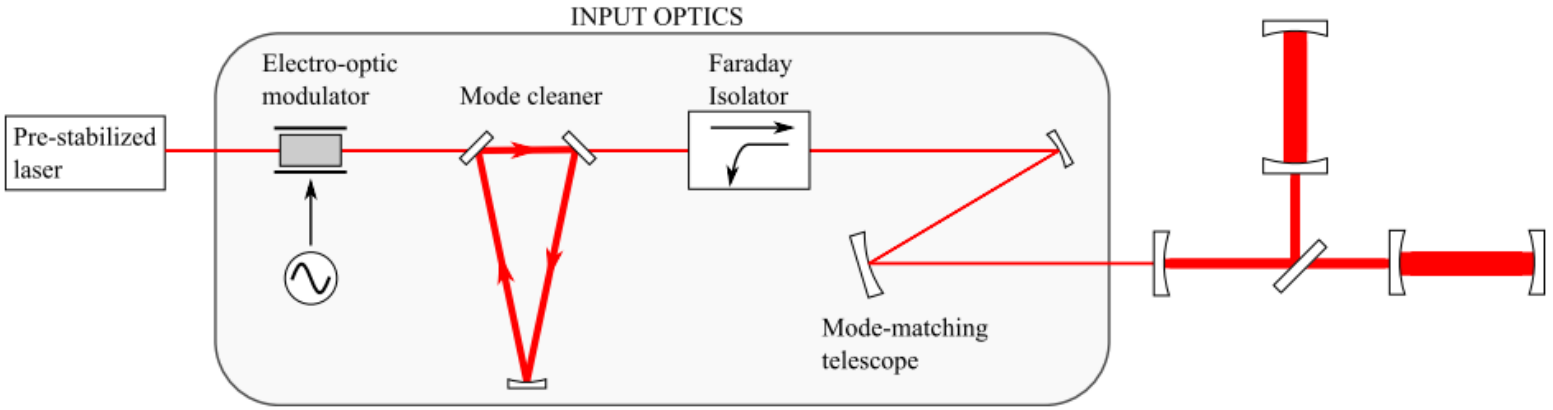
The Advanced LIGO Input Optics

Chris Mueller
on behalf of the UF and UTB Input Optics Groups
and the LLO Commissioning Team

University of Florida
cmueller@phys.ufl.edu
www.phys.ufl.edu/∼cmueller

Amaldi 10 – 9 July, 2013

What is the Role of the Input Optics



Dooley, K et. al.[4]

The Input Optics...

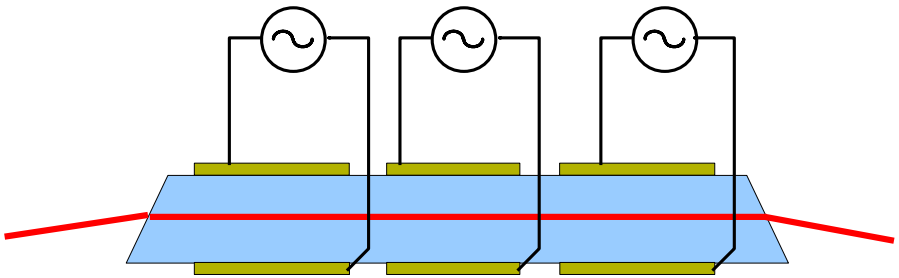
- Adds optical sidebands for sensing and control.
- Passively cleans the spatial structure of the beam.
- Actively and passively stabilizes the laser frequency, pointing, and intensity.
- Isolates the laser from the interferometer's reflected beam.

Requirements of the Input Optics[1][2]

The input optics are required to provide...

- 75% throughput at 165 W of input power.
- A pair of sidebands with low amplitude and phase noise.
- Modulation depth up to 0.8, and an AM/PM ratio of $1 \cdot 10^{-4}$ or less.
- Residual frequency noise of $1 \cdot 10^{-3} \frac{Hz}{\sqrt{Hz}}$ at 100 Hz.
- Beam jitter level of $1 \cdot 10^{-9} \frac{rad}{\sqrt{Hz}}$ at 100 Hz.
- Optical isolation of 30 dB up to 165 W of input power.
- Maintain 95% availability with a 20 s relock time.

