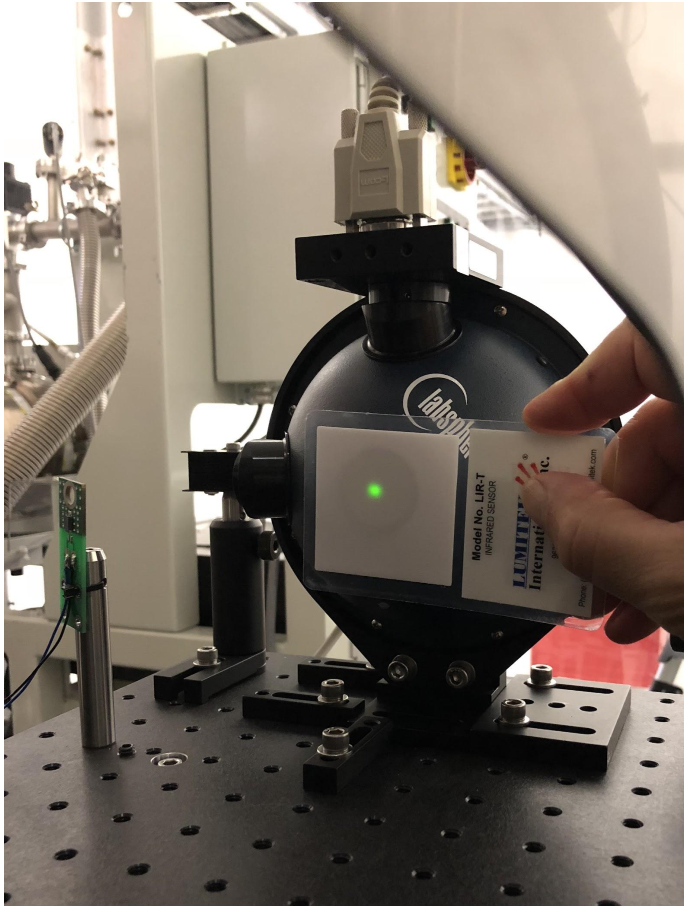
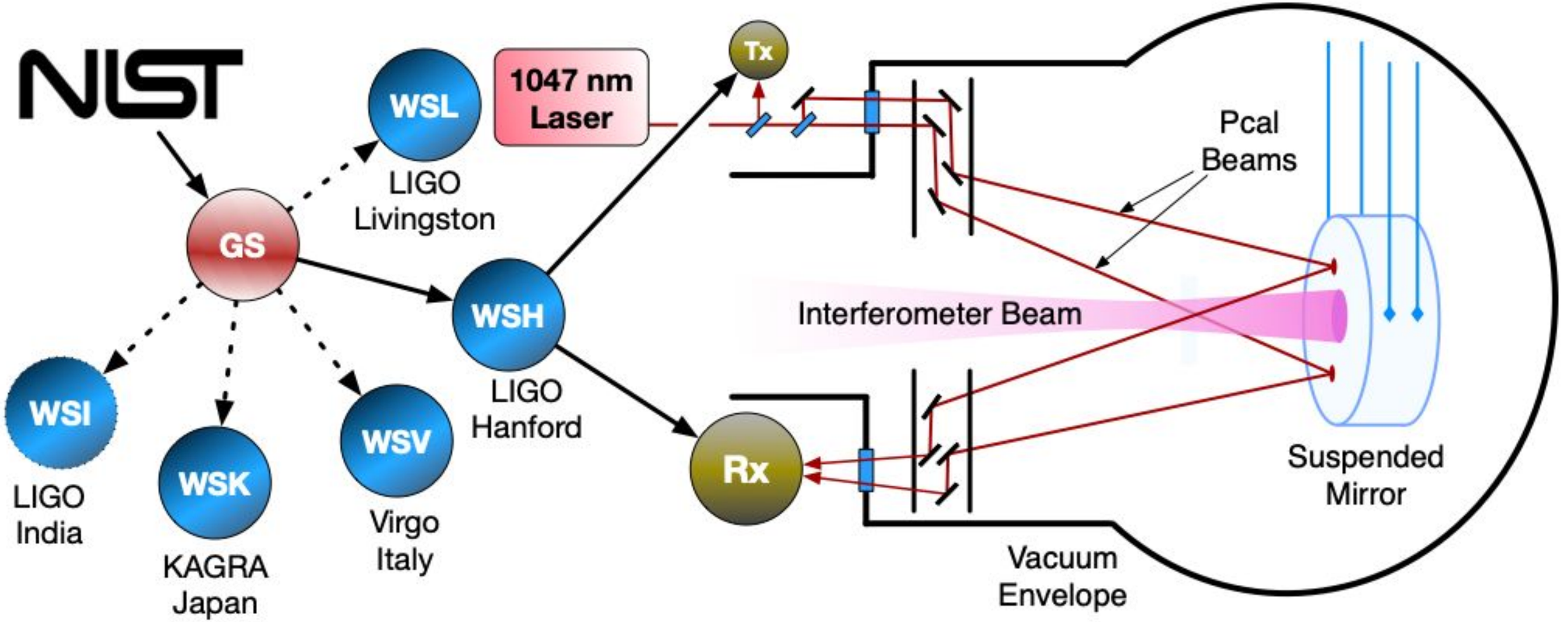
Absolute calibration of the global GW network:

