LIGO II: Requirements for Modulators and Faraday Isolators

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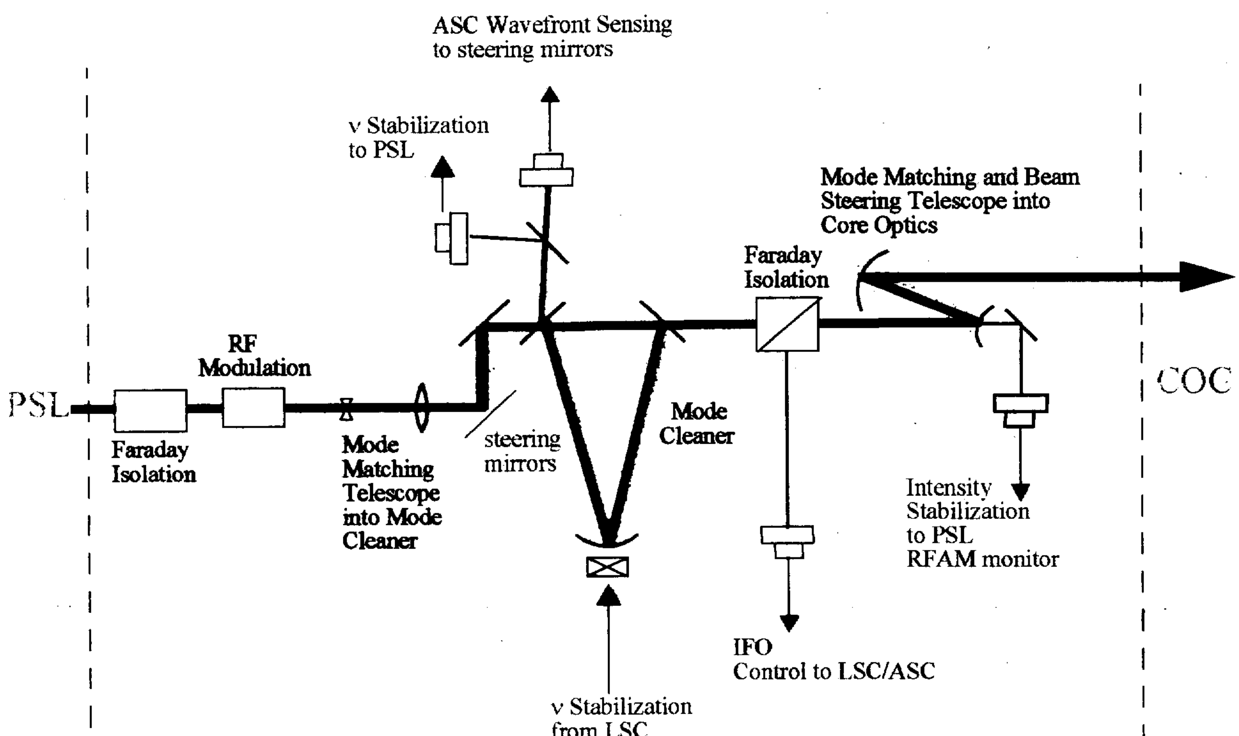
LSC Meeting
Livingston, LA
March 16, 2000

Input Optics

- Input Optics Functions
  - ›› Spatial and Frequency Stabilization (Mode Cleaning)
  - ›› Mode Matching
  - ›› Phase Modulation for Length/Alignment Sensing
  - ›› Isolation and Diagnostic Beam Transport



Functional Requirements

BOLD --> Impacts modulator, Faraday isolator design considerations

Parameter	***LIGO I***	***LIGO II***
Laser Power	**8.5 W**	**180 W**
Overall IO Efficiency (TEM_{00})	**75%**	**66%**
Optical Isolation	**70 dB**	**> 80 dB**
Spatial Stabilization (100 Hz)	$TEM_{01,10}$<3.5 x $10^{-9}/Hz^{1/2}$	$TEM_{01,10}$< $10^{-10}/Hz^{1/2}$
Intensity Stabilization (100 Hz)	< $10^{-8}/Hz^{1/2}$	< $10^{-9}/Hz^{1/2}$
Frequency Noise (100 Hz)	10^{-4} $Hz/Hz^{1/2}$	~ 10^{-6} $Hz/Hz^{1/2}$
TEM_{00}Coupling Efficiency	**95%**	**95%**
Modulation Depths	**Γ=0.5 (resonant); 600 mW** **Γ=0.05 (non-resonant)**	**Γ=0.5 (resonant); 10 W** **Γ=0.05 (non-resonant)**
RF Amplitude Modulation	**< 10^{-3}**	**~ 10^{-5}**

