Calibration of the LIGO Interferometer Using the Recoil of Photons

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G030513-00-D

Motivation

The Photon Calibrator has been developed to provide a physically independent means of evaluating systematic errors in order to analyze the interferometer's strain signal correctly. Using it, we can apply a known force at a specified time to one of the end mirrors and see how the gravitational-wave readout channel responds. My job involves analyzing, installing and implementing this device into the interferometer system here at LIGO.

How Photon Calibration Works

1. Bounce am amplitude-modulated beam off one of the end mirrors
2. Measure the displacement introduced by radiation pressure
3. Compare the measured displacement to the expected reaction:

$$F = 2\cos\alpha \frac{h\nu}{c} \dot{N}_\gamma \quad = 2\cos\alpha \frac{P}{c}$$

$\dot{N}_\gamma = \frac{P}{h\nu}$ is the number of photons hitting the mirror per time

P is the light power

4. The precision of the "expected reaction" depends only on the incident angle and the photoreceiver calibration
5. This process gives *both* timing and amplitude calibrations

Key Components

- Laser

500mW Nd:YLF at 1047nm

Pumped by a laser diode at 808nm

- Polarizer

Ensures an accurate photoreceiver calibration

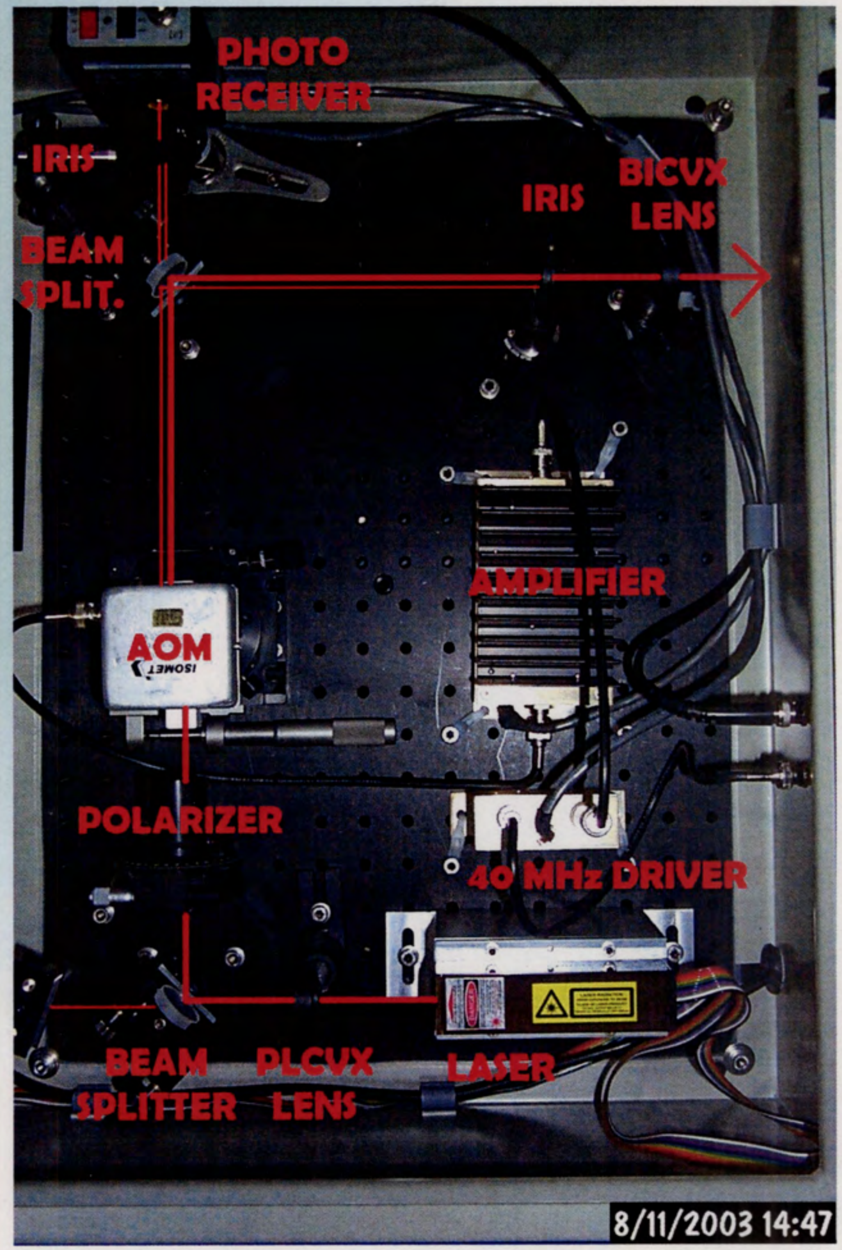
- AOM

Modulates the beam power

- Photoreceiver

Indicates the power of the beam

The *new* design:



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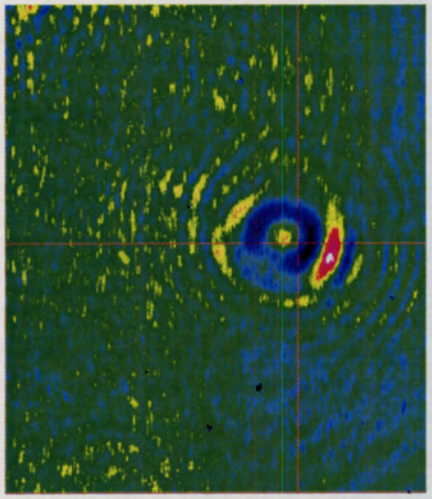
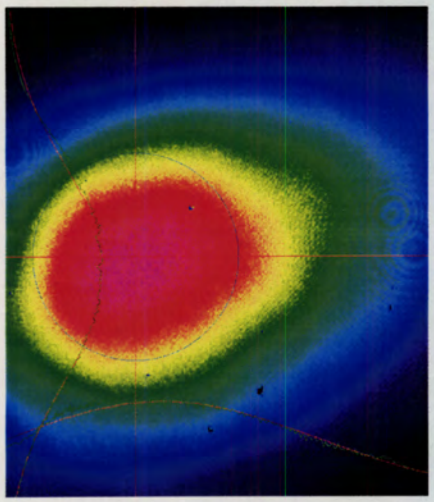
Beam Profiling