O4 and beyond

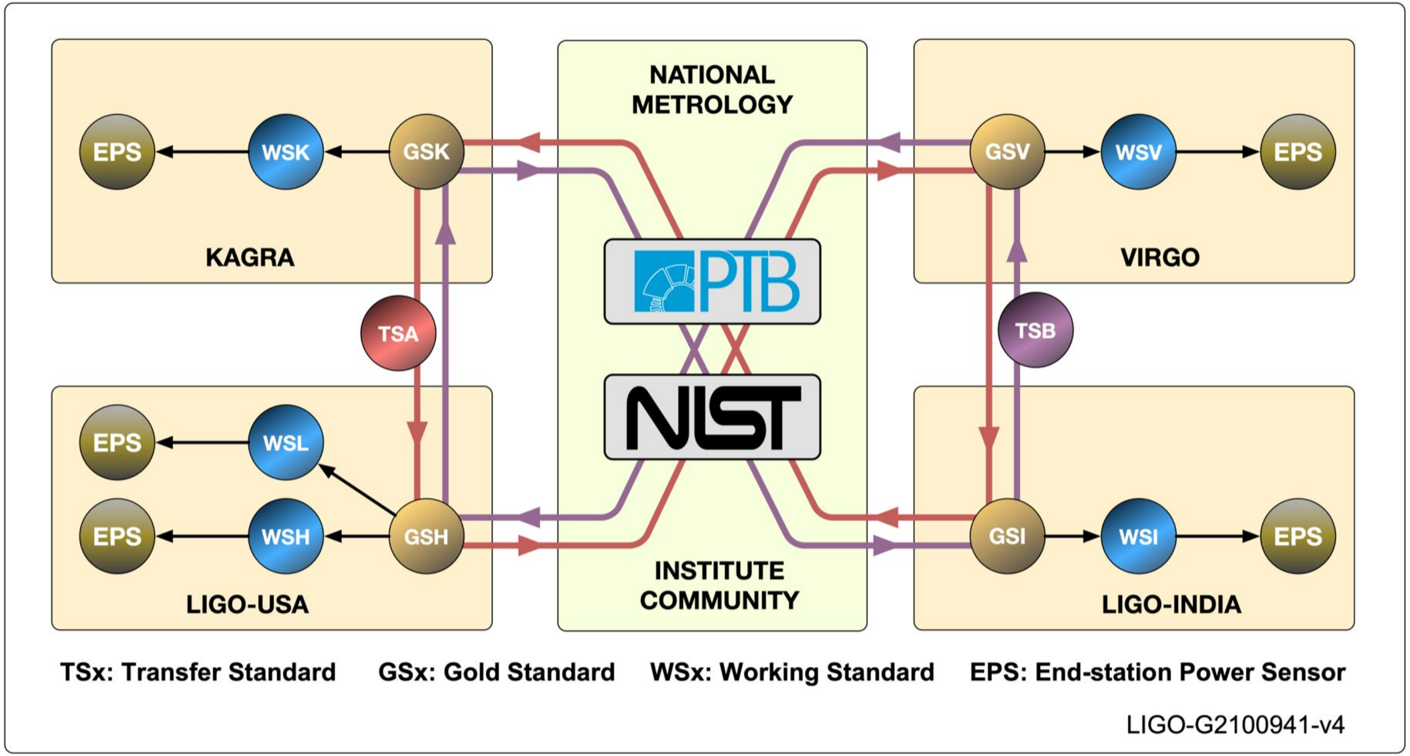


LIGO-G2101737-v1

Transfer of laser power calibration (During O3)



Proposed Plan for O4



NIST/PTB bilateral comparison (conventional methods)

Metrologia

ACCEPTED MANUSCRIPT

A bilateral comparison of NIST And PTB laser power standards for scale realization confidence by gravitational wave observatories

Matthew Spidell[1], John Lehman[1], Marco A Lopez[2], Holger Lecher[3], Stefan Kueck[4], Dripta Bhattacharjee[5], Yannick Lecoeuche[6] and Richard Lenox Savage[6]

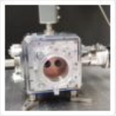
Accepted Manuscript online 16 August 2021 •

Abstract

The Gravitational Wave (GW) observatories calibrate interferometer displacement using photon momentum, with laser power serving as the measurand. These observatories are traceable to the International System of Units through a primary standard maintained by the U.S.'s National Metrology Institute (NMI), the National Institute of standards and Technology (NIST). The bilateral Degree of Equivalence of laser power measurements for various NMIs indicated in the 2010 EUROMET.PR-S2 supplementary comparison reveals scale realization uncertainty unacceptably large for GW event parameterization. We offer here an analysis to identify the source of the discrepancy between the Physikalisch-Technische Bundesanstalt (PTB) and NIST results. Using an improved transfer standard in a bilateral comparison, with representatives of the Laser Interferometer Gravitational-Wave Observatory (LIGO) receiving results prior to their comparison, NIST and PTB demonstrated a Degree of Equivalence of -0.15 % with an uncertainty of 0.95 % (k=2) for combined 100 mW and 300 mW comparison results.

NIST 1-sigma uncertainty 0.42%
PTB 1-sigma uncertainty 0.1%

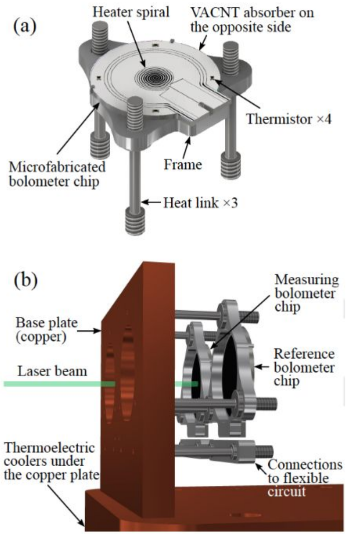
Implementation of new primary standard at NIST



