High-power Photodiode Array

A high-sensitivity detector for laser power stabilization

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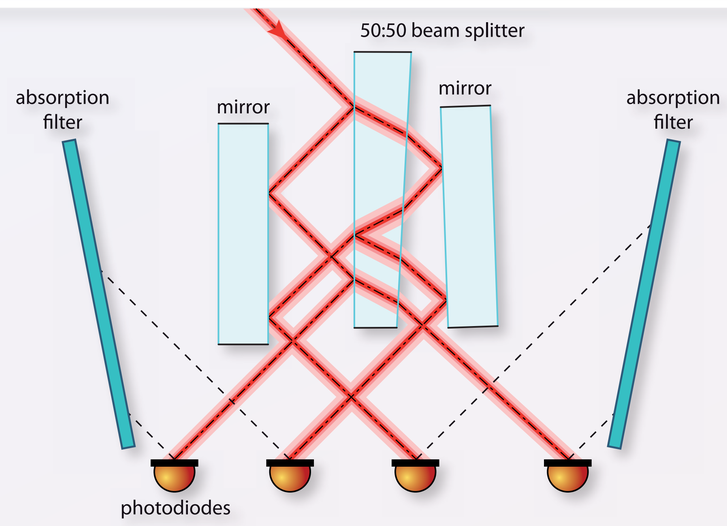
Problem

- Sensitivity of phototdetectors fundamentally limited by maximal detectable power
- High power causes technical problems:
  - Complicated cooling of photodiodes
  - Extremely low noise readout electronics required

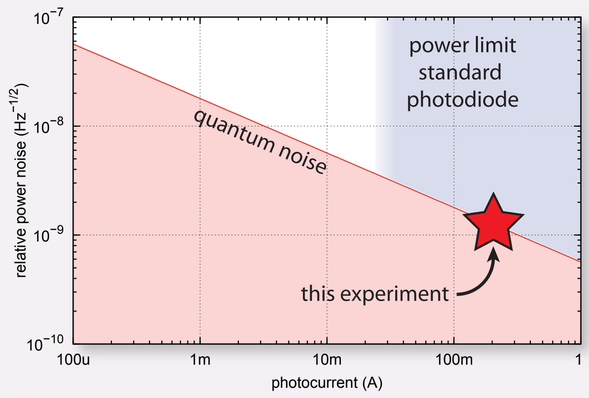
Solution

- Distributing power to several photodiodes
- Individual photodiode readout and electronic summation of photodiode signals



Fundamental sensitivity limit

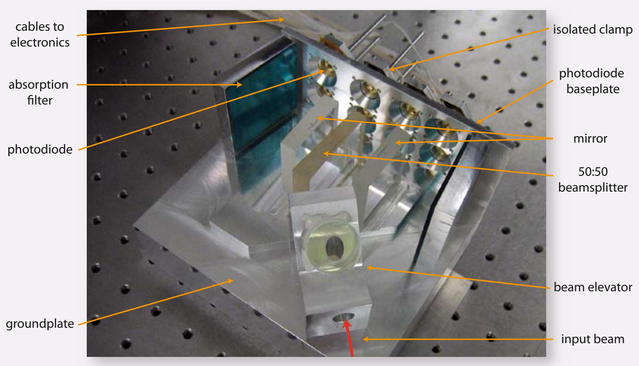
- Relative shot noise decreases with detected power

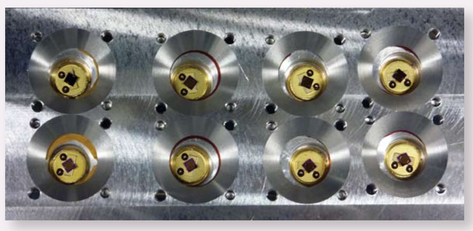


Optical and Mechanical Design

- Laser beam split into four partial beams, ~60 mW each
- InGaAs photodiodes (Perkin Elmer C30642), 2 mm active diameter, package windows removed, electrically isolated mounted
- Photodiode hit at 45° to reduce back reflections
- Spurious reflections at photodiode surfaces absorbed in glass filters, Brewster angle

