Input Optics R&D For Advanced LIGO

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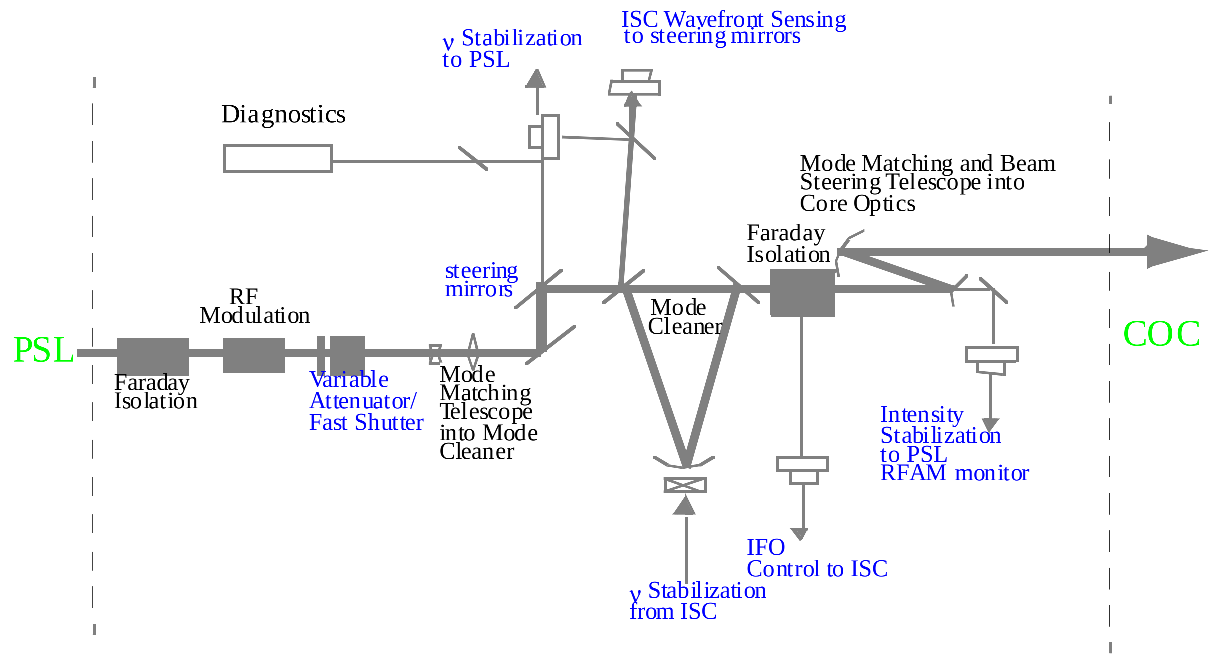
Input Optics Functions

- RF Modulation
- Mode Cleaning
- Mode Matching
- Optical Isolation
- Distribution of Control Beams
- Self Diagnostics



Conceptual layout of IO optical components

Design Considerations

Philosophy

•LIGO I Input Optics works

- LHO 2 km Mode Cleaner locks
for weeks; LLO locks for days

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Contingency plans and fall back positions to manage technical risk

•Where ever possible, leave comfortable margins for meeting requirements

Major Issues

Increased power -->
modal degradation, performance impact

Increased sensitivity -->
increased performance requirements

finite $$ -->
limitations on changes of vacuum envelope

IO System Requirements

Parameter	*LIGO I*	*Advanced LIGO*
Laser Power	8.5 W	180 W
Overall IO Efficiency (TEM$_{00}$)	75%	66%
Optical Isolation	70 dB	(> 85 dB)
Spatial Stabilization (100 Hz), TEM$_{01,10}$	< 3.5 x 10^{-9}/Hz$^{1/2}$	< 4 x 10^{-10}/Hz$^{1/2}$
Intensity Stabilization (100 Hz)	< 10^{-8} /Hz$^{1/2}$	< 3 x 10^{-9}/Hz$^{1/2}$
Frequency Noise (100 Hz)	< 10^{-4} Hz/Hz$^{1/2}$	~ 10^{-3} Hz/Hz$^{1/2}$
TEM$_{00}$ Coupling Efficiency	95%	95%
RF Amplitude Modulation	< 10^{-3}	~ 10^{-6} (TBR)

