inc. and having them initially calibrated at the manufacturer using a commercially-available fast current amplifier such as the Keithly Instruments model 428[1] (0.1 msec rise time) . We would then send one of the units along with a dedicated current amplifier and dedicated volt meter to NIST for absolute calibration at the sub-one-percent level[2]. We propose to make this NIST-calibrated sensor a "gold standard" that we would keep in the lab and use to periodically calibrate a similar "working standard" that we use to calibrate the sensors inside the Pcal boxes.

Conversion from "DC" measurements, which is likely all that NIST would calibrate, to calibration of the modulated power levels would still need some attention, but having a sensor which is, in principal, flat from DC to tens of kHz should go a long way toward the goal of calibrating and continuously monitoring the time series of the power level directed to the ETMs.

The costs for a test of this proposed calibration scheme are significant. They are outlined in Table 1, below.

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[1] R. Savage spoke with Greg McKee at Labsphere who explained that they deliver systems for an OEM that incorporate Keithly current amplifiers that have high output bandwidths. The precision in the current to voltage conversion is specified to be within a fraction of one percent. A quotation, including specifications for the Keithly instrument, is forthcoming.

[2] R. Savage has had several conversations with Josh Hadler, one of the scientist at NIST who is responsible for their power meter calibrations. The cost is approximately $3500.00 for calibration of a single sensor and meter. Labsphere charges $425.00 for their in-house calibration that they specify to be accurate within 3%.

Table 1 Estimated costs for first-article test of proposed calibration scheme

Item	No. reqd.	Unit cost	Total cost
Integrating sphere	3[3]	~$2600	$7800
photodetector	3	~$700	$2100
Calibration at mfgr.	3	~$425	$1275
Calibration at NIST	1	~$3500	$3500
Current amplifier	2	~$4500	$9000
Digital multimeter	2	~$900	$1800
In-box current amp.[4]	1	~500 TBD	~500 TBD
		TOTAL	**$26k**

If this scheme proves successful, the gold standard and working standard could be utilized to calibrate all of the photon calibrators (and other power meters). Only one sensor and in-box current amplifier would be required per additional Pcal. The estimated cost is thus about $5k per additional Pcal. If we upgrade all five additional Pcals, the total additional cost would be ~$25k.

5 Installation upgrade

Experience with the existing Pcals has shown that more space is required to monitor the laser power at the output of the Pcal boxes. We investigated Pcal mounting options recently with respect to end station baffle issues and viewport availability. We propose mounting the Pcal boxes on L-shaped breadboards attached to piers that are bolted to the technical slabs as shown in Figure 4 and Figure 5, below. The Pcal optical components would either be bolted directly to the breadboard or kept as they presently are on a separate 1/2:" thick aluminum breadboard with that breadboard bolted to the L-shaped breadboard. This configuration leaves room along the narrow leg of the L for power measurements and beam steering into the vacuum window. The beam steering optics, and main Pcal optics if they are mounted directly to the L-shaped breadboard, will be covered by an aluminum safety/dust/access control enclosure.

Cost estimates for the proposed Pcal piers are ~$1000.00 each and the breadboards (4' thick from TMC) are about $1800.00 each, so the mounting upgrade would be about $3k per end station not including the aluminum sheet metal enclosures (~$20k for all six end stations).

[3] Gold standard, working standard, and one for inside one Pcal box.

[4] We will have to either build or identify a source for accurate, stable, fast, low-current, current amplifiers for use with the sensors inside each pcal box. They should output voltages in the +,- 2V range to be read by the DAQ.

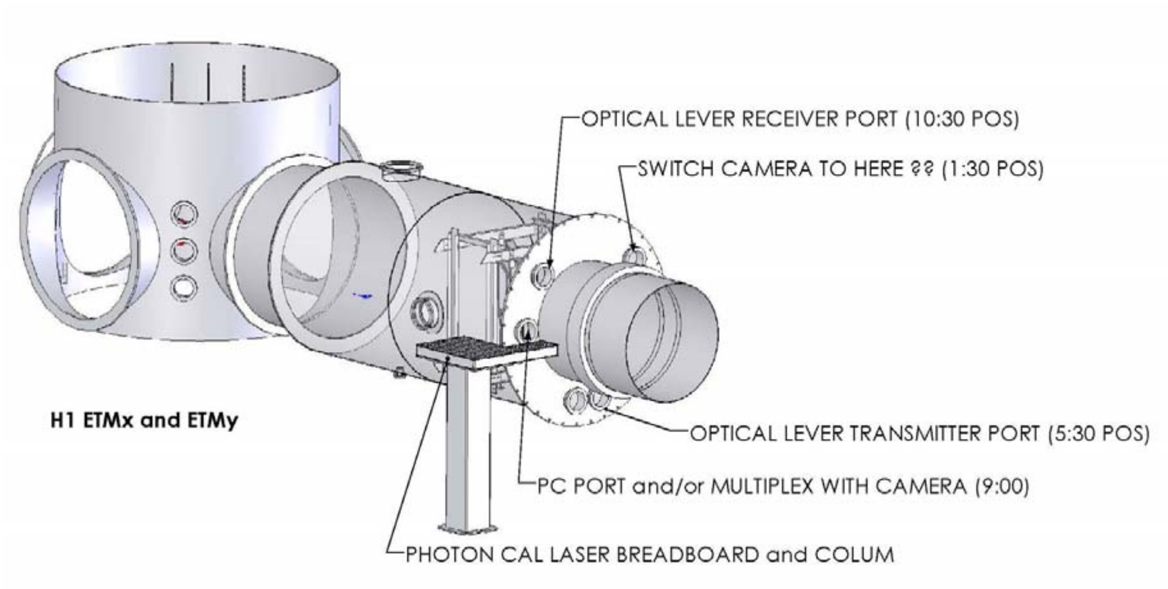

Figure 4 Proposed mounting structure the for Pcal boxes at end stations.

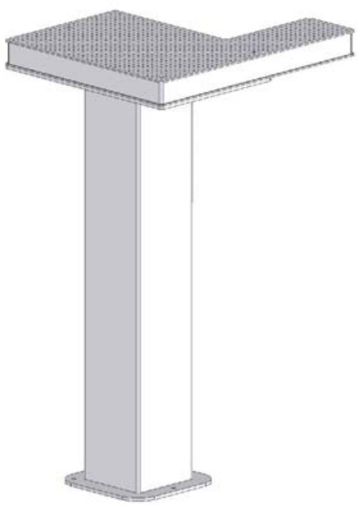

Figure 5 Pcal support structure – breadboard and pier.

Note that viewport utilization at the LHO end stations requires special consideration since two interferometers will share one set of spool ports for photon calibrators, optical levers, ETM cameras, etc.

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