Progress Report: Scattered Light Measurements and CCD Calibrations

Hunter Rew, Mentor: Joseph Betzwieser

August 20, 2014

Abstract

In order to measure losses due to scattered light from optics within the interferometer, we have measured a calibration factor for the Basler ACE 100gm cameras to be used to calculate power on the cameras sensor (CCD) from exposure and the sum of pixel intensities (p_i). This value is $9.8 \pm 0.5 \times 10^{-10} W \cdot \mu s \cdot p_i^{-1}$ for 8 bit monochromatic images and $5.9 \pm 0.3 \times 10^{-11} W \cdot \mu s \cdot p_i^{-1}$ for 12 bit monochromatic images, where the errorbars represent one standard deviation.

1 Theory overview

Due to the imperfections in optics, when light reflects from a mirror or transmits through a lens a small percentage of the light is scattered in an unintended direction. This scattering results in power loss and noise in the interferometer (IFO) which must be either accounted for or corrected [3]. In order to measure this scattering, there are cameras attached to viewports throughout the IFO aimed at specific optics such as the input mode cleaner (IMC), input test masses (ITMs), and end test masses (ETMs). One can determine where light is being scattered through analysis of the images from these cameras, however, the images alone can not tell how much light is being shown. To calculate this, one must know how the cameras CCD converts incident light to a pixel value at a given exposure. Then a conversion factor can be written in the form

$$\frac{Power(W) \times Exposure(\mu s)}{Intensity} = constant \tag{1}$$

where Intensity is the sum of pixel values. Thus, the power incident on the CCD can be calculated as some constant multiplied by the total light intensity per microsecond of exposure.

2 Experimental setup and procedures

To begin, we installed a camera facing the Y-arm ETM with a beamsplitter to reflect 50% of the incoming light towards a PDA100A, connected to channel L1:LSC-Y_EXTRA_AI_2, in order to measure the power reaching the CCD [1]. This, however, had inherent problems, since the area of the photodetector (PD) is much (roughly 7 times) larger than the area of the CCD. In the end, this merely gave us an upper limit on the incident power, as we knew the PD was at least receiving as much light as the CCD, but could potentially receive several times more.

We built a new setup in the optics lab, as shown in figures 1 and 2, consisting of the following:

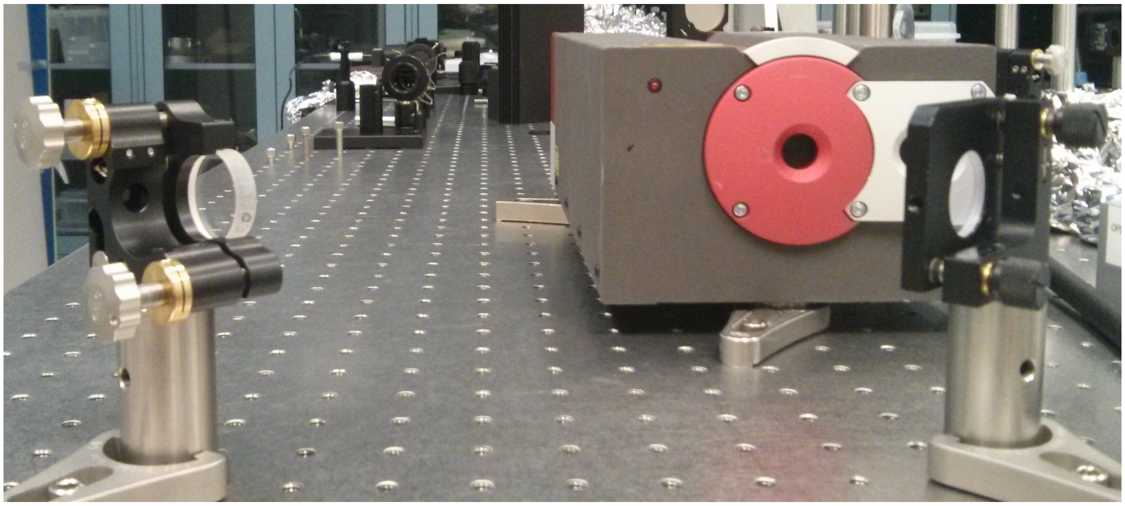

Figure 1: Infrared laser with two mirrors to control its path towards the camera.

- Innolight Prometheus 50NE laser
- Innolight Prometheus line power supply (not pictured)
- 2 infrared mirrors
- 30 mm diverging IR lens
- 65 mm converging IR lens
- lever controlled iris
- NE10A absorptive ND filter
- Thor Labs CM1-BS015 beam splitter
- Ophir NOVA laser power meter
- Basler acA640-100gm camera.