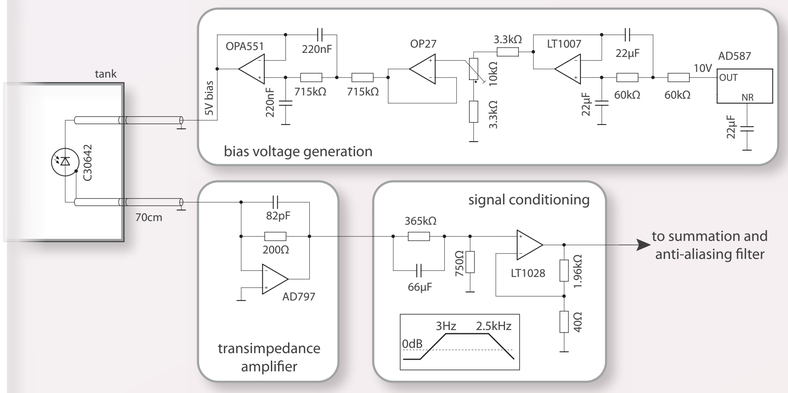
- No active cooling, temperature rise of ~6 K of photodiode package at full photocurrent
- All components vacuum compatible
- Each photodiode aligned for minimal pointing noise coupling

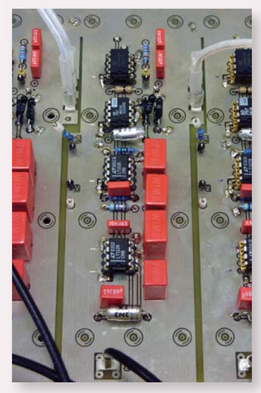




Low Noise Readout Electronics

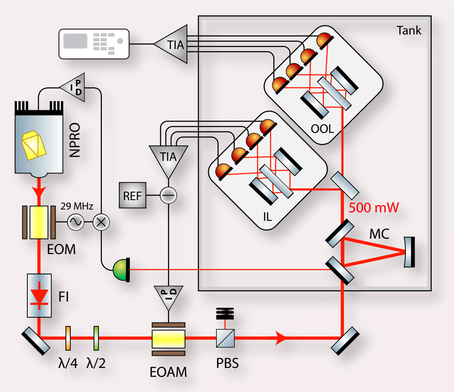
- Each photodiode read out by own transimpedance amplifier, 200 Ω low current-noise resistor
- Photodiodes in vacuum, electronics placed outside, ~70 cm shielded cables
- Signal conditioning filter, 34 dB amplification between 3 Hz and 2.5 kHz
- Added four signals after conditioning filter, total photocurrent ~200 mA
- A/D converter card in computer used to measure power noise, 1 Hz to 1 kHz
- Electronic noise with full current was factor of ~2 larger than with no light on photodiodes

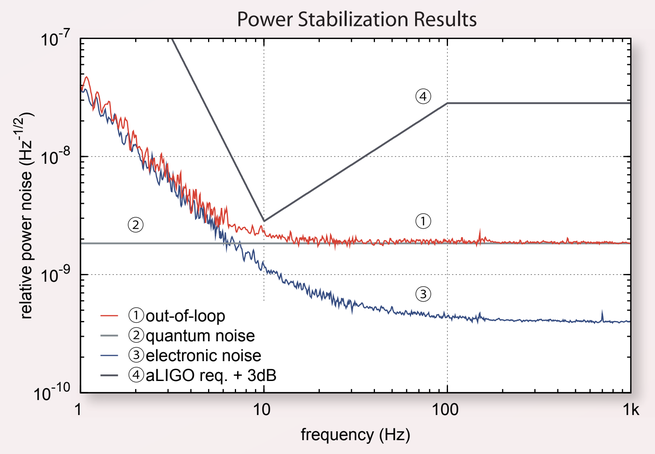




Detector Sensitivity

- Sensitivity of the photodiode array measured in power stabilization experiment [2]
- Second equal detector used to suppress power fluctuations (bandwidth ~80 kHz)
- Out-of-loop (OOL) measured power noise is sum of the uncorrelated noise of both detectors
- OOL relative power noise of $2.4\times10^{-9}\,Hz^{-1/2}$ at 10 Hz, $1.8\times10^{-9}\,Hz^{-1/2}$ for f >15 Hz ($1.7\times10^{-9}\,Hz^{-1/2}$ at 10 Hz with subtracted OOL detector noise)
- First experiment fulfilling the Advanced LIGO power noise requirements [3]



