Performance of the LIGO Pre-stabilized Laser System

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Ninth Marcel Grossmann Meeting on General Relativity
Rome 2000

LIGO-G000154-00-W

PSL Design and Performance Assessment

Design:

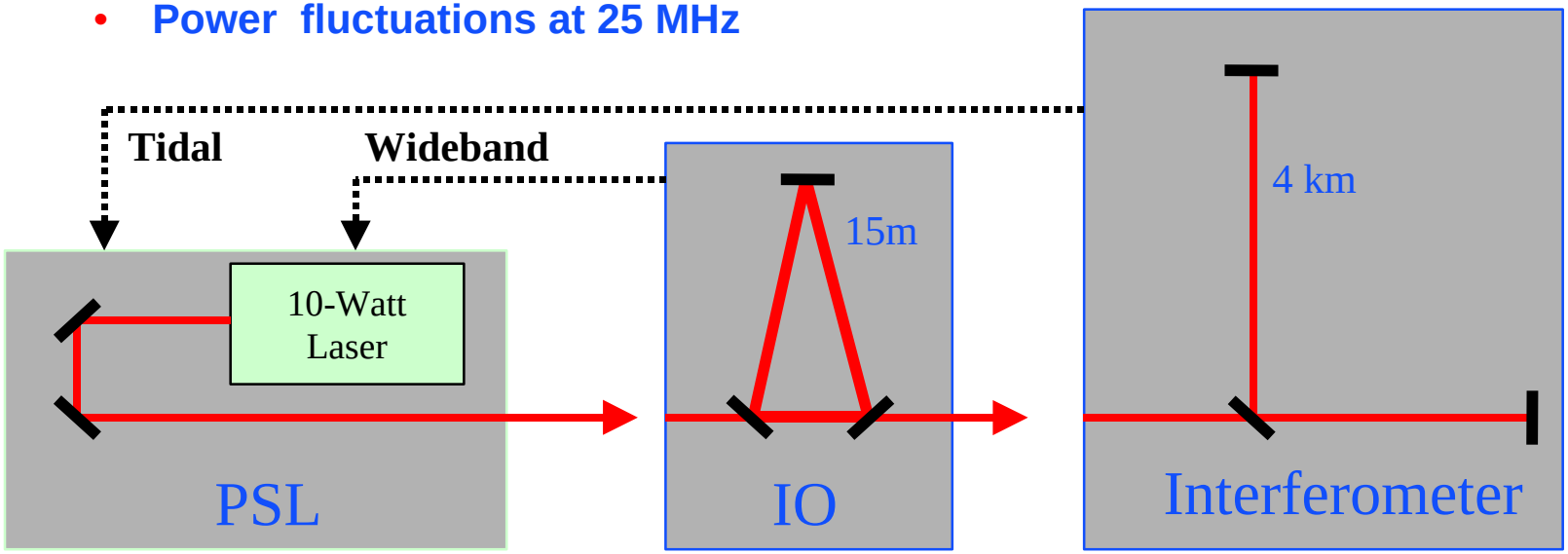
- Peter King, Rich Abbott, Alex Abramovici, Stefan Seel, Jim Mason, Stan Whitcomb, Virginio Sannibale - Caltech
- Peter Fritschel - MIT
- Eric Gustafson, Nob Uehara - Stanford

Performance Assessment:

- Robert Schofield - U of O
- Nergis Mavalvala, Caltech
- Joe Kovalik - LLO
- Michael Landry, David Ottaway - LHO
- Rana Adhikari, P. Csatorday - MIT
- Benno Willke - GEO