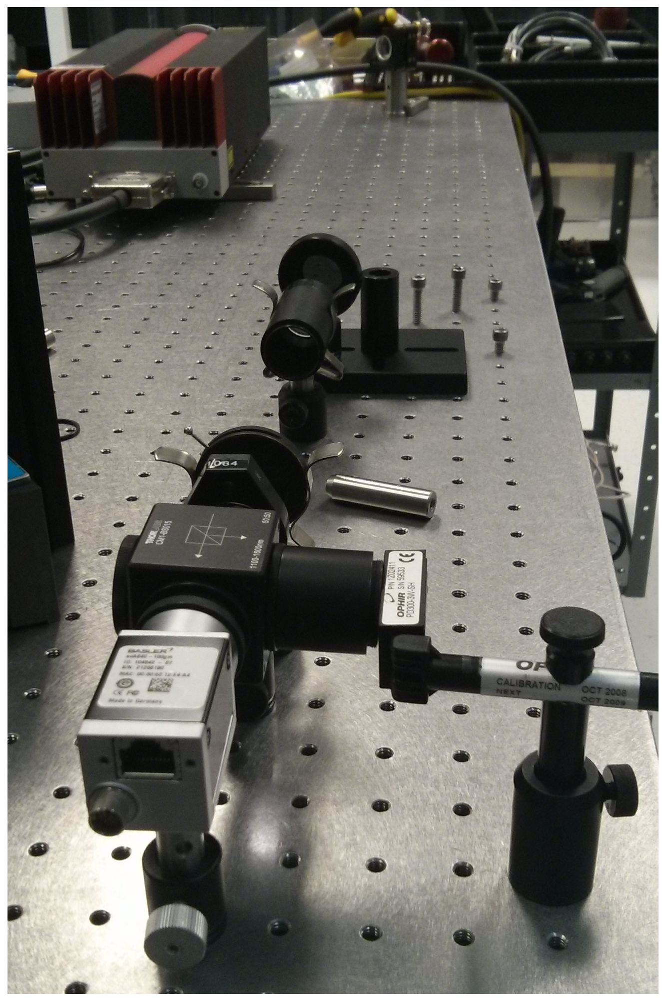

Figure 2: From front to back: camera, power meter, beamsplitter, 65mm lens, iris, -30mm lens, ND filter

When the beam reaches the first lens, it diverges to spread out the power. A pinhole sized beam is then allowed through the iris before reaching the converging lens, where it will be focused to a point on both the CCD and PD. We used this setup to start at a $4\mu s$ exposure, then increasing exposure in intervals until the image was nearly saturated. At this point we would decrease the power supplied to the laser in order to continue to longer exposures. Once we reached the point where the lasers power couldn't be reduced further, the ND filter was added to reduce the power to the CCD and PD by a factor of 10. With this method we were able to span from 4 to $1200\mu s$, at powers from 8.2 to $1.6\mu W$. Each power reading carried an uncertainty of $\pm 100nW$, which also limited how far we could reduce the power. 12 bit and 8 bit monochromatic data were taken for each exposure and power setting.

3 Experimental data and the data analysis

Because the ratio between exposure and pixel sum is constant at a given power, we were able to remove noise from each image by choosing a reference image at each power, and subtracting it from all other images at that power. A remaining image now represents an exposure equal to the difference of the images which it came from, with less noise than either. Plots of the 12 and 8 bit calibrations, calculated from Equation 1, are given in figures 3 and 4. For the 8 bit images, the mean calibration is $9.8 \times 10^{-10} W \cdot \mu s \cdot p_i^{-1}$, where p_i is the sum of the pixel values, or intensities. The standard deviation is $0.5 \times 10^{-10} W \cdot \mu s \cdot p_i^{-1}$. This is within the upper limit of the values measured by our camera and PDA100A, $1.4 \pm 0.2 \times 10^{-9} W \cdot \mu s \cdot p_i^{-1}$, where the uncertainty is the total fluctuation seen across all measurements. The mean calibration for the 12 bit images is $5.9 \times 10^{-11} W \cdot \mu s \cdot p_i^{-1}$ with a standard deviation of $0.3 \times 10^{-11} W \cdot \mu s \cdot p_i^{-1}$, roughly 16 times smaller than the 8 bit calibration, as would be expected. Error bars in the plots are presented as 20% due to differences in readings from different power meter heads.