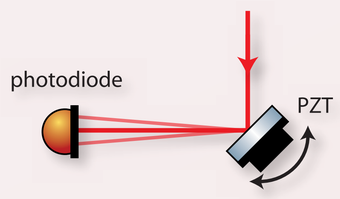


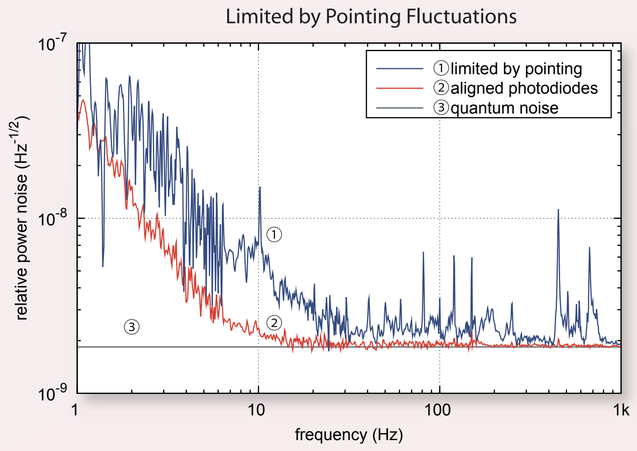
Noise Sources

- Considerable noise sources eliminated in the experiment [4]:
  - Air particles (~250 ft^{-3}), eliminated by using tank with HEPA filtered air
  - Beam pointing fluctuations, eliminated by using mode-cleaner for pointing fluctuations suppression and by aligning the photodiodes to position of smallest pointing coupling
- Limiting noise sources in final results:
  - Electronic noise below 7 Hz
  - Shot noise above 7 Hz at a level of $1.8\times10^{-9}\,Hz^{-1/2}$

Measurement of Pointing Coupling

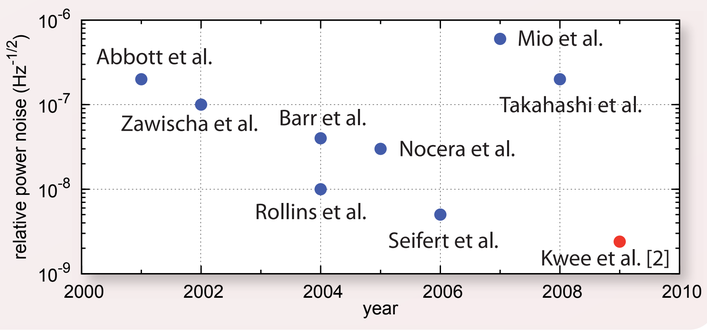
- Beam pointing modulated with a PZT
- Aligned photodiode to reduce coupling
- Lowest achieved coupling: 3 m^{-1}





Comparison

- Power stabilization results of several experiments
- Out-of-loop measured residual power noise at 10 Hz



References

1. Email: patrick.kwee@aei.mpg.de, Homepage: http://www.aei.mpg.de/~pakwee/
2. P. Kwee, B. Willke, and K. Danzmann, "Shot-noise-limited laser power stabilization with a high-power photodiode array" Opt. Lett., 34(19):2912-2914, 2009. doi:10.1364/OL.34.002912
3. Pre-Stabilized Laser Design Requirements. Internal Technical Report LIGO-T050036, 2009.
4. P. Kwee. "Laser Characterization and Stabilization for Precision Interferometry" Ph.D. thesis, Universität Hannover, 2010.

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