Role of the Pre-stabilized Laser System

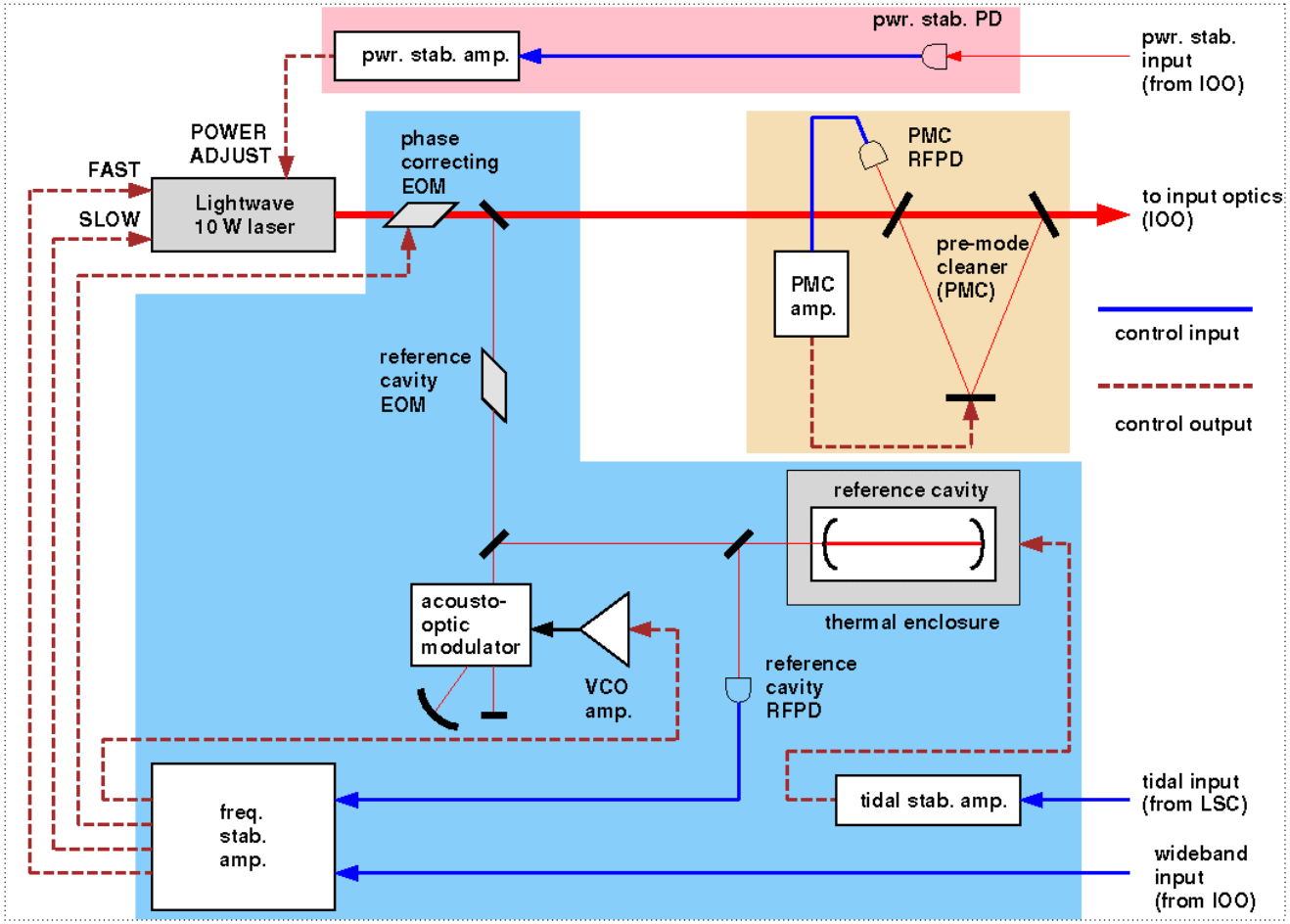
- Deliver pre-stabilized laser light to the long mode cleaner
  - **Frequency fluctuations**
  - **In-band power fluctuations**
  - **Power fluctuations at 25 MHz**
- Provide actuator inputs for further stabilization
  - **Wideband**
  - **Tidal**