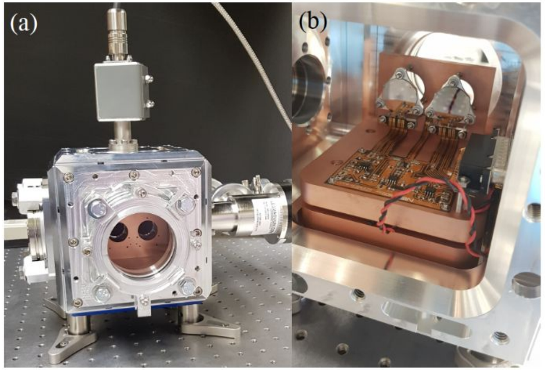
High-accuracy room temperature planar absolute radiometer based on vertically aligned carbon nanotubes

Anna K. Vaskuri, Michelle S. Stephens, Nathan A. Tomlin, Matthew T. Spidell, Christopher S. Yung, Andrew J. Walowitz, Cameron Straatsma, David Harber, and John H. Lehman

NIST 1-sigma uncertainty 0.07%
PTB 1-sigma uncertainty 0.10%

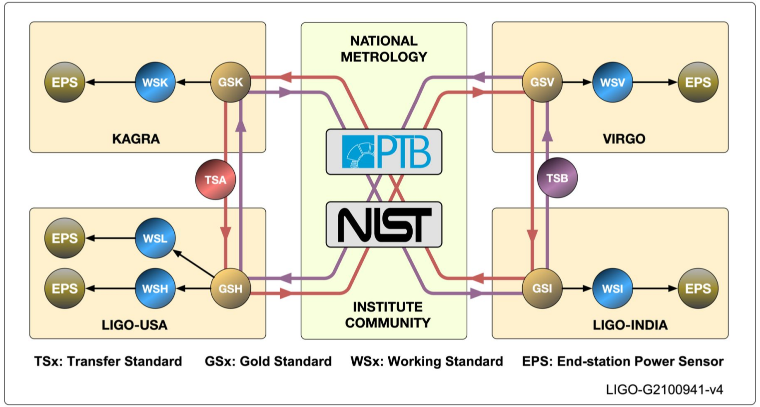


PARRoT expected to "...lower the expanded measurement uncertainty (k=2) from 0.84% to 0.13%."



VACNT: vertically-aligned carbon nano-tubes

Overall strategy for O4 and beyond



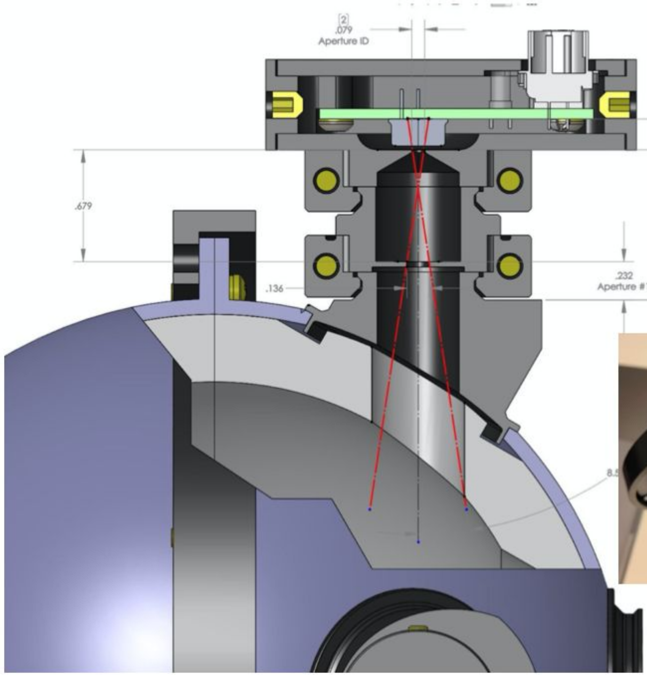
- Updating transfer standard hardware
- Calibrating TSA and TSB
  - At NIST (Boulder, USA) and PTB (Braunschweig, Germany)
- Propagating TSA/TSB calibrations to local Gold Standards
  - Responsivity ratio measurements in local Pcal labs
    - Calibration subway maps (see later slides)
- Propagating local Gold Standard calibrations to local Working standards
  - Local responsivity ratio measurements in Pcal labs
- Propagating local WS calibrations to end station power sensors (EPSs)
  - Local Rx/WS responsivity ratio measurements at observatory end stations