Requirements for LIGO II Modulators

- Power handling
  - ›› 180 W PSL light into IO

  - – EOMs must transmit full power over long periods and preserve modal quality;

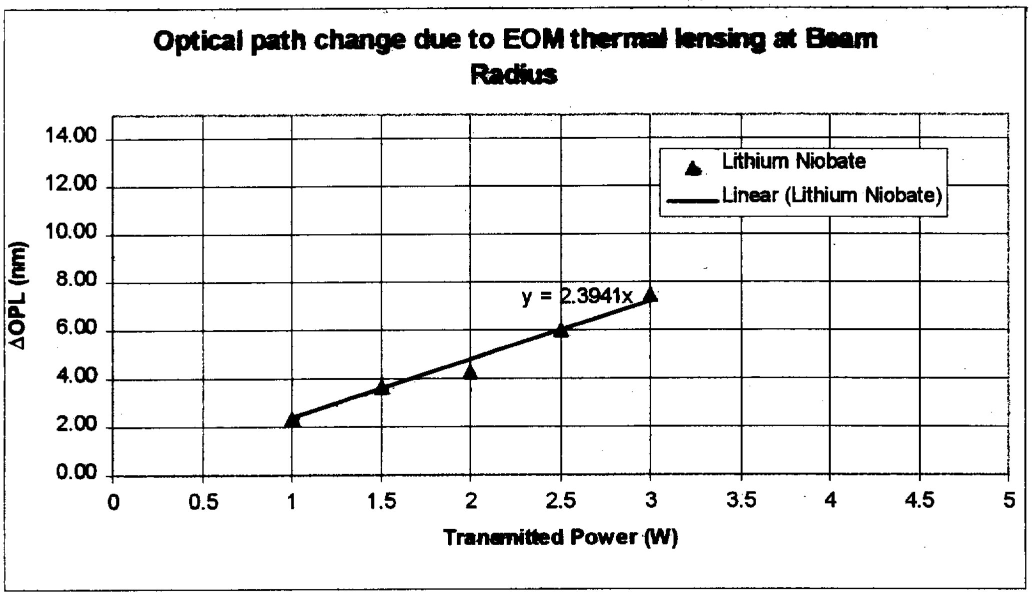
    - > 95 % in (compensated) TEM00 mode

    - > 5000 hours MTBF

    - RFAM: sideband power fluctuation < 10^{-4}; demodulated AM in GW band at shot noise for 100 mW (or as high as we can measure)
- Physics issues
  - – Thermal lensing
  - – Thermoelastic stress --> depolarization
  - – Photorefractive damage
  - – Second harmonic generation

Thermal Lensing in $LiNbO_3$

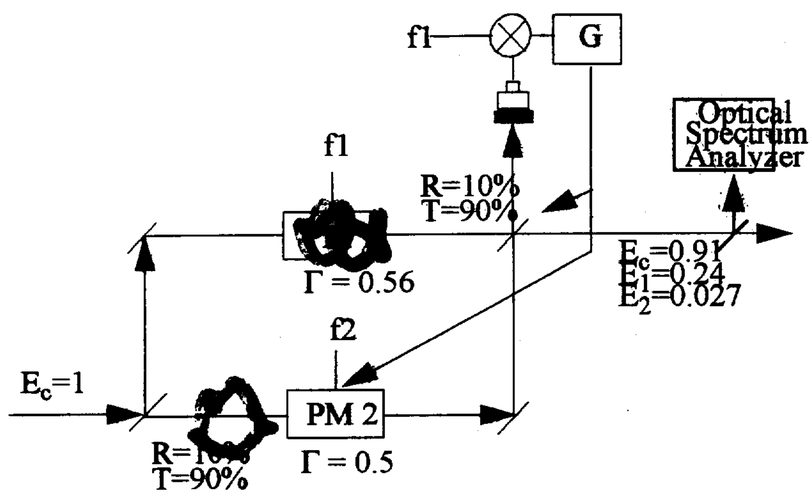
- LIGO I results; Shack-Hartmann measurement