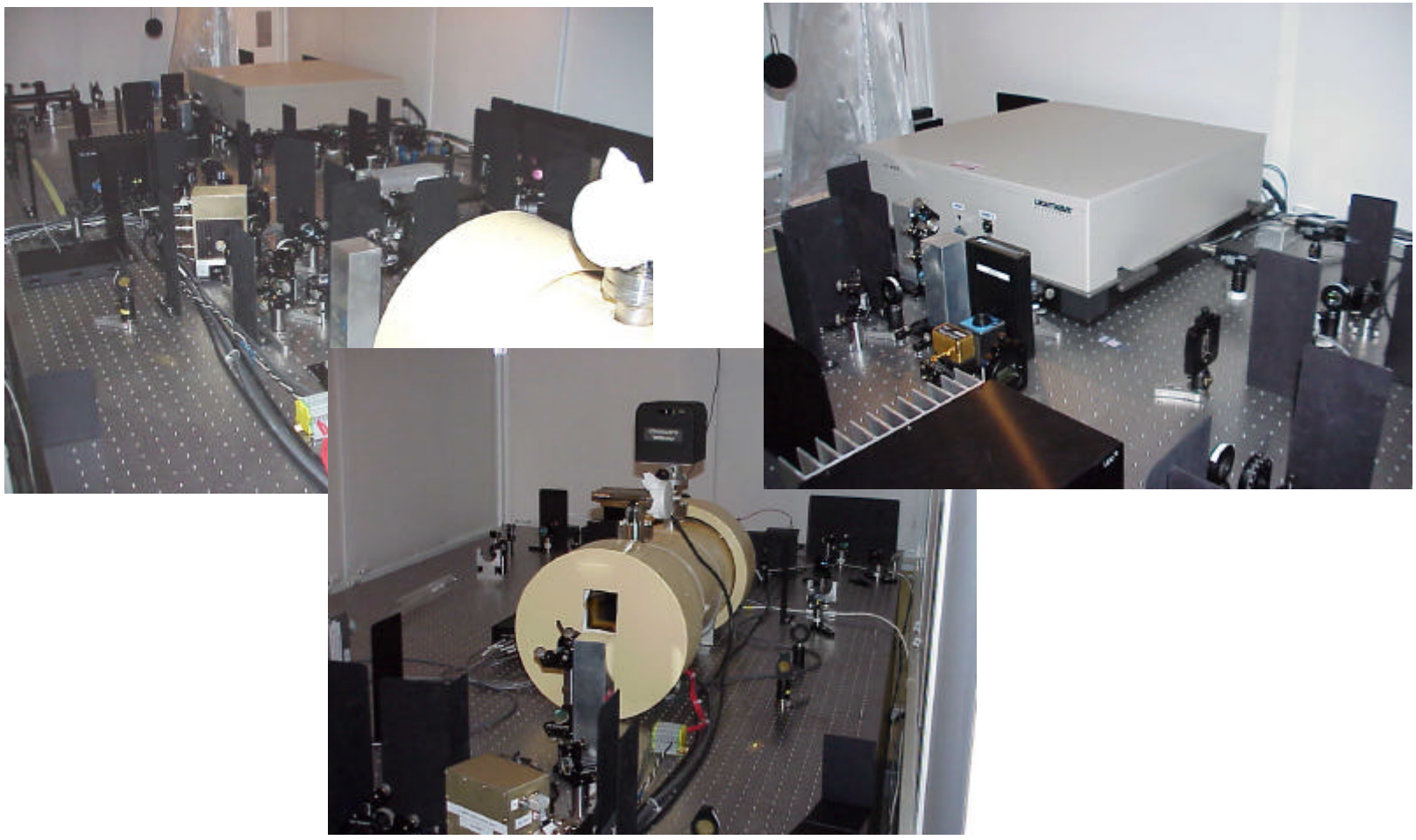
Overview of Performance Requirements

- Reliability : > 5,000 hours MFBF
- Robustness : > 40 hours without loss of lock
- Frequency noise : < 100 mHz/rtHz at 100 Hz
- In-band power noise : $\Delta P/P$ < 1e-8/rtHz after MC
- Power noise at 25 MHz : < 1.01 X SN for 600 mW
- Wideband actuator : for further frequency stabilization
- Tidal actuator : to compensate for common-mode length changes of long arms due to earth tides