Building updated transfer standards: TSA and TSB

- Updated PD board with integrated AD590 temperature sensor
- Detector spacer (factor of 10 attenuation)
- Updated clamping scheme to increase robustness

LIGO-G2101737-v1

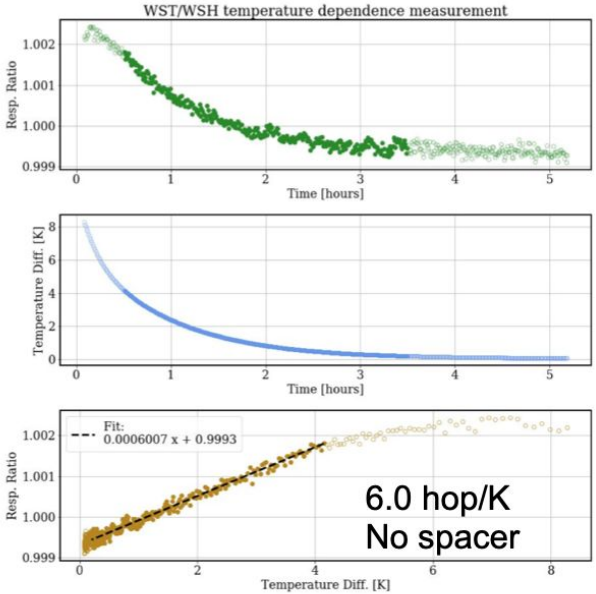
Detector spacer to block view of bore in Spectralon shell