Beam behind the first BS

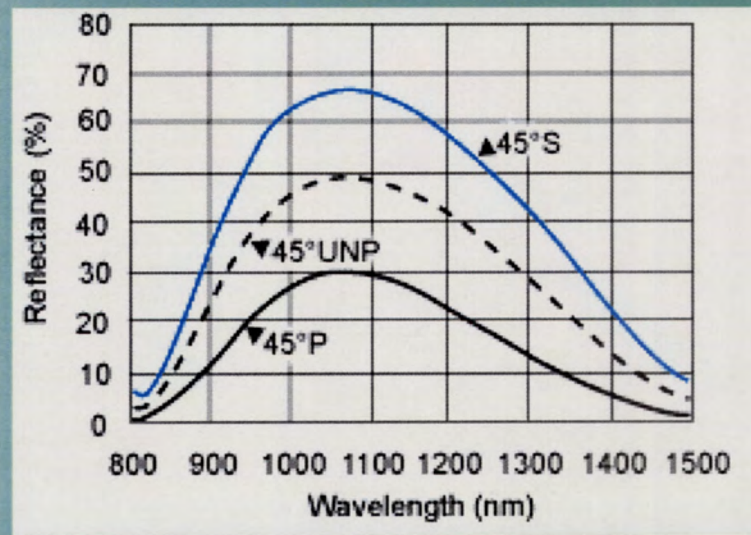




Beam that strikes the end mirror – approximately 6-7mm in diameter

- The first beam splitter effectively dumps excess pump diode light

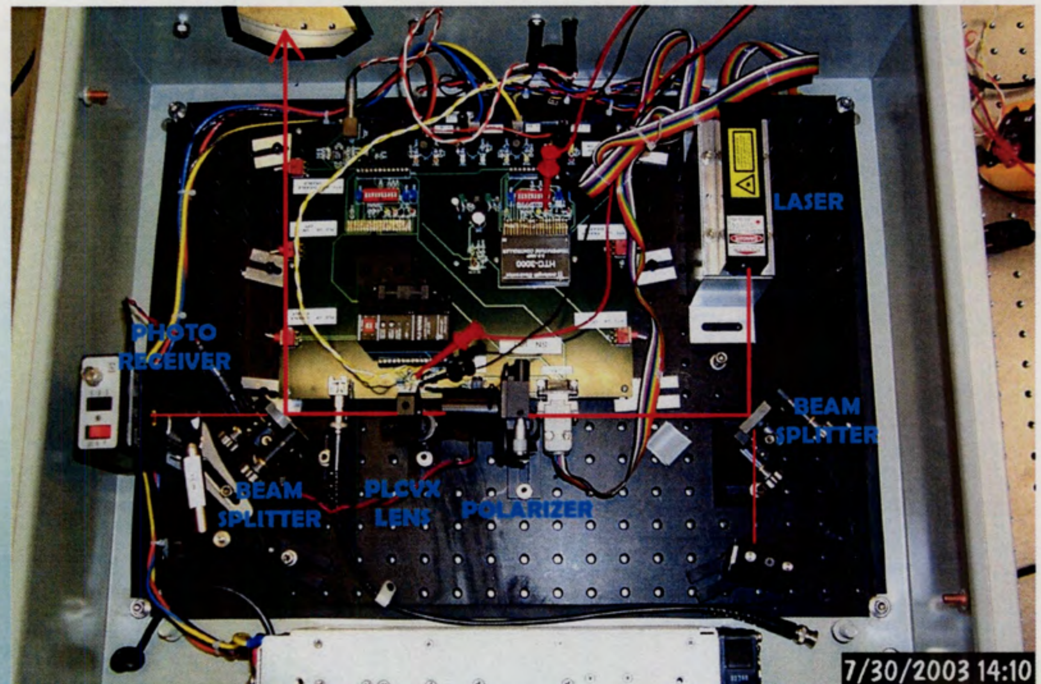
Beam Splitter Reflectance (courtesy cvilaser.com):



- A lens was necessary in order to shoot the laser through the AOM
- A lens is also used to clean up the beam that strikes the end mirror (at a distance of 228 inches)

Modulation

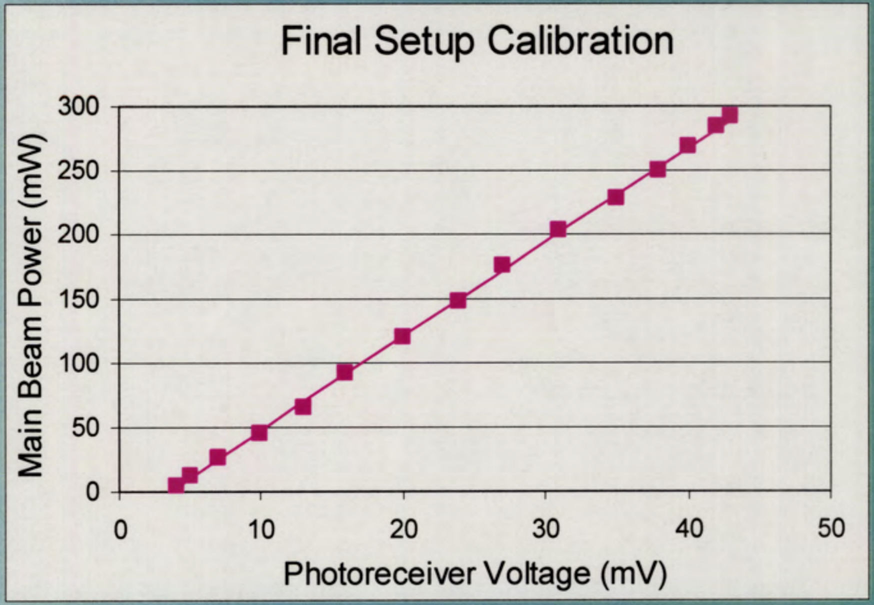
The *old* design:

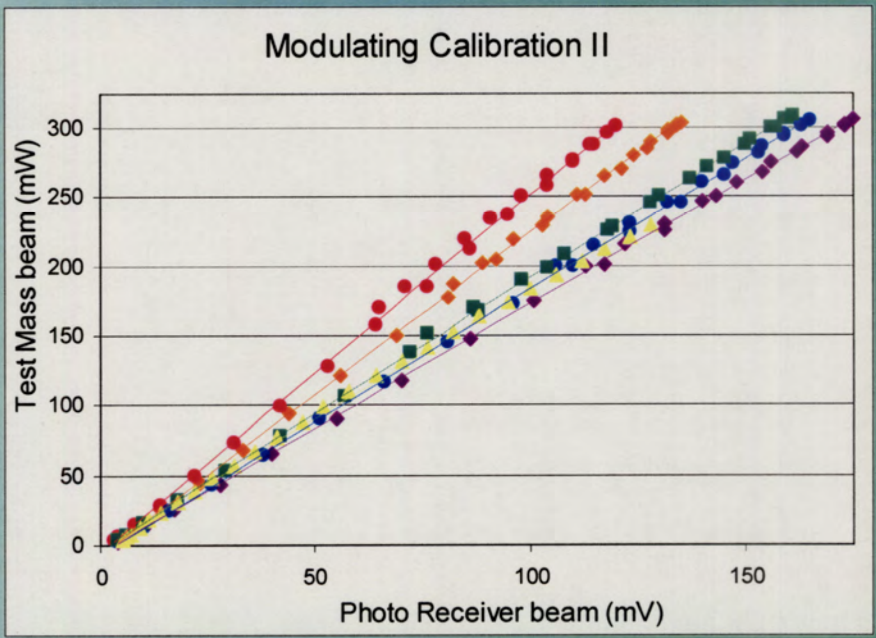


- The original method of modulation was to vary the laser diode current
- This was found to be not working and an AOM is now used instead
- An AOM (Acousto-Optic Modulator) deflects a portion of a beam that passes through it. The intensity of the deflected beam depends on the amplitude of an applied RF signal.
- Currently, we achieve between 50% to 60% modulation

Calibrations

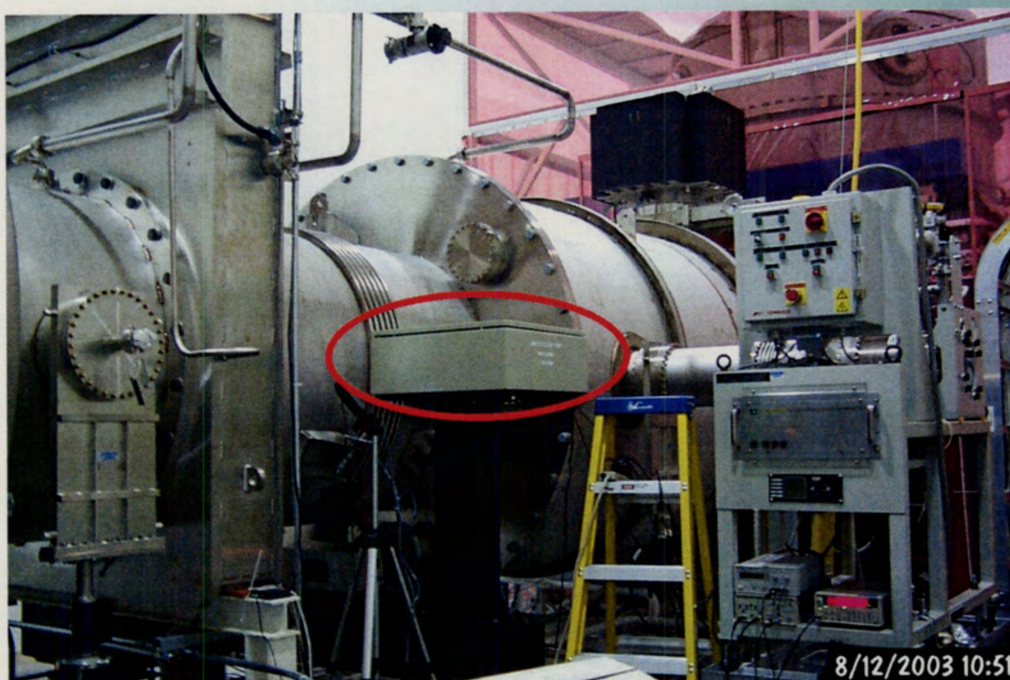
- The photoreceiver calibration is essential to retrieving meaningful data from the photon calibrator
- There should be a linear relationship between the photoreceiver voltage signal and the power of the beam exiting the box.
- The exact slope of this relationship depends slightly on the alignment of all the components





