Investigation of Variations in the Absolute Calibration of the Laser Power Sensors for the LIGO Photon Calibrators

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LIGO-G080427-00-W

Overview

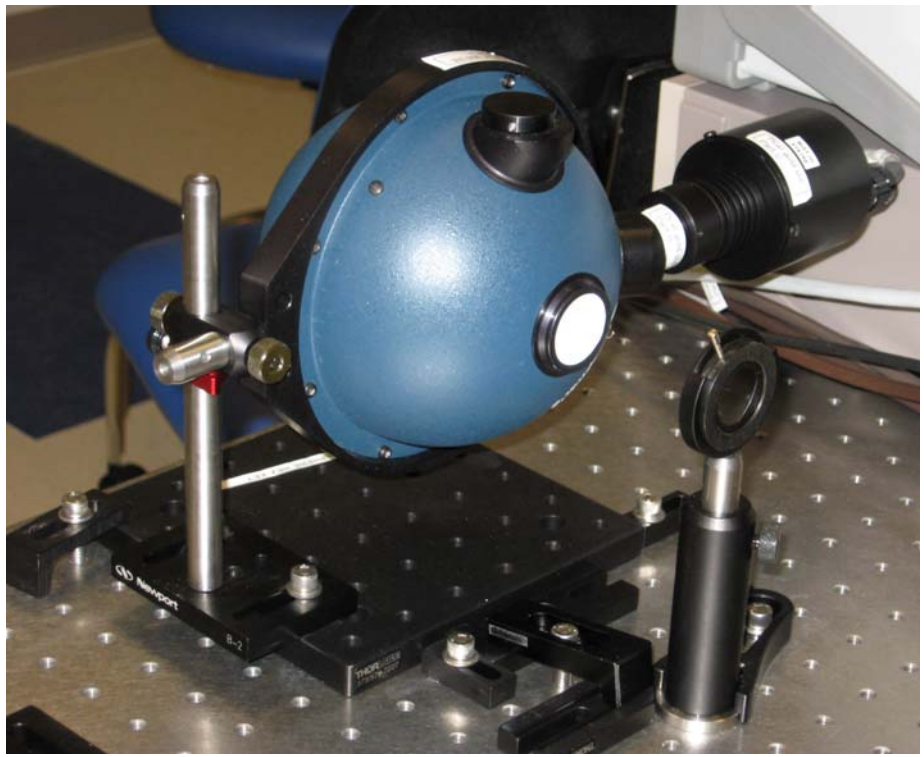
- Review from last talk
- Slow variations
- Fast variations
- Working standard calibration errors
- Pcal (New Focus) photodetector calibrations
- Summary of work done

Review: Photon Calibrators

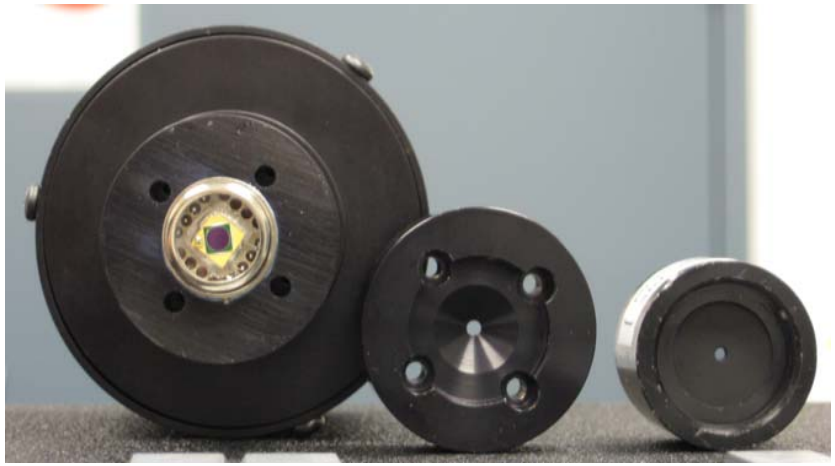
- Independent method for calibration of the interferometer using radiation pressure
- Displacement is proportional to power
  - Accuracy at 1% level in displacement requires accuracy at 1% level in power