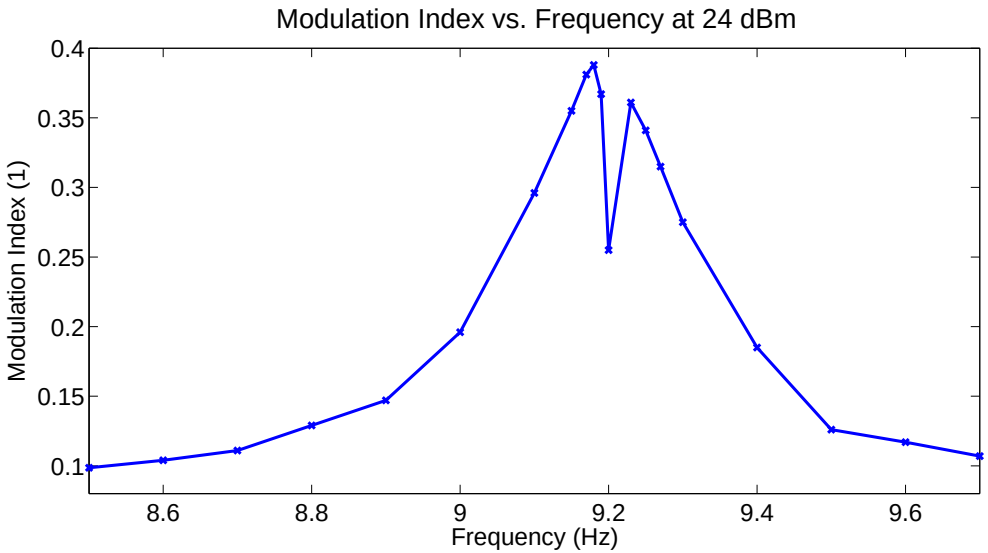
Design of the aLIGO EOM



Key Design Characteristics

- Wedged surfaces reduce parasitic interferometers and RFAM.
- Series modulation using one crystal with three separate pairs of electrodes simplifies resonant circuit design.
- Hand-wound inductors are capable of dealing with deep modulation depths.