Installation and Implementation

- The photon calibrator was installed at the X arm end station
- The laser was aligned to strike the end mirror
- A DAQ channel was connected in order to retrieve the internal photoreceiver signal



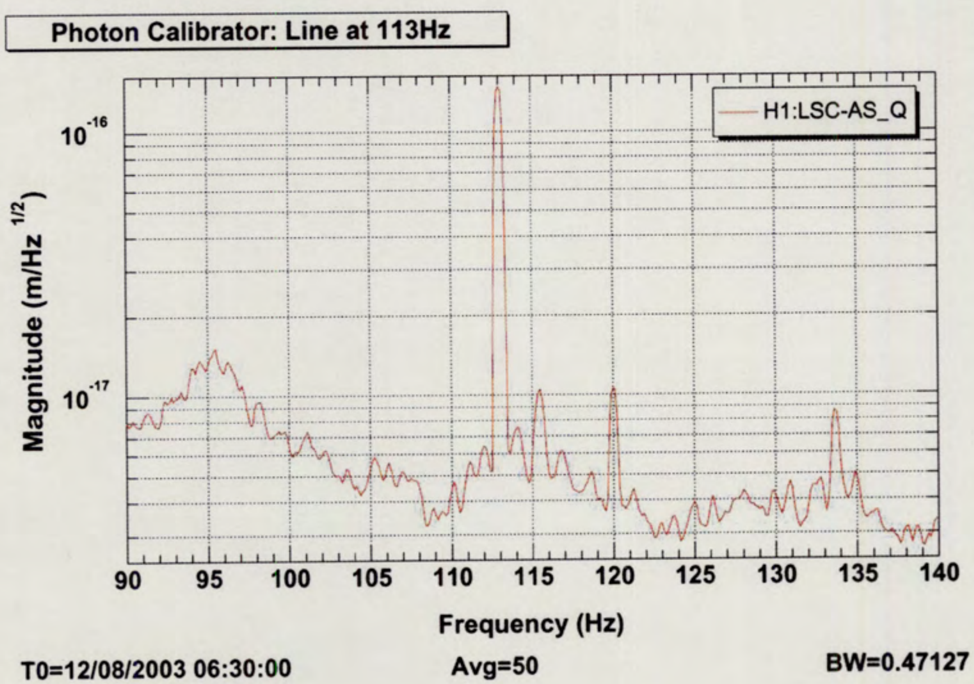
- A function generator was set up temporarily for an input signal
- Only interferometer lock is necessary for capturing data