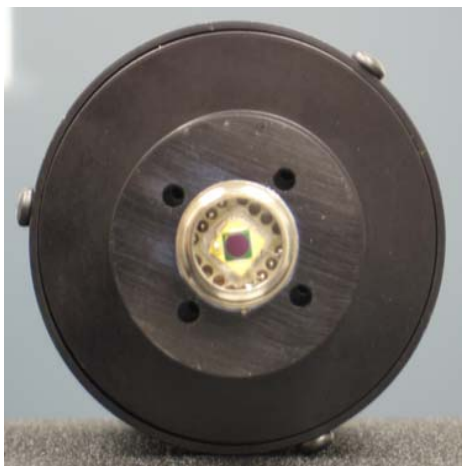
Review: Integrating Spheres

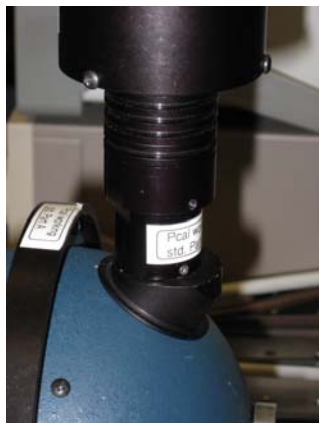
- Sphere lined with light-scattering material to reduce sensitivity to beam position, pointing variations, polarization, spot size, etc.
- Gold standard: calibrated by NIST, stays in lab to preserve calibration
- Working standard: can be taken to the end stations or Livingston