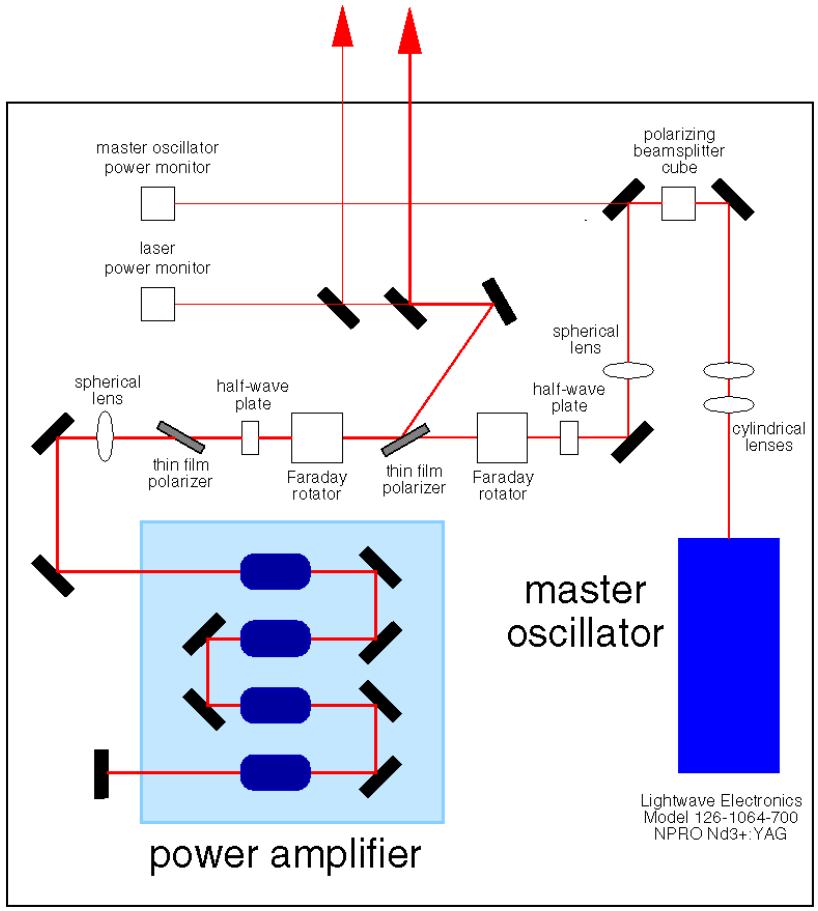
PSL Optical Layout



Washington 2k PSL

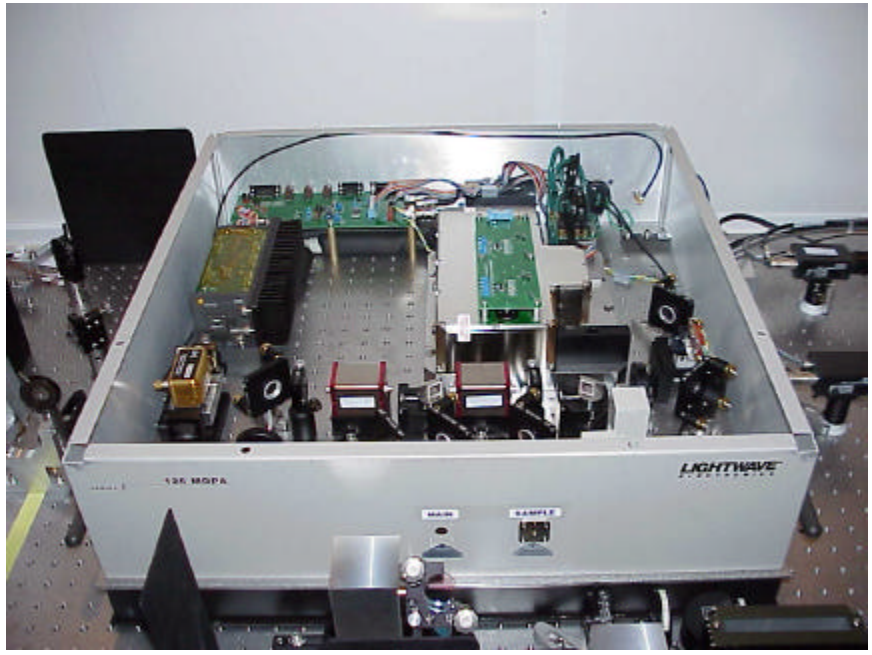


LIGO 10-Watt Laser



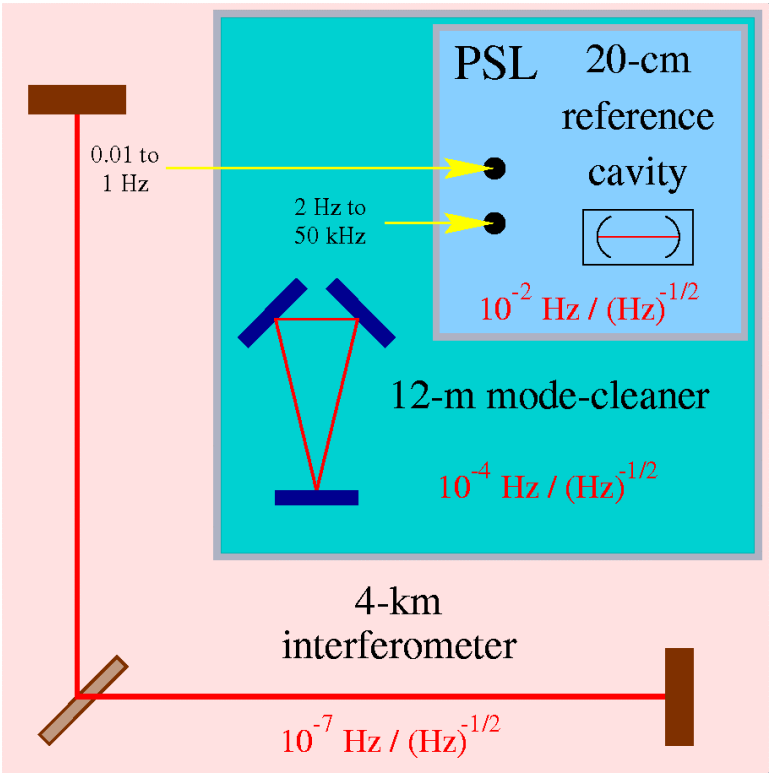
- Master Oscillator Power Amplifier configuration
- Lightwave Model 126 non-planar ring oscillator
- Double-pass, four-stage amplifier
- All solid state:
  amplifier utilizes 160 watts of laser diode pump power