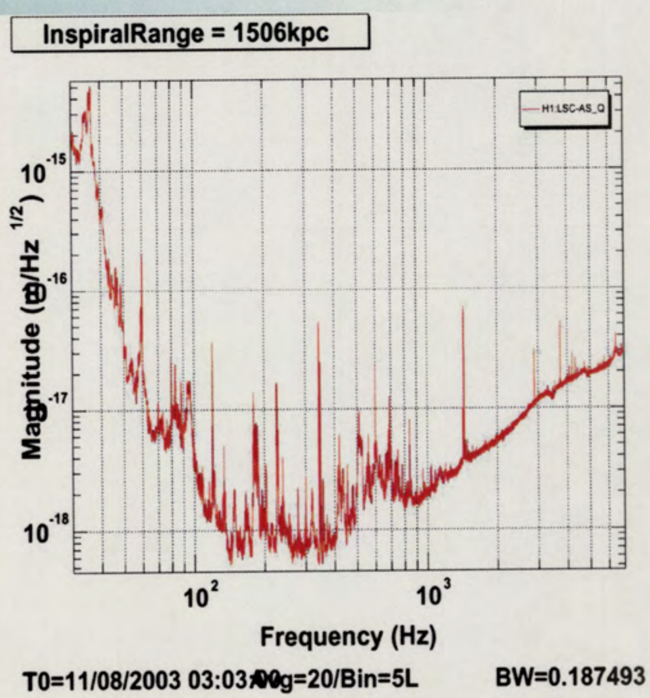
Results

- We have observed that the mirror is definitely being driven by the photon calibrator, currently at 113 Hz for 100mW rms beam power

- Calculations estimate the mirror's displacement to be about 10^{-16} meters

- Calculations from the photon calibrator data estimate the background noise of the interferometer to be about $2 \cdot 10^{-18}$ meters

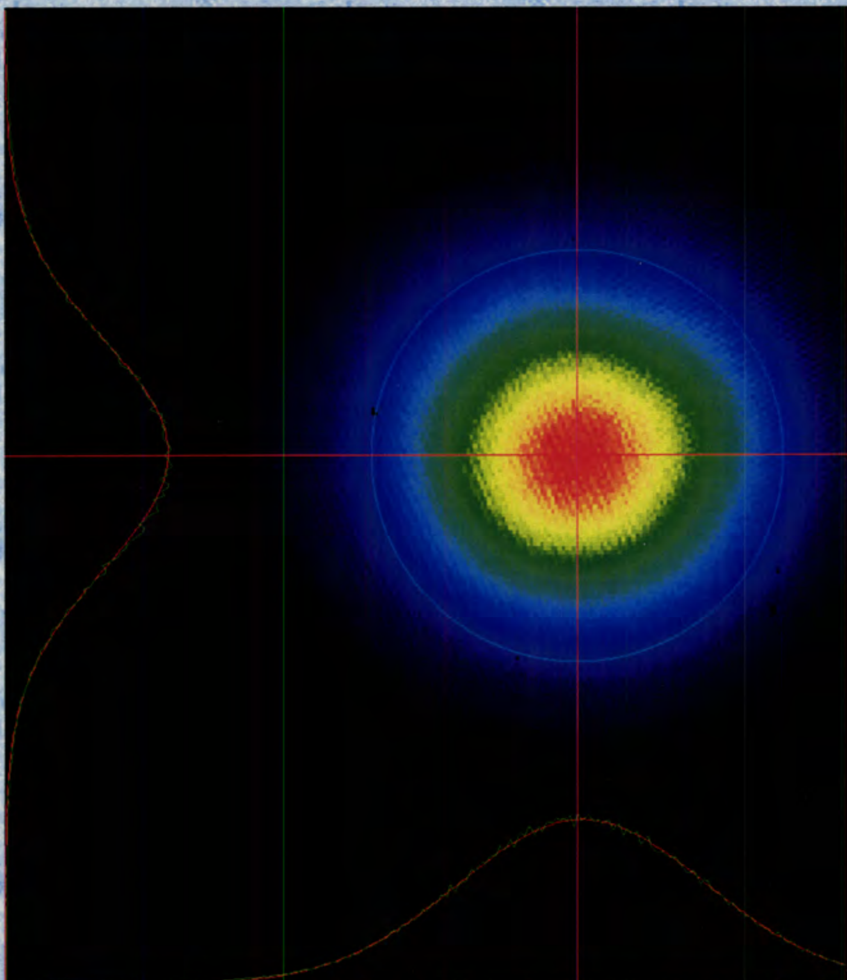




Future Work

- Different AOM's should be investigated in order to achieve deeper modulation and cause less beam distortion
- An AWG channel needs to be setup at and connected to the photon calibrator
- Measurements of the mirror response should be taken as the laser is aligned at different points on the mirror
- Comparisons should be made between the photon calibrator's excitation of the mirror and an excitation through the LSC system

The End



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