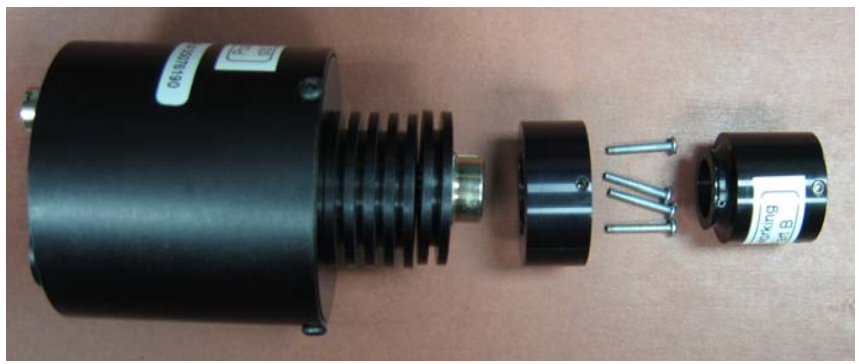


Photodetector Assembly

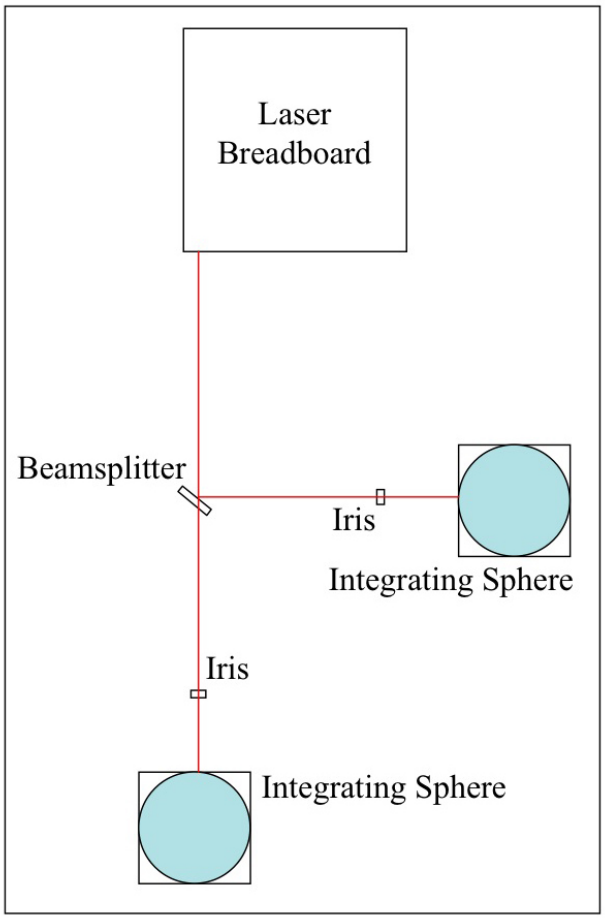








Review: Absolute Calibration

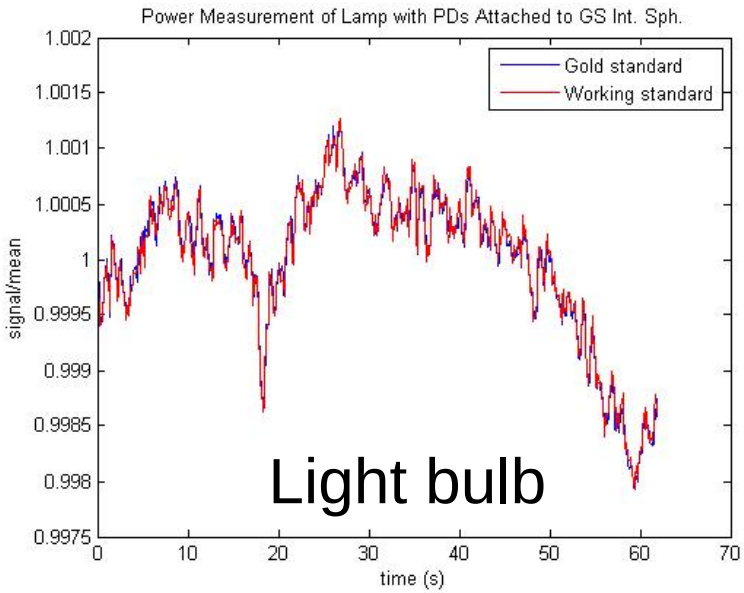


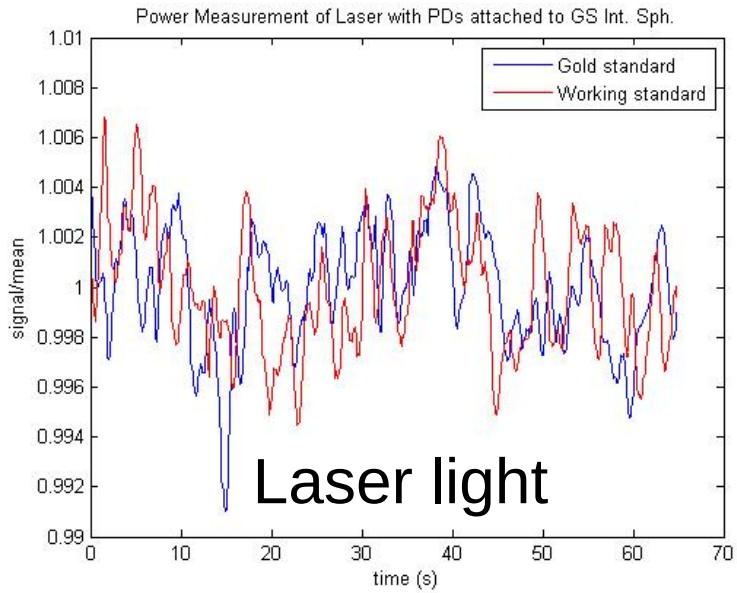
- Transfer of gold standard calibration to working standard
  - Swapping integrating spheres and taking ratios
- Transfer of working standard calibration to photon calibrator photodetectors

Goals of Project

- Assess errors involved in absolute calibration
  - GS to WS
  - WS to photodetector
- Create calibration procedure and evaluate errors involved

Slow Variations: Review



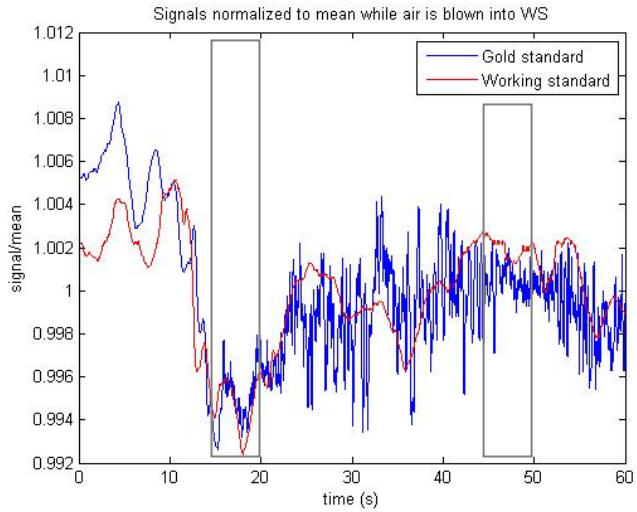


- Amplitude of <1%, Period of 5-20s
- Interaction between laser light and integrating sphere
  - Absent when PD is removed from sphere
  - Absent when lamplight is used