Performance of the LIGO 10-W Laser



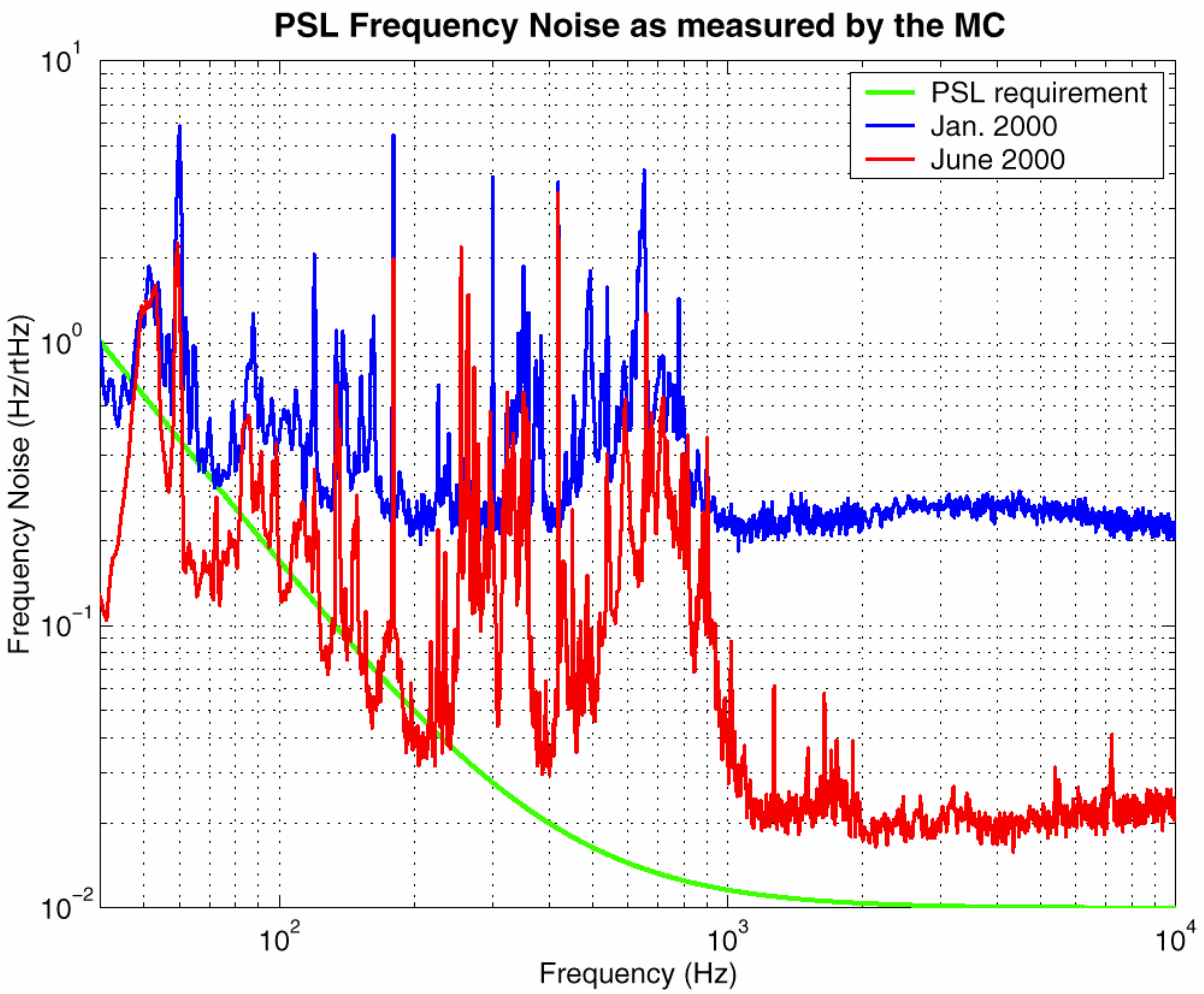
- WA-2k PSL > 15,000 hours continuous operation
  - » Two power supply failures
- TEMoo power > 8 watts
- Non-TEMoo power < 10%
- Free-running frequency noise ~100 Hz/rtHz at 100 Hz. Falling as 1 / f
- Six units delivered to LIGO to date.