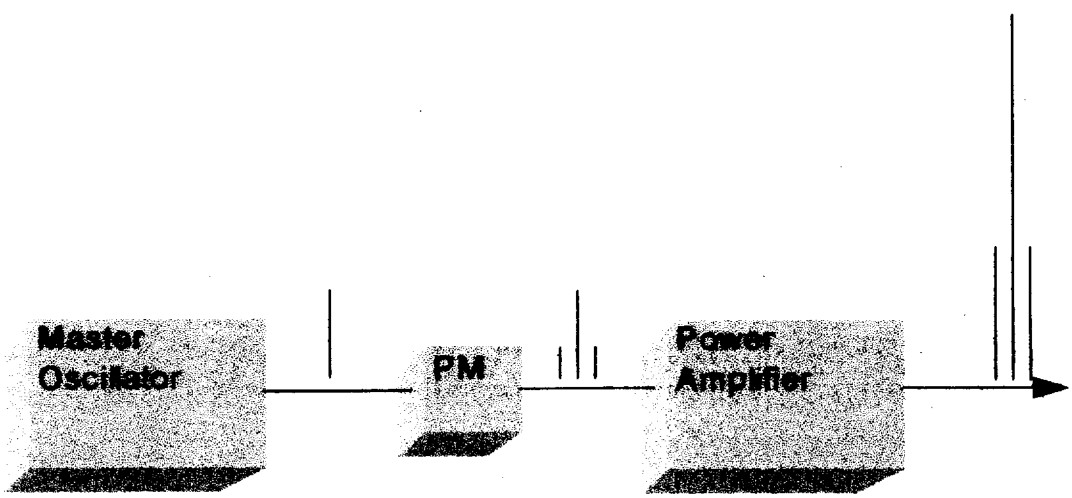
- Extrapolate to LIGO II
  - ›› ~ 400 nm OPD at 180 W powers
  - ›› ~ 5% in higher order modes uncompensated by focus shift
    - --> parabolic focusing elements
    - --> adaptive optics

Alternative Modulation Methods

- *alternative modulator architectures* to circumvent high powers
  - ›› Mach-Zender modulation

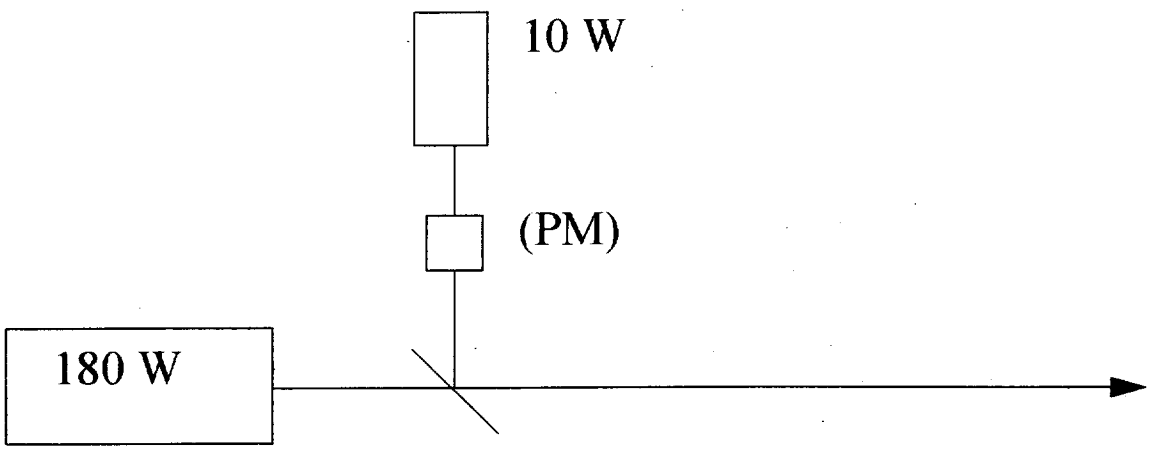


  - ›› Pre-modulation



Alternative Modulation Methods

›› Sub-carrier (or low power modulation)

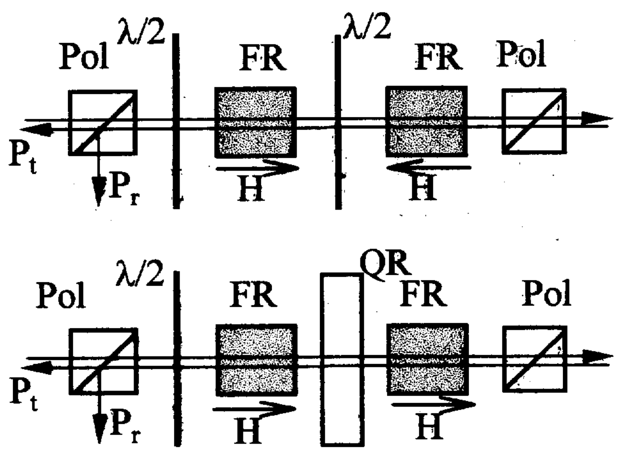


Requirements for LIGO II Isolators

- Power handling
  - ›› ~ 150 W PSL light into FI
    - – FIs must transmit full power over long periods and preserve modal quality; location of FI after mode cleaner in LIGO I
    - – FIs must maintain isolation ratios > 35 dB
- Physics issues
  - – Thermal lensing
  - – Thermoelastic stress --> depolarization