Slow Variations: Laser Speckle

- Occurs when coherent, monochromatic light hits a diffuse surface
- Phase shifts and direction changes from the rough surface cause complex interference patterns
- Air currents can vary the spatial patterns so that the PDs sense more or less intense patches

Slow Variations: Speckle Evidence

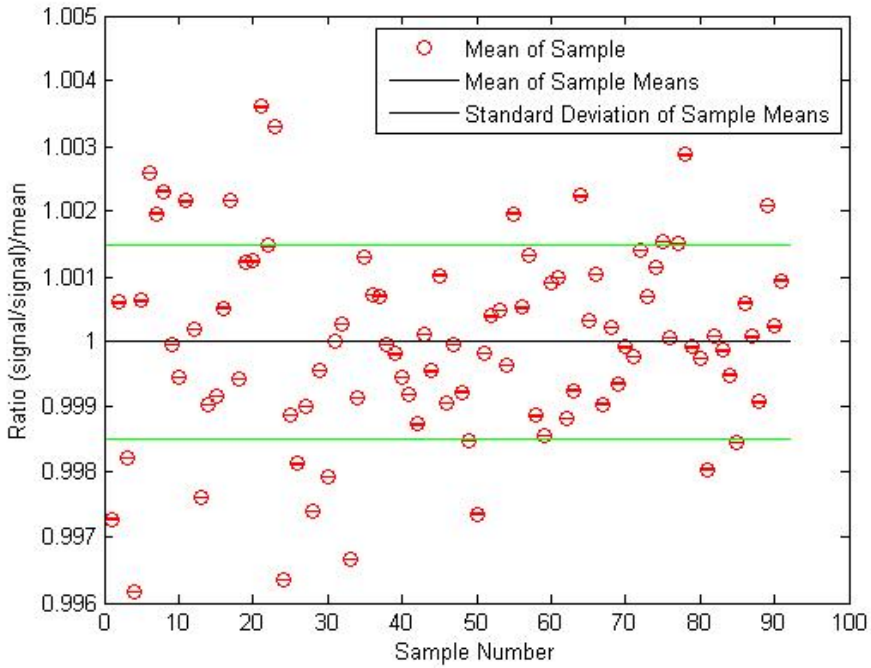


- Integrating spheres have been used to generate speckle for detector array calibration purposes[1]
- Laser speckle is visible when a laser pointer is directed towards a sphere
- Manipulating air currents disturbs variations

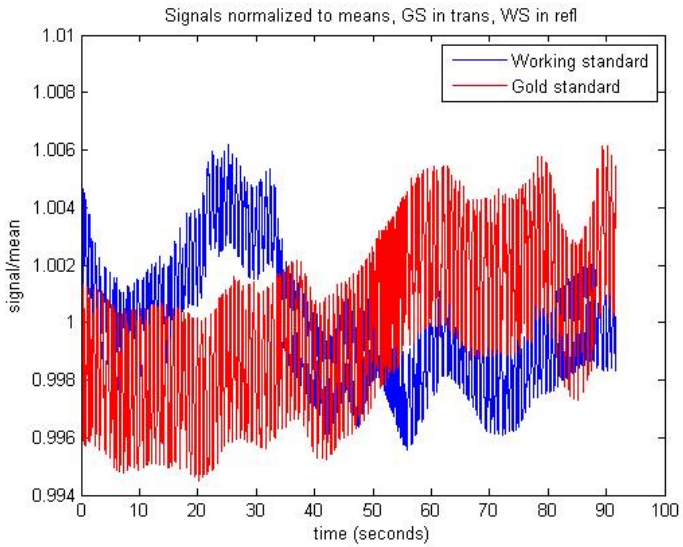
[1] Boreman, G.D.; Sun, Y.; James, A.B. (April 1990). Generation of laser speckle with an integrating sphere. Optical Engineering 29 (4), pp. 339-342