Frequency Noise



- Three nested feedback control loops
- Sensors
  - » 20-cm fixed reference cavity
  - » 12-m suspended modecleaner
  - » 4-km suspended arm cavity
- Actuators
  - » SLOW – NPRO temperature
  - » FAST – PZT bonded to NPRO
  - » EOM between MO and PA
  - » Frequency shifter
- Ultimate goal: $\Delta f/f \sim 3 \times 10^{-22}$

Frequency Servo Performance



N. Mavalvala

P. Fritschel

In-band Power Noise

- Requirement:

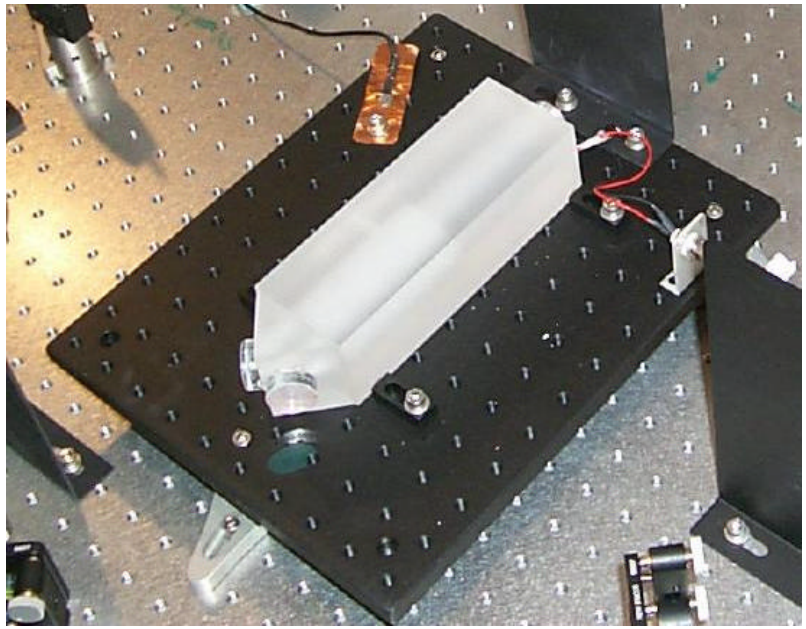
  $\Delta P/P < 10^{-8}$ 1/rtHz after the long modecleaner

- Driven by:
  - » Coupling to length signal via offset from fringe center
  - » Radiation pressure noise in the modecleaner

- Sensor: Photodetector situated after the 12-m MC, outside the vacuum env.
- Actuator:
  - » Current Adjust actuator delivered with laser did not meet requirements
  - » Current shunt actuator designed by P. King and R. Abbott at Caltech
  - » 10-W laser modified to include actuator – meets requirements
- Stabilization after MC has not yet been attempted.

Power Noise at 25 MHz Modulation Frequency

- Requirement: $\Delta P/P$ at 25 MHz < 1.01 times shot noise limit for 600 mW (~ 9×10^{-10})
- Technical noise of laser is above this limit.
- Solution: passive filtering in a Fabry-Perot cavity
- Technical noise filtered as $1/(1 + (f / f_c)^2)$ f_c is the cavity half



Required Filtering by the Pre-modecleaner

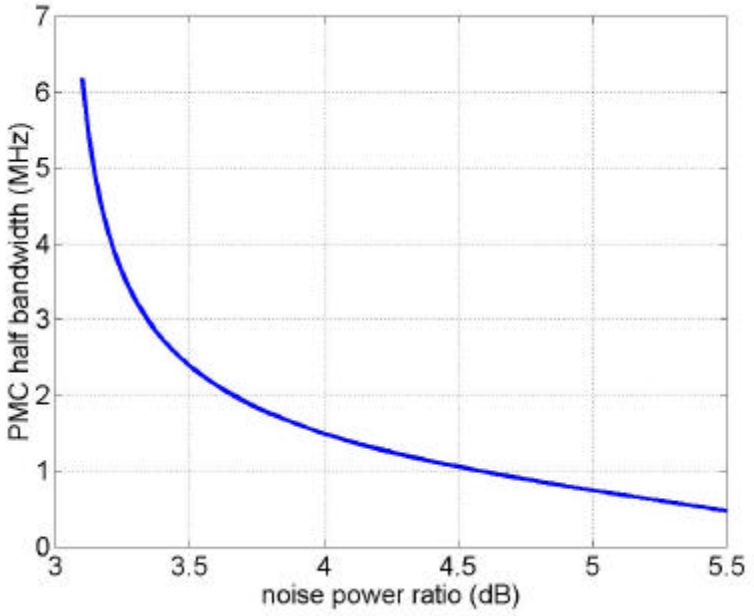
- Filtering by PMC:

$V_{trans}(f)=1+ (V_{in}-1)(1+(f/f_c)^2)^{-1}$

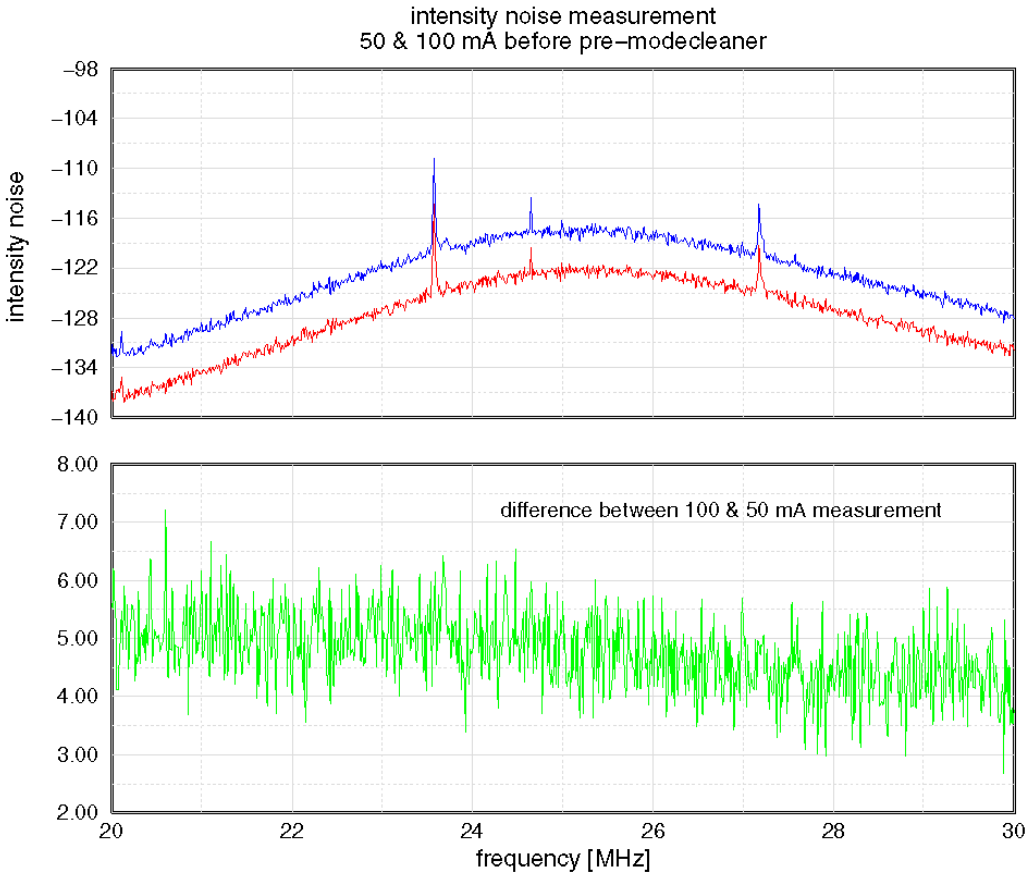
V is the ratio of the PSD of the RIN to the SN limit

f_c is the PMC half bandwidth

- To determine required f_c:
  - » Measure the RIN before the PMC at 50 mA and 100 mA