E-O Modulation in Advanced LIGO

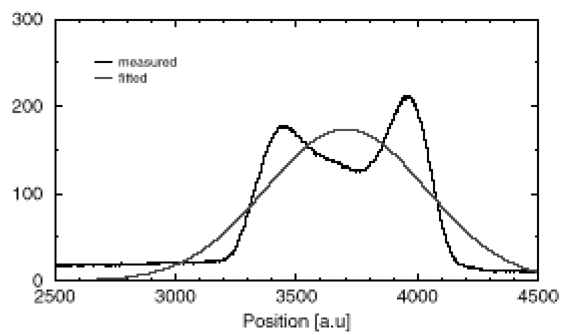
Two approaches

- **Serial modulation --> materials problem**

- **Find an E-O material that can handle 180 W (1 KW/cm^2)**

$LiNbO_3$ won't work:

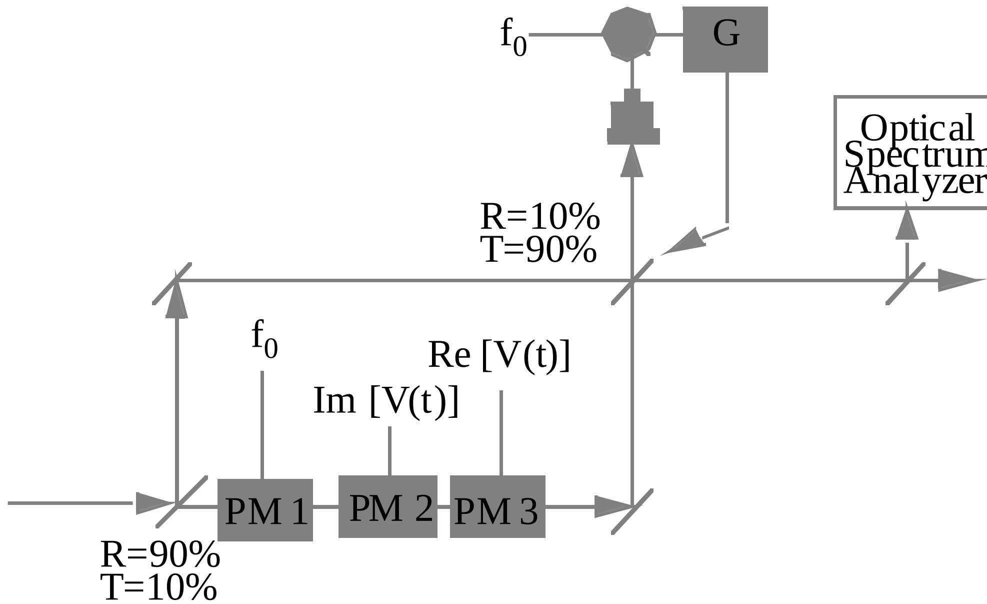
Severe thermal lensing



- **KTP does work; 300 W CW power, 1064 nm (H. Injeyan, TRW); RTA should also work (lower loss tangent)**