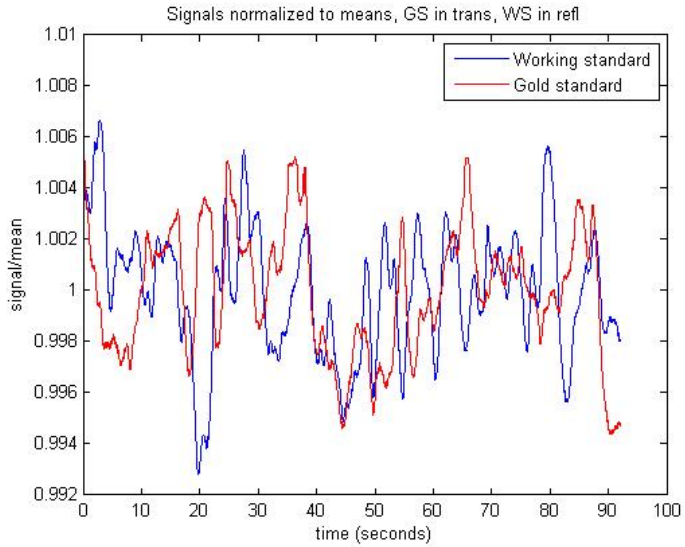
Slow Variations: How do we deal with this?

- Taking a long enough time series to average out the variation
- Took hour-long time series
- Divided into 2400 point samples (~60s)
- Calculated for each sample:
  - Mean
  - Standard deviation: ~0.2%
  - Standard deviation of mean (standard error): ~0.004%
- Calculated for group of samples:
  - Mean
  - Standard deviation: 0.15%
- Error bars should be about the same as overall standard deviation, not equal because not white noise: points correlated



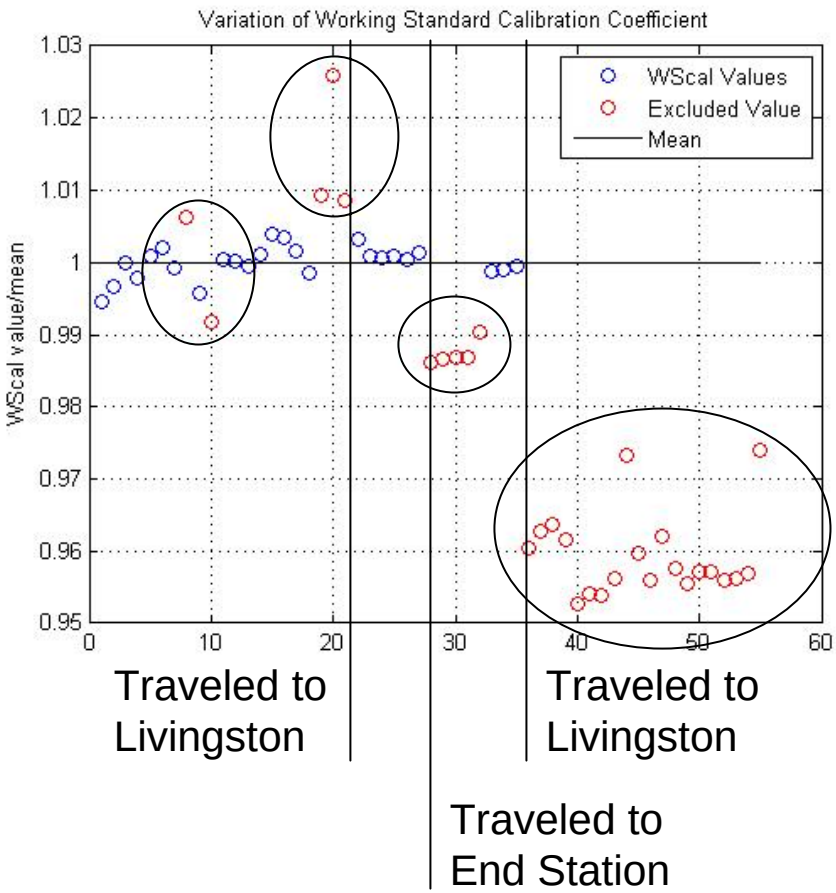
Fast Variations





- 60 Hz variation with a constant magnitude of ~5 mV
- Grounding problem?
- For now: add filter using amplifier
- Later: try photodetector assembly put together by one company; integrated better in terms of grounds?