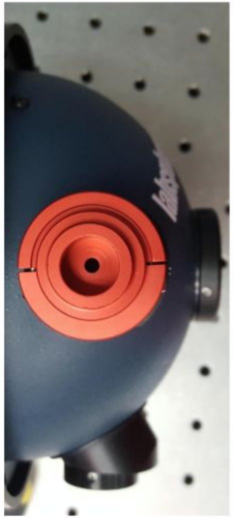


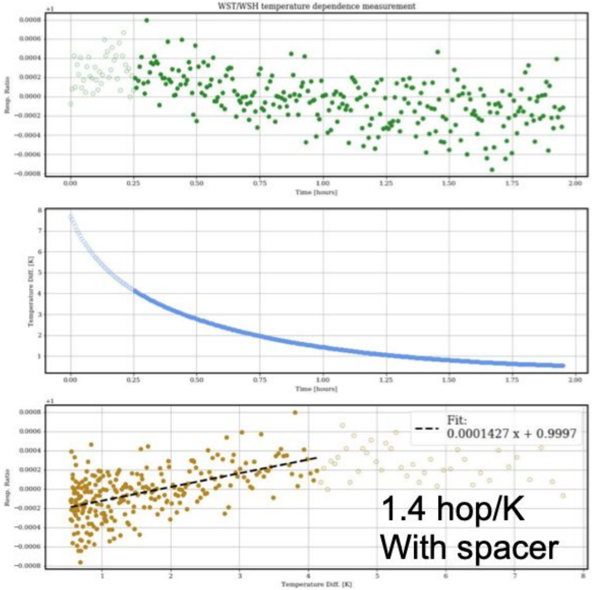
LIGO-G2001928-v2

Advantage of detector spacer

- Temperature coefficient reduced by ~ factor of four





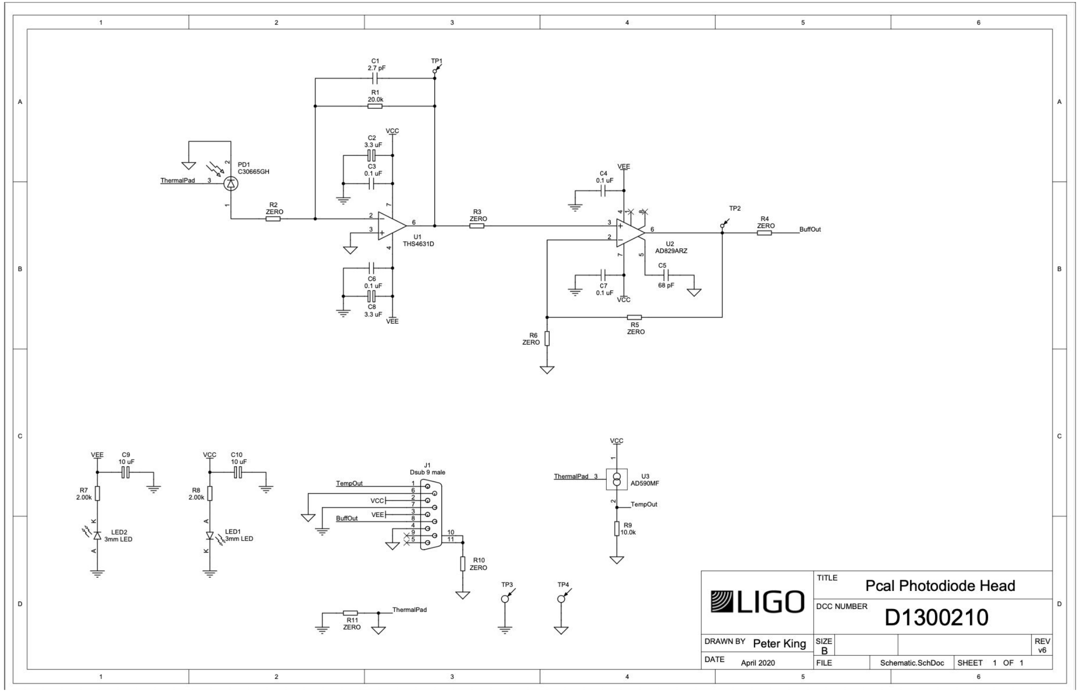


LIGO-G2001928-v2

Required transimpedance gain change due to spacer

- Spacer attenuation: 0.247 V / 2.655 V = 0.0903 or 1/10.75
- Sphere attenuation:
  - ~0.8 A/W for InGaAs at 1047 nm
  - Transimpedance gain of 20 k ohm -> 0.8 A/W x 20e3 V/A = 16e3 V/W
  - NIST calibration of WSS: 8.2 V/W
  - Sphere attenuation (without spacer): 8.2 / 16e3 = 1/1951
    - With spacer: 1/1951 x 1/10.75 = 1/20,976
- For Transfer Standard responsivity ratio measurements, P_laser ~ 330 mW
  - Working standard (for LIGO) could see up to 1 W at end station (one beam). 1W -> 8 V => 8 V / W into sphere
    - 1 W x 0.8 A/W /20,976 => 3.81e-5 A; 8 V/3.81e-5 A -> 2.1e5 V/A PD gain
      - Currently using 20 k ohm transimpedance gain (R1 on v6 board)
      - Change gain of U2 (AD829) to 10 (R5 -> 2.05 k ohm; R6 -> 226 ohm; C5 -> 3 pF) -> gain of ~2e5 V/A from PD