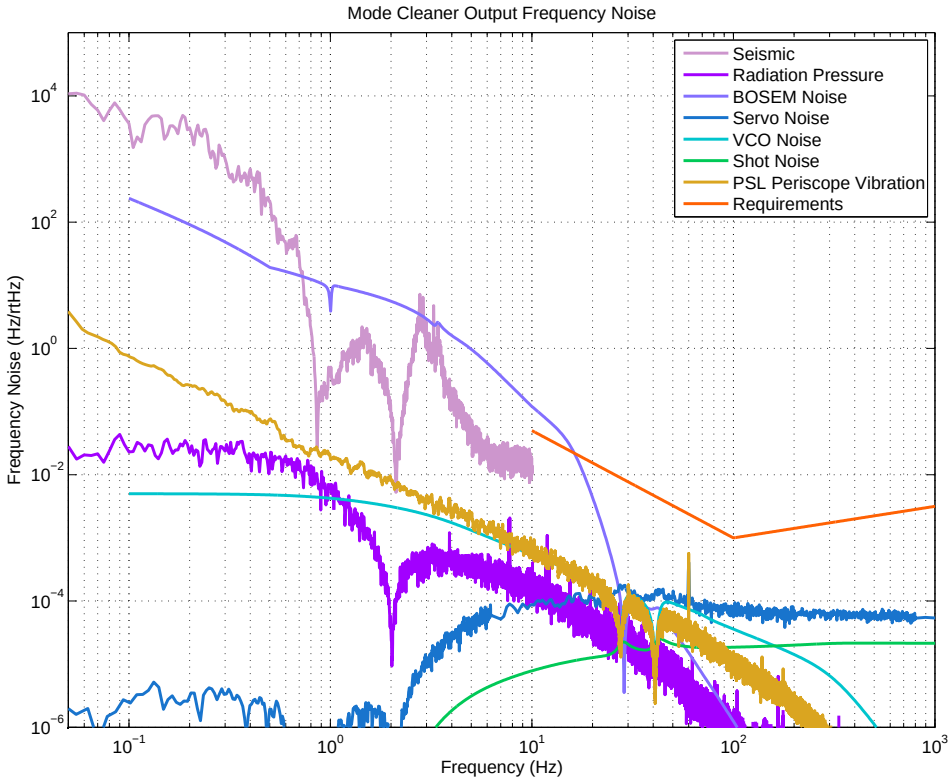
Measurements of the aLIGO EOM



Sideband	9.1 MHz	24.0 MHz	45.5 MHz
AM Index	$3.9 \cdot 10^{-5}$	$1.0 \cdot 10^{-6}$	$6.2 \cdot 10^{-6}$
PM Index	0.39	0.085	0.15
AM/PM	$1.0 \cdot 10^{-4}$	$1.2 \cdot 10^{-5}$	$4.1 \cdot 10^{-5}$

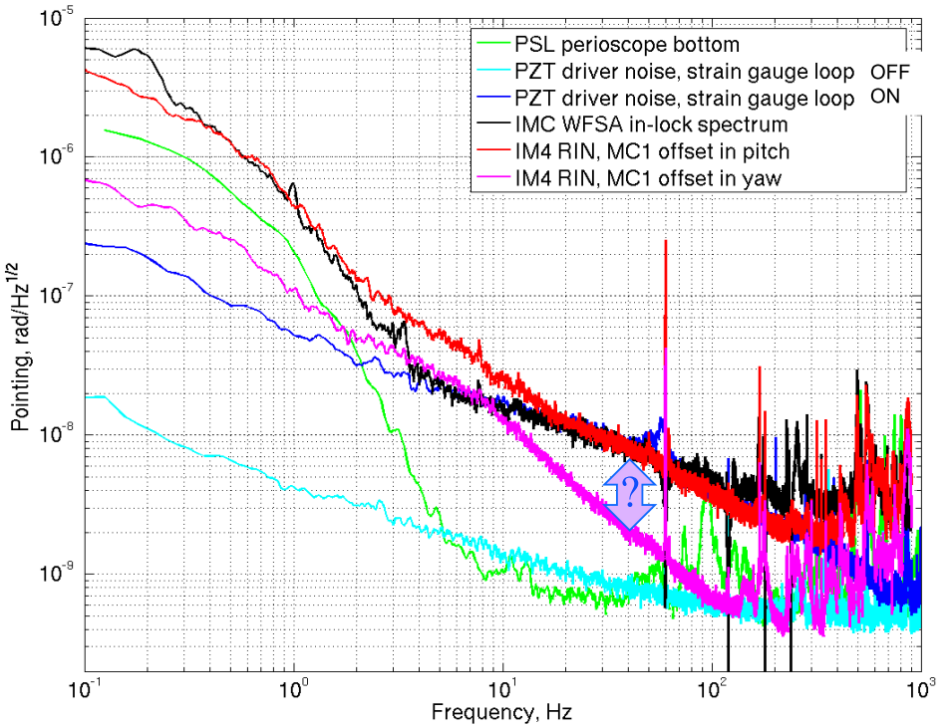
- Repeated RFAM measurements indicate long term stability.
- RFAM drift after the mode cleaner is still under investigation.