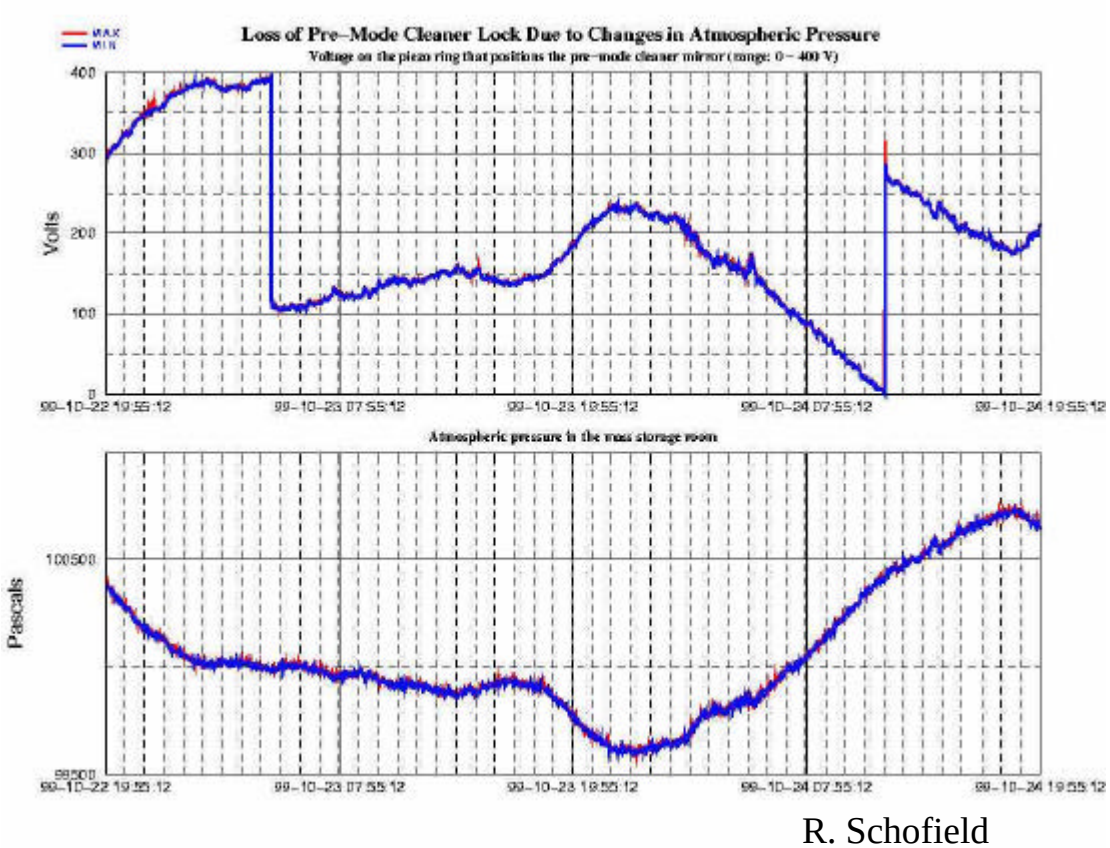
RIN Measurements at 50 mA and 100 mA



- Noise ratio of ~ 5
  - Req. f_c ~ 0.8 MHz
- f_c for present PMC ~ 1.7 MHz
  - ASD ~ 2 x spec.

P. King, B. Willke

Sensitivity of Pre-modecleaner to Atmospheric Pressure Variations



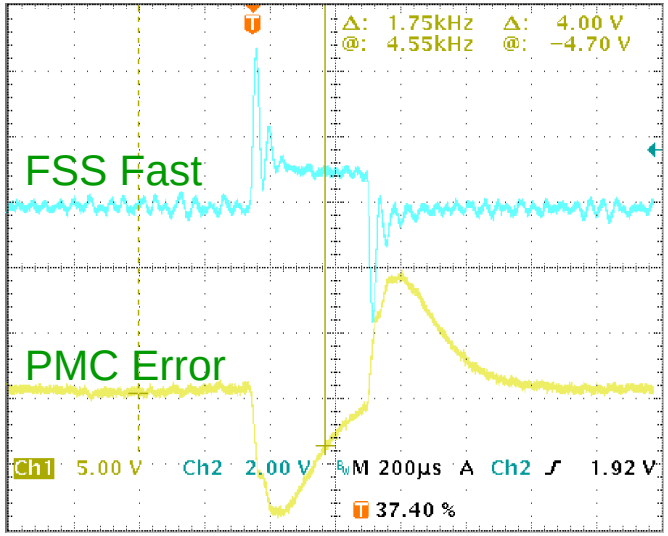
R. Schofield

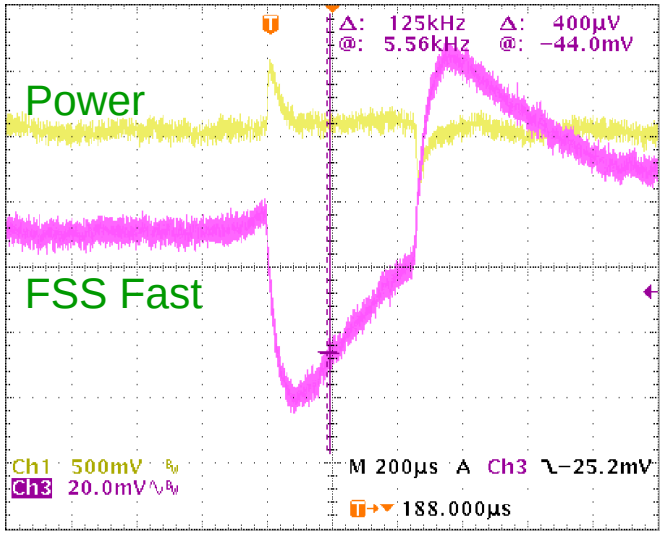
- Optical path length changes:

strain ~ 2.7 x 10^{-9} per Pascal

- Solution:
  - » Wider range PZT
  - » “Smart” acquisition sequence
  - » Vacuum tank for PMC

Frequency Glitches





- Eliminated (temporarily?) by decreasing NPRO pump laser diode current
- Cause under investigation by Lightwave, Inc.

Summary

- Laser has operated for > 15000 hours
- Frequency and PMC lock very robust
- Frequency noise close to requirement
- In-band intensity noise loop with PD after MC not yet tested.
  - » Current shunt actuator promising
- PMC performance close to requirements
  - » Vacuum chamber being fabricated
- Laser frequency glitches under investigation
- Further reduction of acoustics-driven frequency noise in progress
- LA-4k, WA-4k, and 40-m Lab PSLs being fabricated and installed