Depolarization Compensation - High Power FIs

- Thermo-elastic effect dominant mechanism for birefringence in TGG (Khazanov, et al, JOSA B 2000)
- Possible to use two FRs to minimize birefringence and depolarizationCavity Misalignment



$$\gamma_a = \frac{A_1}{\pi^2} p^2 \approx 0.014 p^2$$

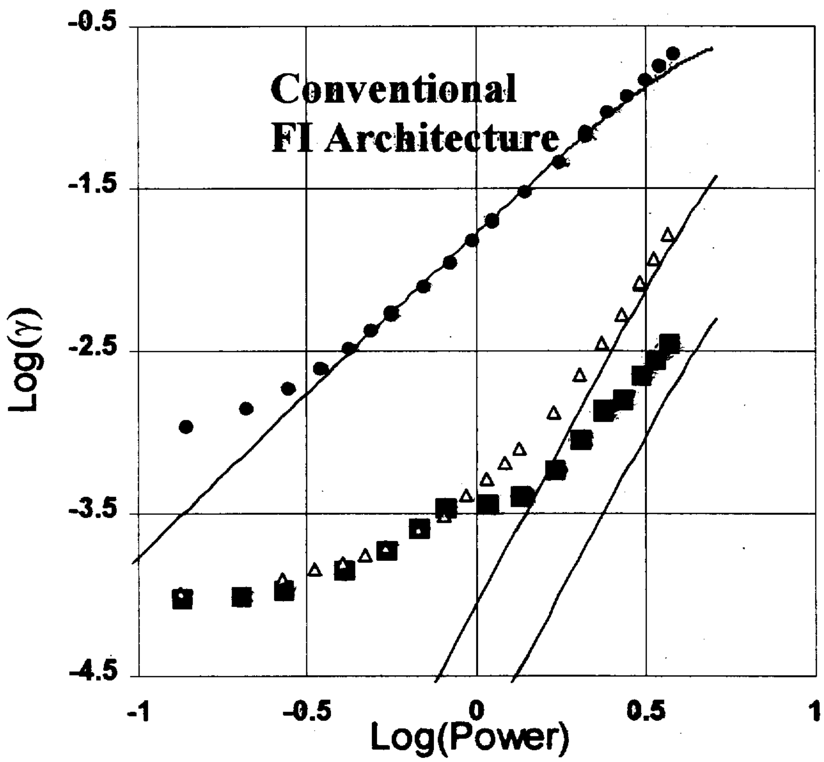
$$\gamma_b = \frac{8A_2}{\pi^4}[2a^2 + \sin^4(\frac{\pi}{8})] \cdot p^4 \approx 0.85 \cdot 10^{-4} p^4$$

$$\gamma_c = \frac{16a^2 A_2}{\pi^4} \cdot p^4 \approx 1.07 \cdot 10^{-5} p^4$$

$$p = \frac{P_h Q}{\lambda \kappa}$$

Depolarization Compensation - High Power FIs

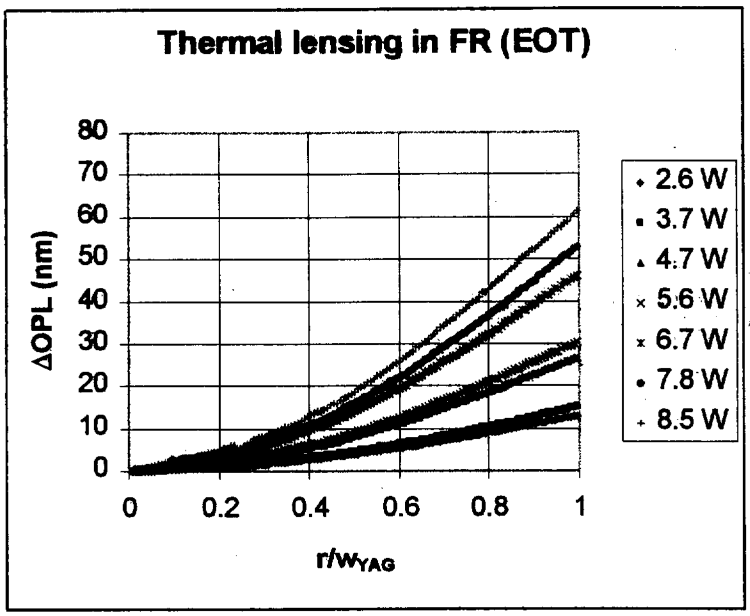
- Measurements using 5.5W 532 nm light (5X greater absorption than 1064 nm)



- Should allow for good isolation at LIGO II powers

Thermal Lensing in TGG

- TGG better than Faraday glass
- LIGO I results



- LIGO II extrapolation (120W)

--> ΔOPD ~ 600-800 nm

--> 12-15% power in higher order modes *which cannot be compensated by focus shift!!*