Frequency Noise After the Input Mode Cleaner



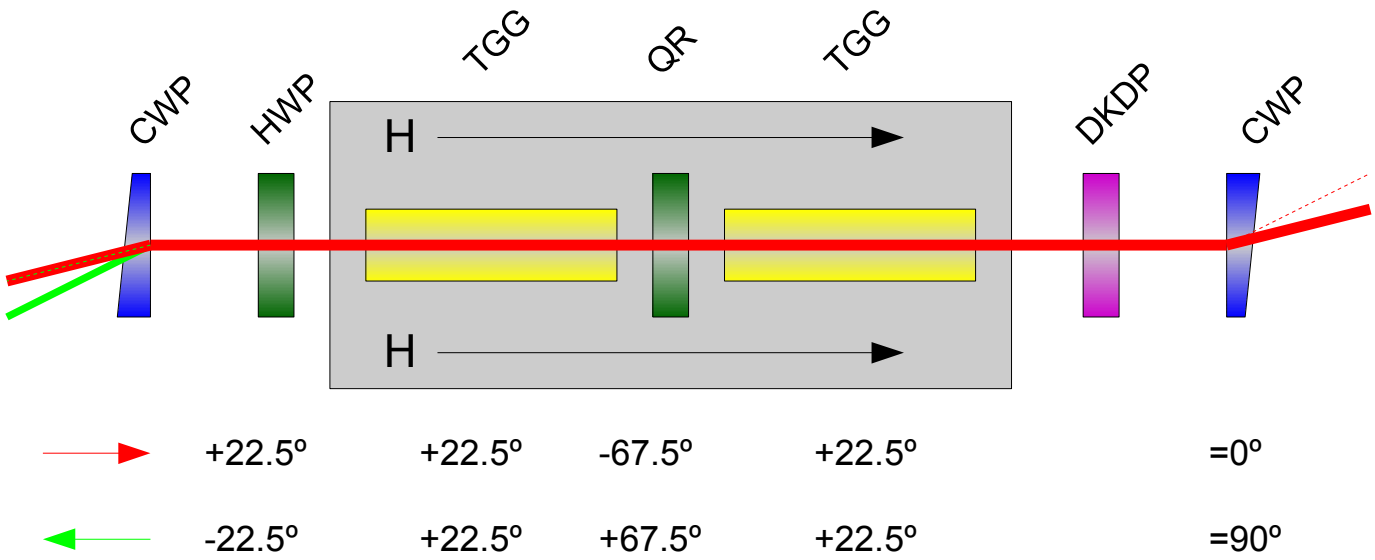
- We have tried to predict the residual frequency noise based on measured noises and modeled transfer functions.
- We will soon measure the frequency noise by comparing it to the PRC length.

Pointing Noise Before the Input Mode Cleaner



- Jitter noise should drop to the cyan/light green curves with the piezo controller strain gauge off. [3]
  - This noise will not spoil the aLIGO sensitivity *if* the residual motion of PR3 can be reduced.[3]

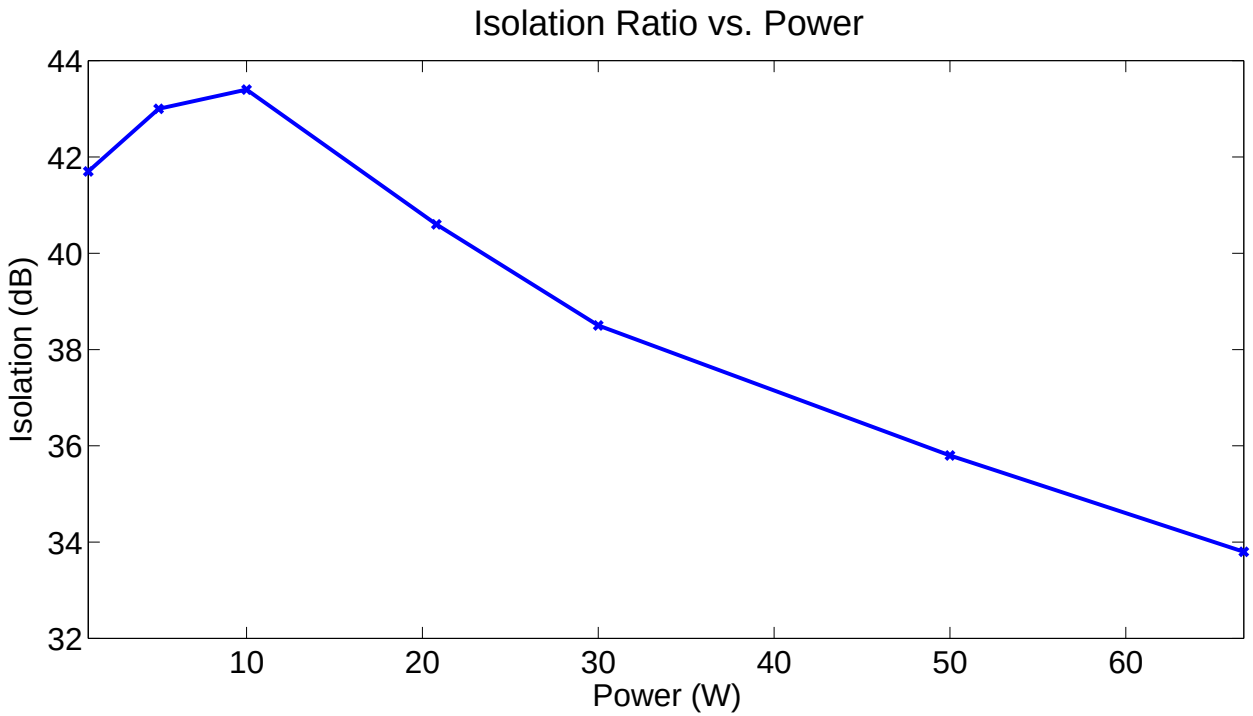
Optical Isolation: Design



Design

- Calcite wedge polarizers for 40 dB isolation.
- Thermal depolarization compensated.
- Thermal lensing compensated.