E-O Modulation in Advanced LIGO

Alternative Method: Mach-Zehnder modulation --> architecture problem

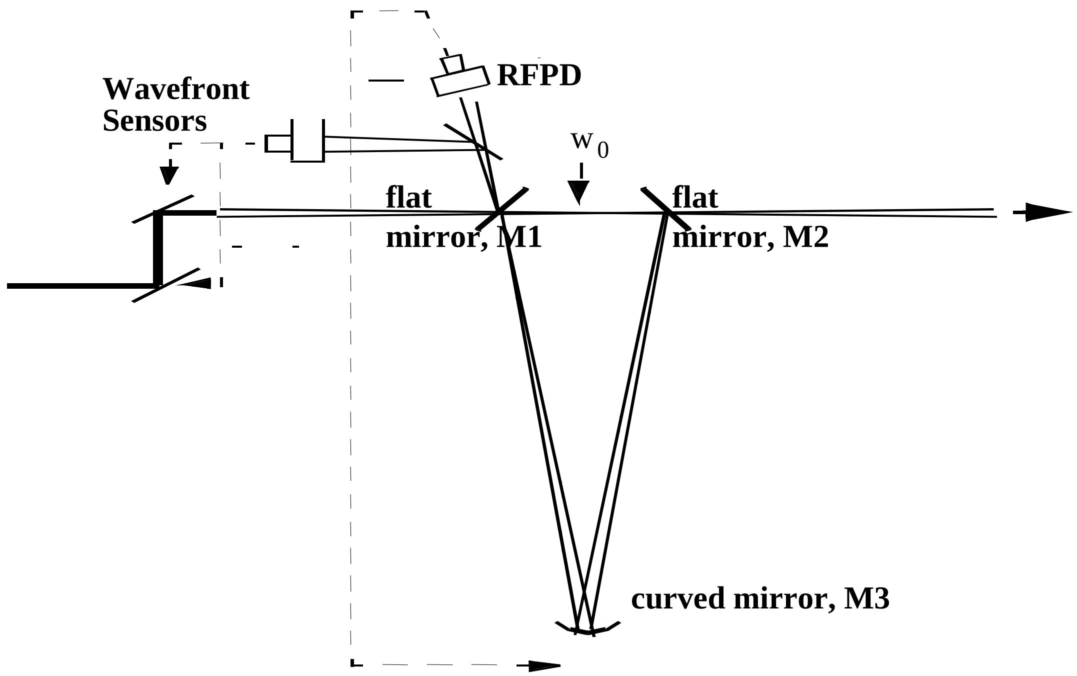


Prototype developed for initial LIGO detectors, but not well characterized

>> R&D effort

Mode Cleaner

- 3 mirror, triangular cavity
- double pendula suspensions
- most likely fused silica substrates (sapphire not ruled out, though)

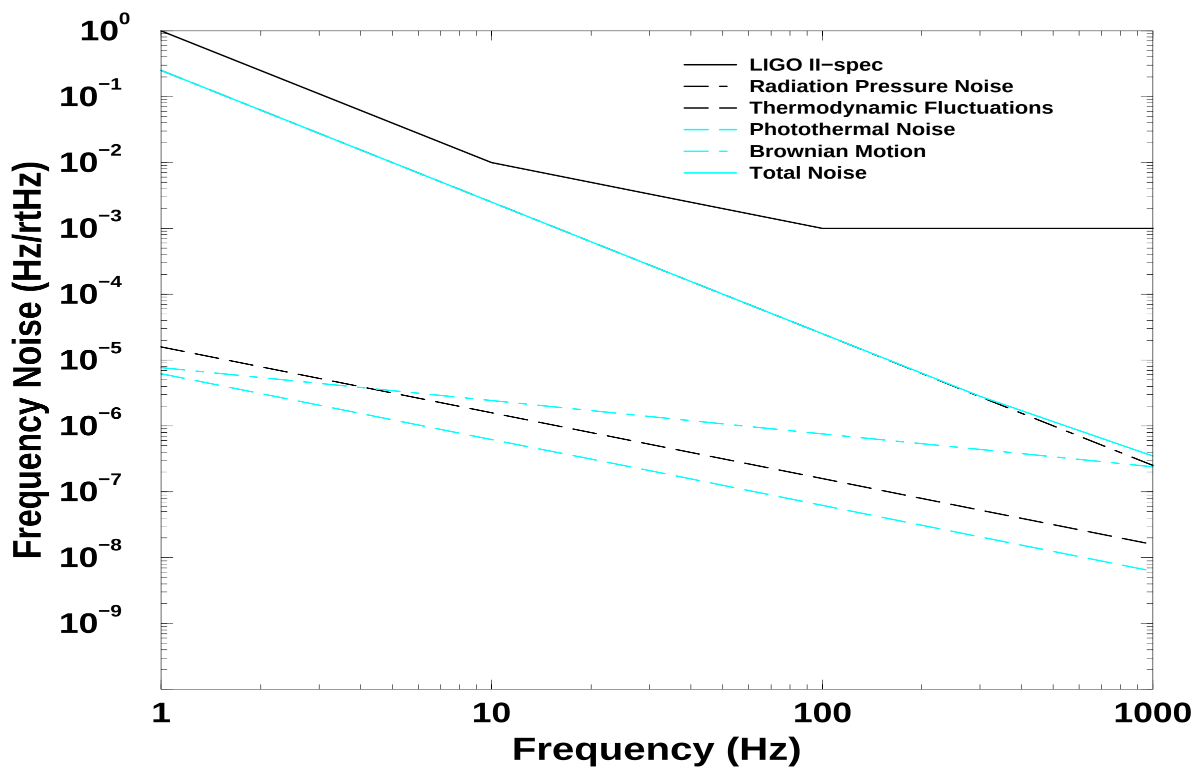


Design Parameters

Parameter	*Value*
Mode Cleaner Length	**16.6551 m***
Free spectral range	**9.000 MHz**
Mirror Dimensions	**20 cm diameter** **10 cm thick**
MC Flat mirror reflectivity (intensity)	**0.9985**
MC Curved Mirror Reflectivity (intensity)	**0.9999**
Assumed mirror losses	**15 ppm**
Finesse	**2026**
MC curved mirror RC	**28.00 m**
Cavity *g* factor	**0.407**
Transmission $\mathbf{TEM}_{01/10\ \text{modes}}$	**1 ppm**
Max HO mode Transmission	**1.5 ppm**
Waist size	**2.7 mm**
Stored Power	**97 kW**
Intensity at flat mirrors	**410** $\mathbf{kw/cm^2}$
Transmittance	**97%**