WS Calibrations



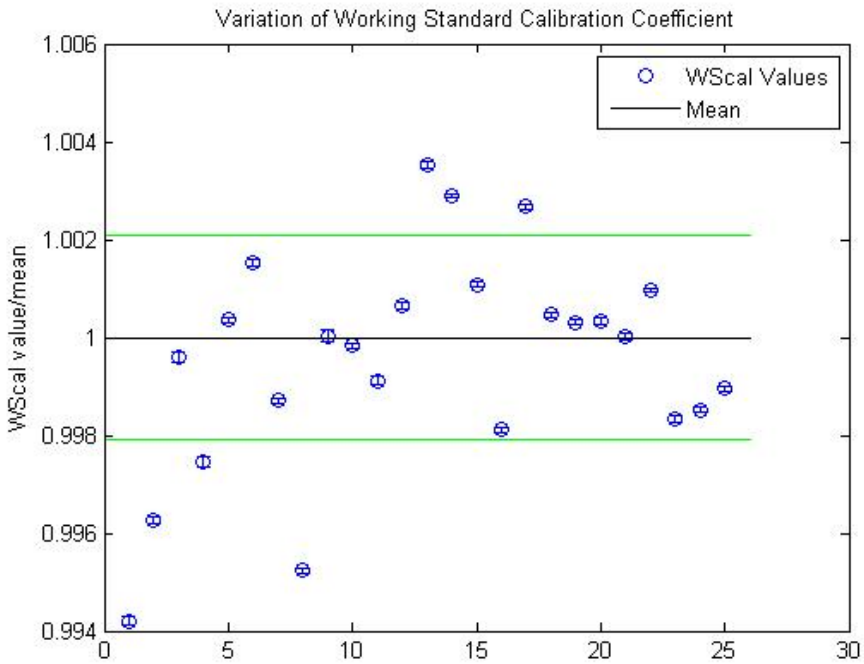
- # 19-21, 1-2.5% from the mean, systematic error not identified but suspected
- # 29-32, ~1.5% from the mean, photodetector was loose
- # 36-55, ~4% from the mean, photodetector seal was broken
- # 8 and 10, power varied using half-wave plate, caused glitches, producing a larger uncertainty

WS Calibration Errors: Analysis

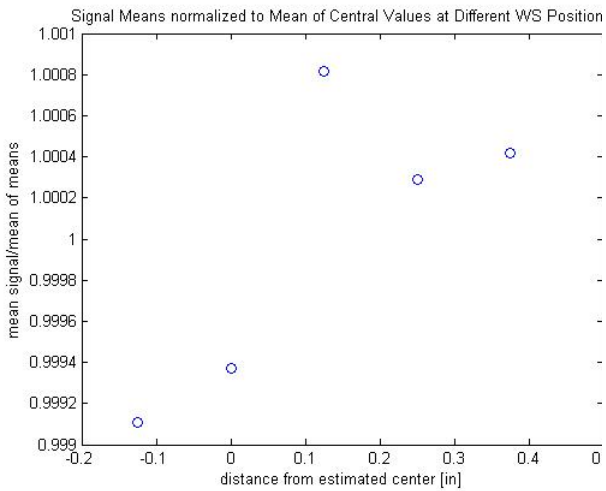
- For each calibration
  - $C_w = C_g \, \mathrm{sqrt}((V_w/V_g)(V_w'/V_g'))$
  - Calculate standard deviation of the mean (σ/sqrt(N)) of ratios
  - Use propagation of error to determine uncertainty in calibration coefficient