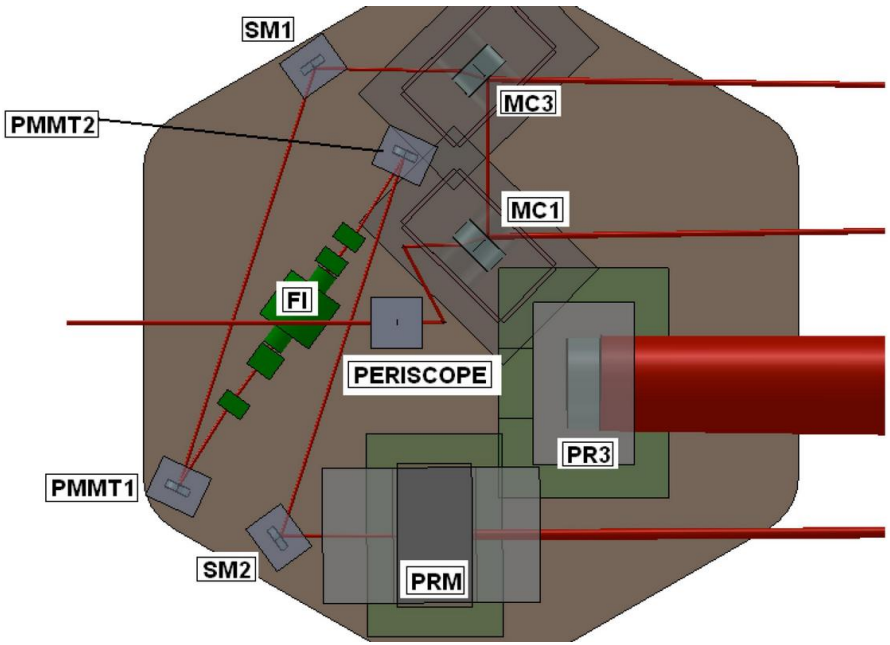
Optical Isolation: Measurement



Measurement

- The Faraday isolator can be re-optimized in-vacuum at different powers – not done in these measurements.
- In-vacuum measurements will be made soon.