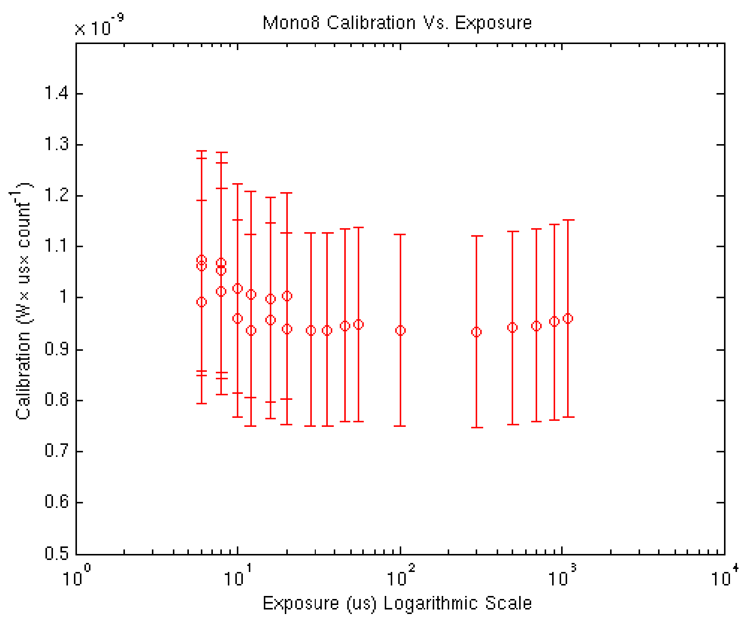

Figure 3: 8 bit calibrations vs exposure on a logarithmic scale. Fluctuations in the calibration at lower exposures could be the result of noise fluctuations, as the sum of the pixel values is smaller compared to the noise.

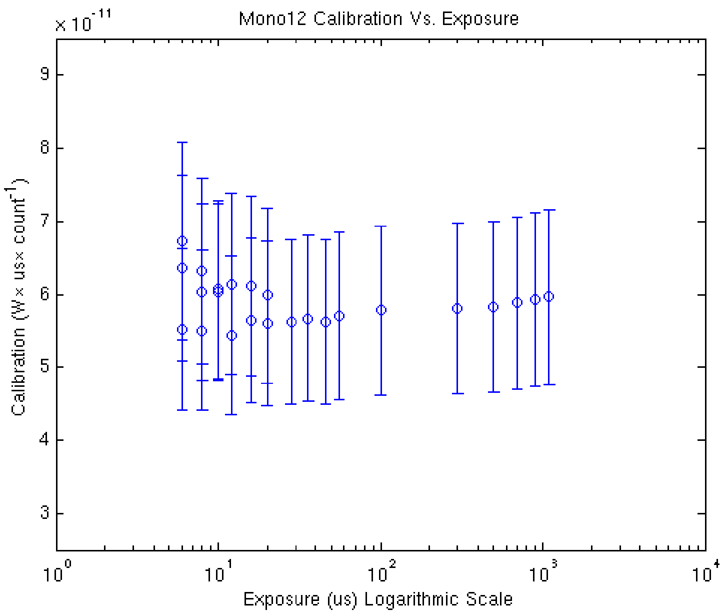

Figure 4: 12 bit calibrations vs exposure on a logarithmic scale.

4 Conclusions and Future Work

We find that the calibration factors for the Basler acA640-100gm are $9.8 \pm 0.5 \times 10^{-10} W \cdot \mu s \cdot p_i^{-1}$ for 8 bit monochromatic images and $5.9 \pm 0.3 \times 10^{-11} W \cdot \mu s \cdot p_i^{-1}$ for 12 bit monochromatic images. Each errorbar represents one standard deviation from the mean. These values are in agreement with our independently measured upper limit on 8 bit calibrations of $1.4 \pm 0.2 \times 10^{-9} W \cdot \mu s \cdot p_i^{-1}$. Next we will remove the PDA100A from its current place on the IFO and and use it in the lab to repeat the procedures detailed above, with the hopes of more precise power readings. The objective in determining this factor is to measure power loss in the IFO across various optics. We have already begun with the ETM on the Y arm, checking power loss in parts per million at different exposure levels [2].

References

[1] Joseph Betzwieser and Hunter Rew. Added temporary gige camera with power meter. https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=13151. Accessed: 07-07-2014.

[2] Hunter Rew, Joseph Betzwieser, and David Feldbaum. Analysis of etmy scatter. https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=13414. Accessed: 07-07-2014.

[3] Peter R. Saulson. *Fundamentals for Interferometric Gravitational Wave Detectors*. World Scientific Publishing, New Jersey, 1994.