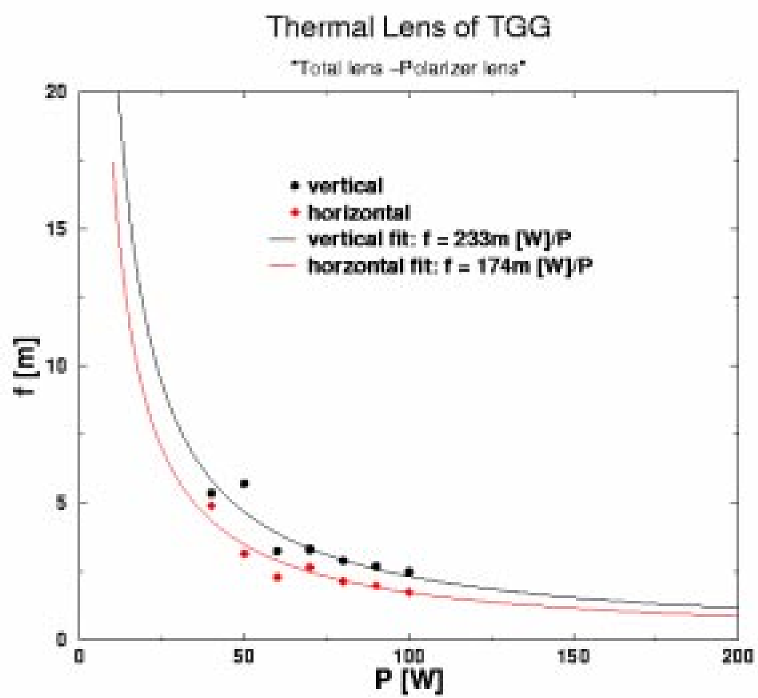
LIGO 2 Mode Cleaner

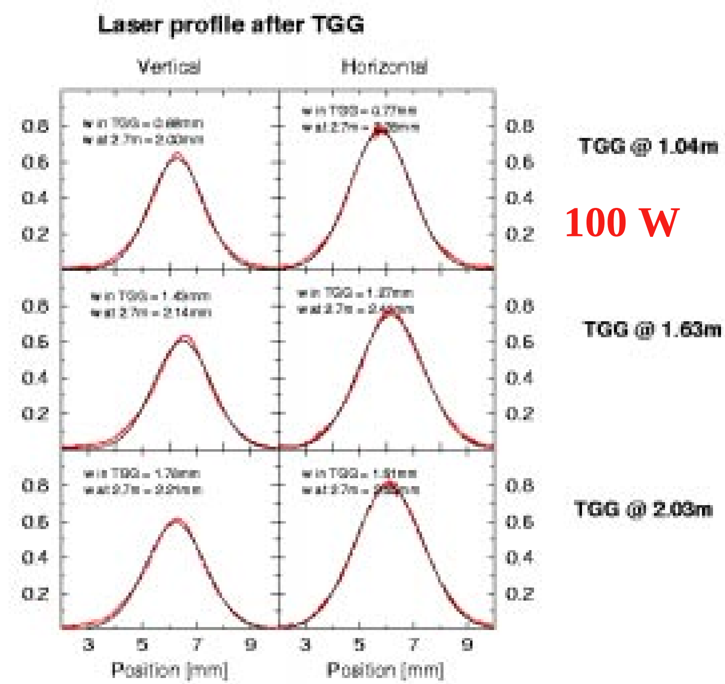
Design Frequency Noise Performance



Optical Isolation

Technical Issues: 1) Increased power >> thermal lensing





~ 3-5% uncompensatible modal degradation

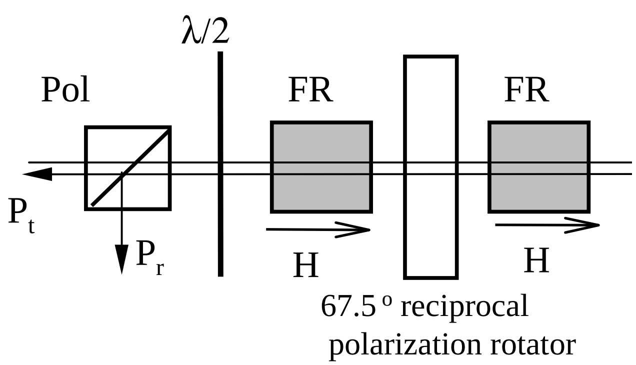
Optical Isolation

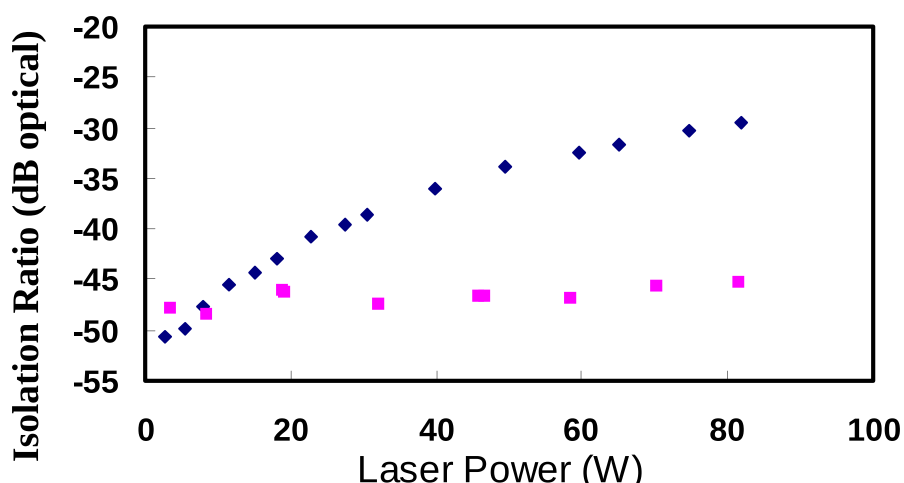
Technical Issues (cont'd)

2) Increased power >> thermally induced stress birefringence >> isolation ratio

A) Novel thermally compensating design

(Khazanov, et al., JOSA B, (2000)



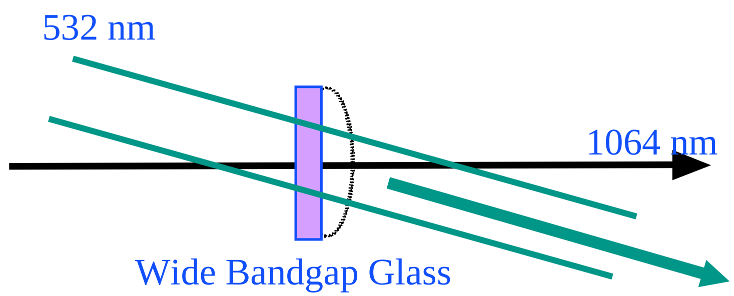


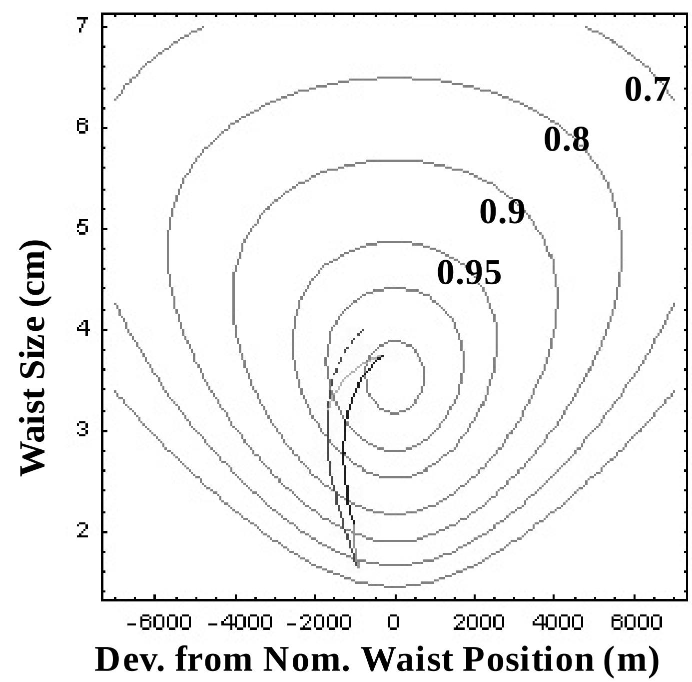
B) Commercially available high power Fis (EOT)

Mode Matching Telescope

Similar to current LIGO Telescope
- **2 mirror design (vacuum envelope constraints)**
- **Accommodates wide range of mode matching parameters**
- **All large (20 cm) optics**

- **in-situ adjustment with feedback**





R&D Issues For Advanced LIGO

- Modulator Development:
  - RTA performance
  - MZ modulation
- Isolator Development:
  - Full FI system test (TCFI, EOT)
  - Possible thermal compensation (-dn/dT materials)
- Telescope Development:
  - in-situ mode matching adjustment
- Mode Cleaner Development:
  - LASTI PSL-MC Prototype