Input Optics Throughput

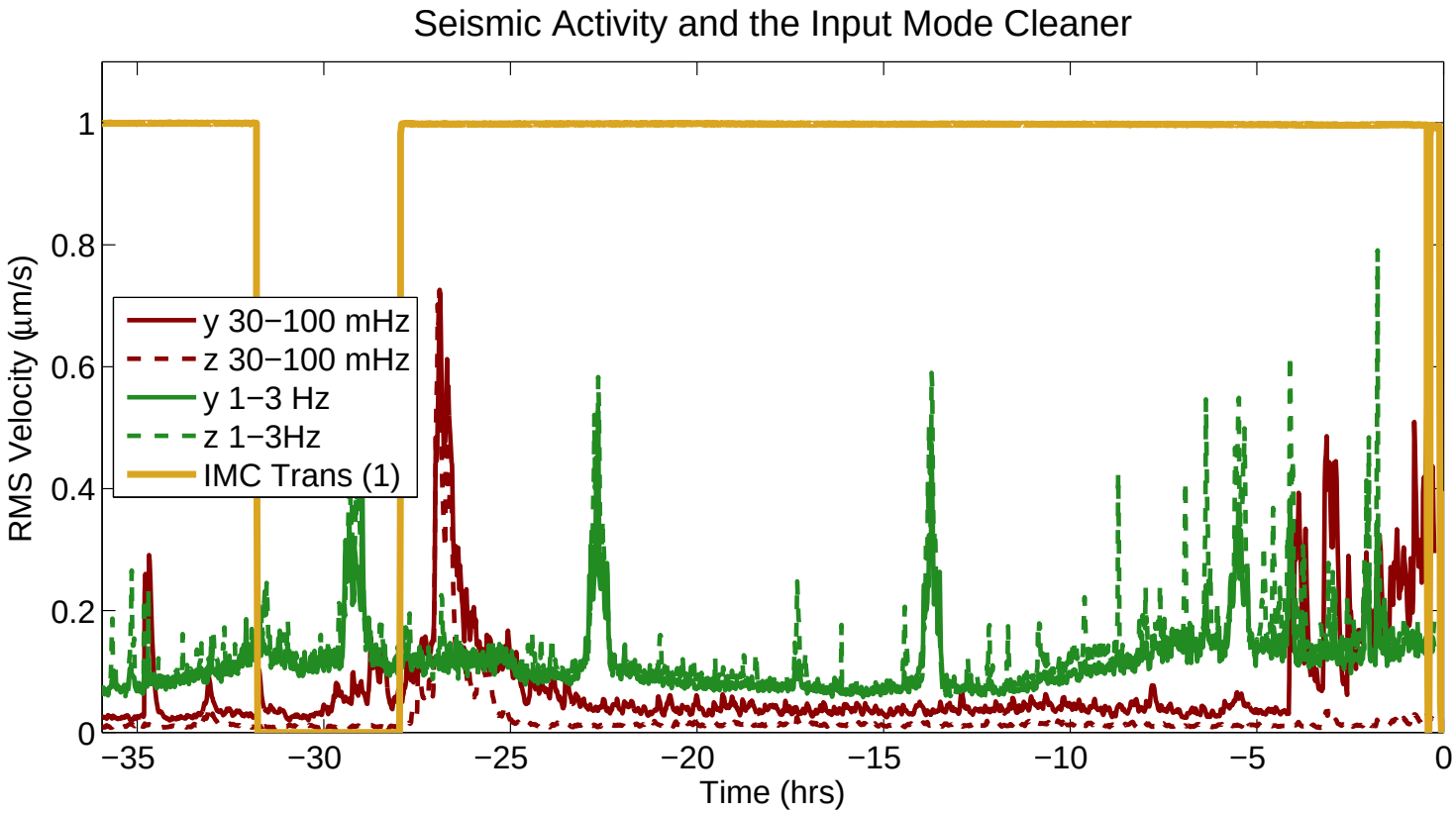


Static Losses	
IMC MM	3%
IM1	520 ppm
FI	3.3%
IM3	2350 ppm
PRC MM	?
Total	6.5% + ?

Thermal Lensing	
IMC	75 ppm @ 120 W
FI	∼3.3% @ 120 W

- IMC lensing number is made by tracking the TEM_{10} mode while changing the power.
- Everything appears on track to get 75% throughput at all power levels.

Availability of the IMC



- Lock lasts ∼indefinitely when left alone.
- Rides out small earthquakes and trains.
- Re-lock time is less than 1 min with room for optimization.

The State of the Input Optics

Completed

- Livingston and Hanford installation.
- In-air checkout of the Faraday isolator and EOM.
- Rapid and robust locking of the input mode cleaner.
- High power testing of in-vacuum components.

Happening Soon

- In-vacuum checkout of the Faraday isolator.
- Examine the interaction between RFAM and the IMC.
- Insure that pointing noise is within the aLIGO requirements.
- Confirm that the IMC frequency noise is within the aLIGO requirements.

References

Arain, M., Mueller G., Martin R., Quetschke, V., Reitze, D. H., Tanner, D. B., and Williams, L. "Input Optics Subsystem Design Requirements Document." LIGO DCC Document: LIGO-T020020-04-D. 6 September, 2009.

Adhikari, R., Ballmer, S., and Fritschel, P. "Interferometer Sensing and Control Design Requirements." LIGO DCC Document: T070236-00-D. 28 Februaru, 2008.

Frolov, V., Barsotti, L., Martynov, D. "LLO PSL Beam Jitter Measurements." LIGO DCC Document: G130042-v6. 10 April, 2013.

Dooley, K. et. al. "Characterization of Thermal Effects in the Enhanced LIGO Input Optics." Arxiv: 1112.1737. 8 December, 2011.