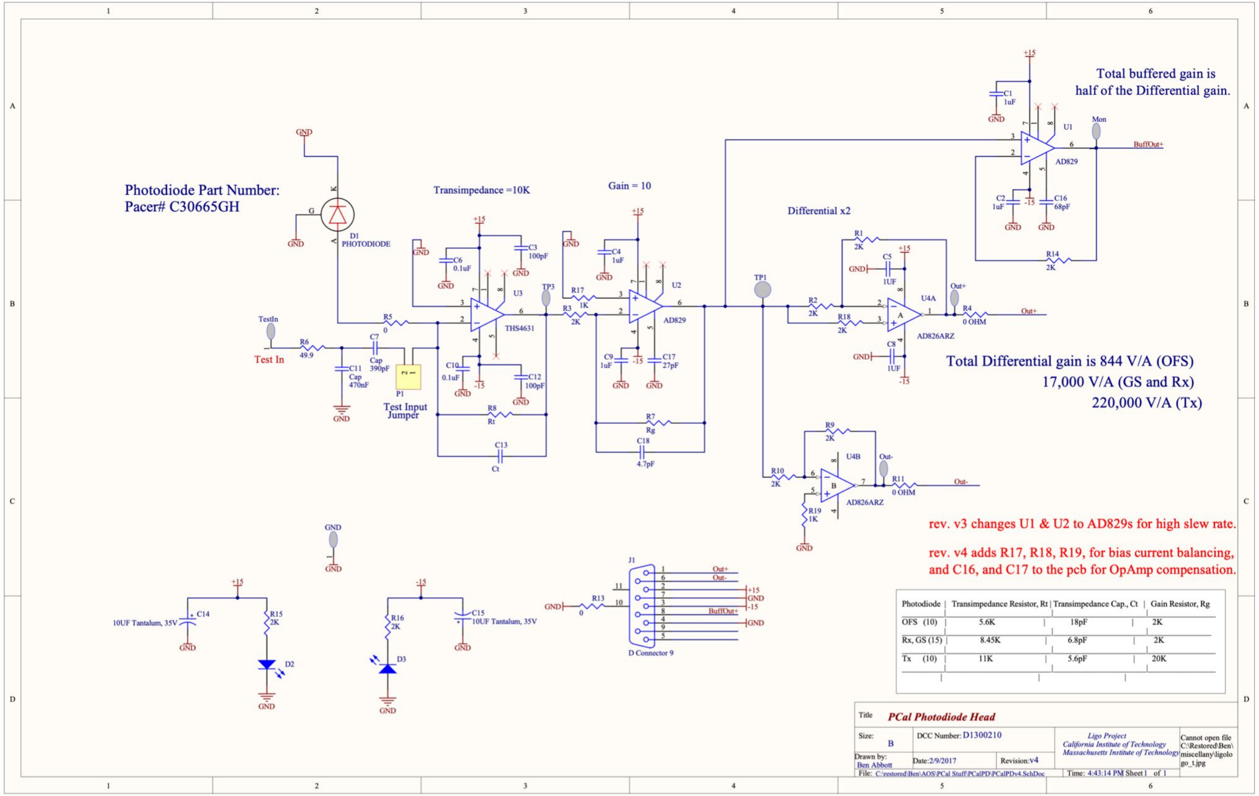
Upgraded PD boards for transfer standards: D1300210-v6



- Single ended output
- Used for all Transfer Standards.
  - TS, GS, WS

Rx (end station) power sensor: D1300210-v4

- Differential output
- No AD590.



Looking Ahead: Methods and procedures

- Analysis of NIST/PTB results
- Temperature dependence measurements (UTRGV?)
- Responsivity ratio measurements in Pcal labs
- Responsivity ratio measurements at observatory end stations
- Optical efficiency measurements

Participants in effort to upgrade power standards

- LIGO (LHO)
  - Sudarshan Karki (MS&T), Varun Srivastava (Syracuse), Rick Savage (LHO)
- Virgo (LAPP)
  - Paul Lagabbe, Loic Rolland
- KAGRA (NAOJ)
  - Darkhan Tuyenbayev, Dan Chen
- LIGO India (RRCAT)
  - Asmita Malik (RRCAT)
- UTRGV (Brownsville)
  - Francisco Llamas, Volker Quetschke
- NIST (Boulder)
  - Matt Spidell