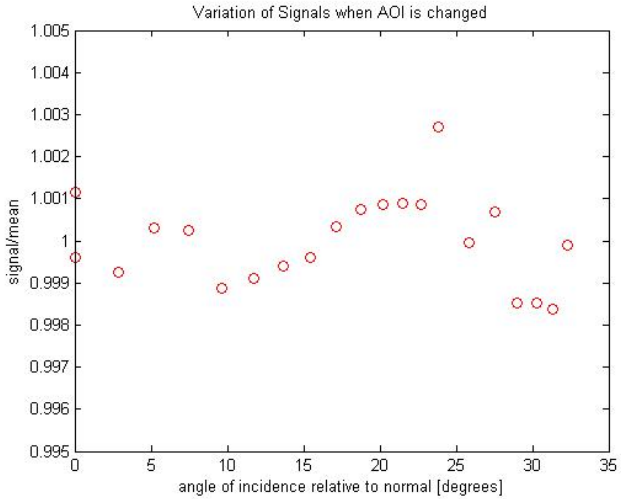
WS Calibrations: Statistics

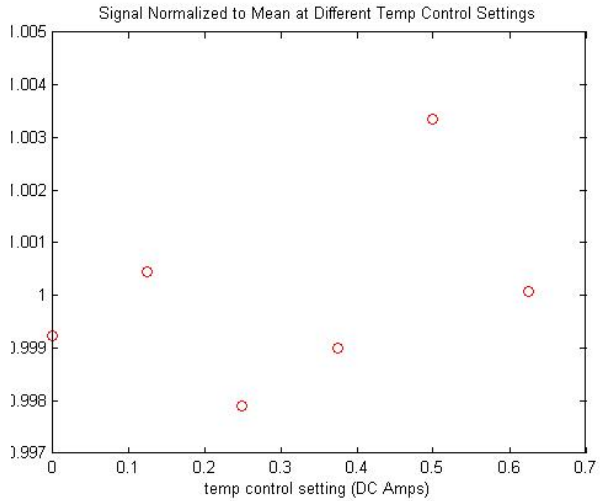
- 25 calibrations included
- Mean: 3.20 V/W
- Standard deviation: 0.0067 V/W (0.21%)
- Individual estimates of error much smaller than standard deviation
  - Indicates presence of systematic errors?
  - Indicates the fact that the error actually does not improve by sqrt(N)



WS Calibration Errors: Systematic



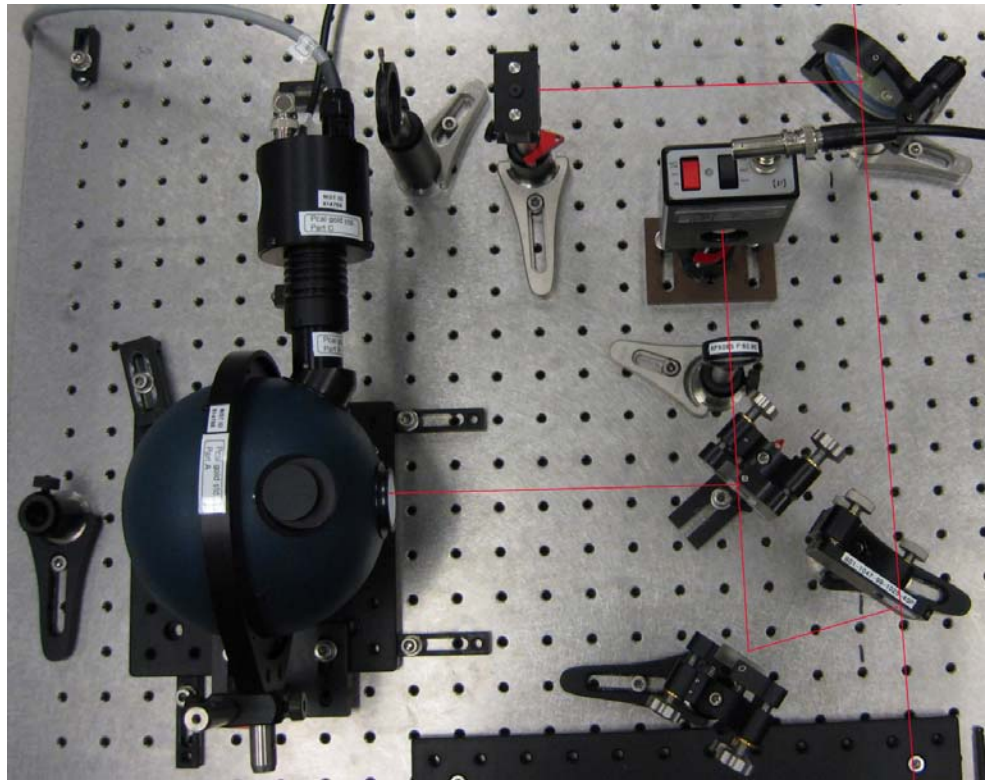




- Beam placement: standard deviation of 0.073%
- Pointing: standard deviation of 0.11%
- Temperature controller setting: standard deviation of 0.19%
- Combined (added in quadrature): 0.23%

PD Calibration

- Created layout to simulate Pcal PD calibration
- No swapping: need to know PD response per power to integrating sphere
- After 8 calibrations: standard deviation of 1.1%



Summary

- GS to WS calibration errors investigated: 0.21% standard deviation
- Source of slow variations is laser speckle
- Fast variations dealt with through filtering and new receiver assemblies
- Shipping loosens screws, causing problems: looking into ways to improve shipping conditions
- Generated and tested WS Calibration procedure
- Preliminary investigation into Pcal PD calibration variations: 1.1% standard deviation