Photodetection at a New Sensitivity Level

High-power optical AC coupling at the $10^{-10}\,\mathrm{Hz}^{-1/2}$ level

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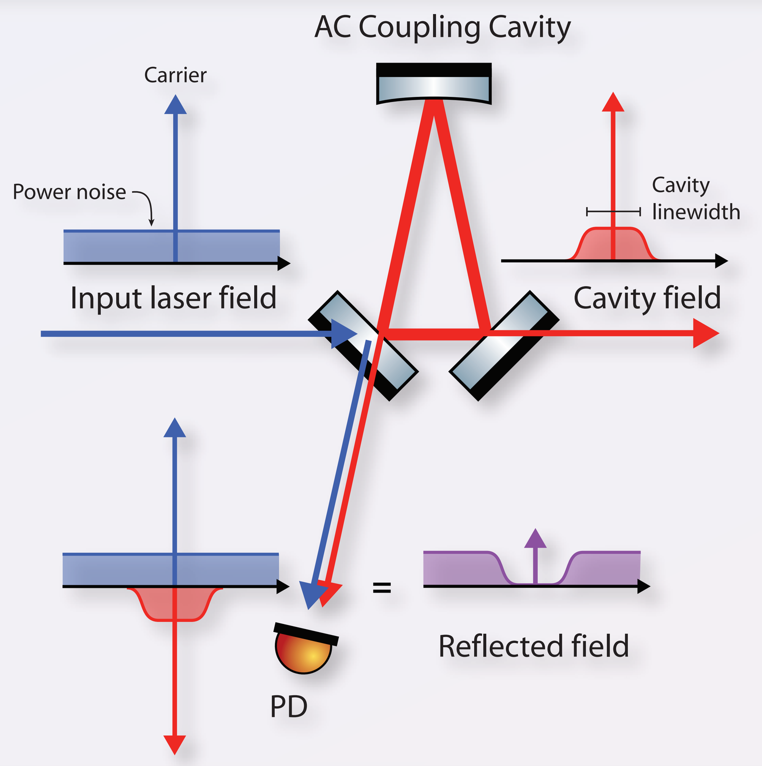
Problem

- Problems of traditional photodetection schemes measuring small power fluctuations:
  - High power on photodiodes
  - Limited at $10^{-9}\,\mathrm{Hz}^{-1/2}$ to $10^{-8}\,\mathrm{Hz}^{-1/2}$ relative power fluctuations

Solution

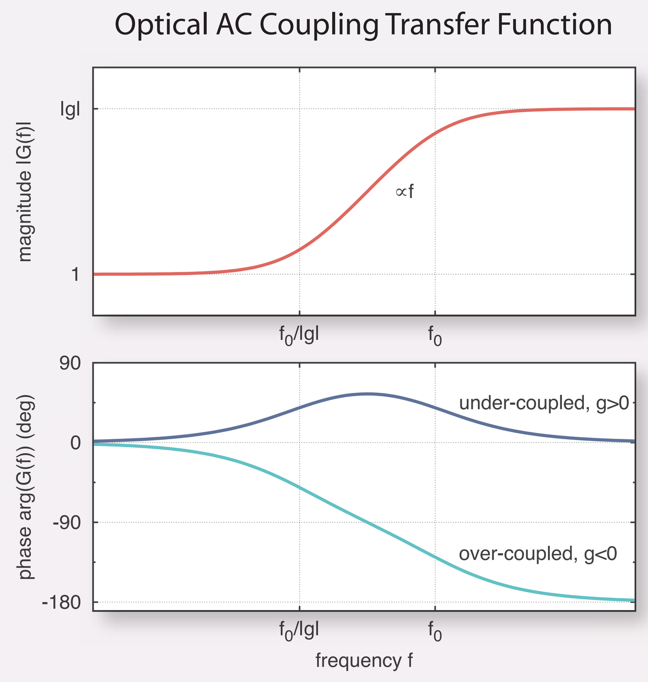
- Optical AC coupling [2,3] increases sensitivity of a photodetector by using an optical resonator
- Advantages of optical AC coupling:
  - Equivalent photo currents of several 10A possible, reaching $10^{-10}\,\mathrm{Hz}^{-1/2}$ level
  - New power stabilization schemes possible



Functional Principle [2]

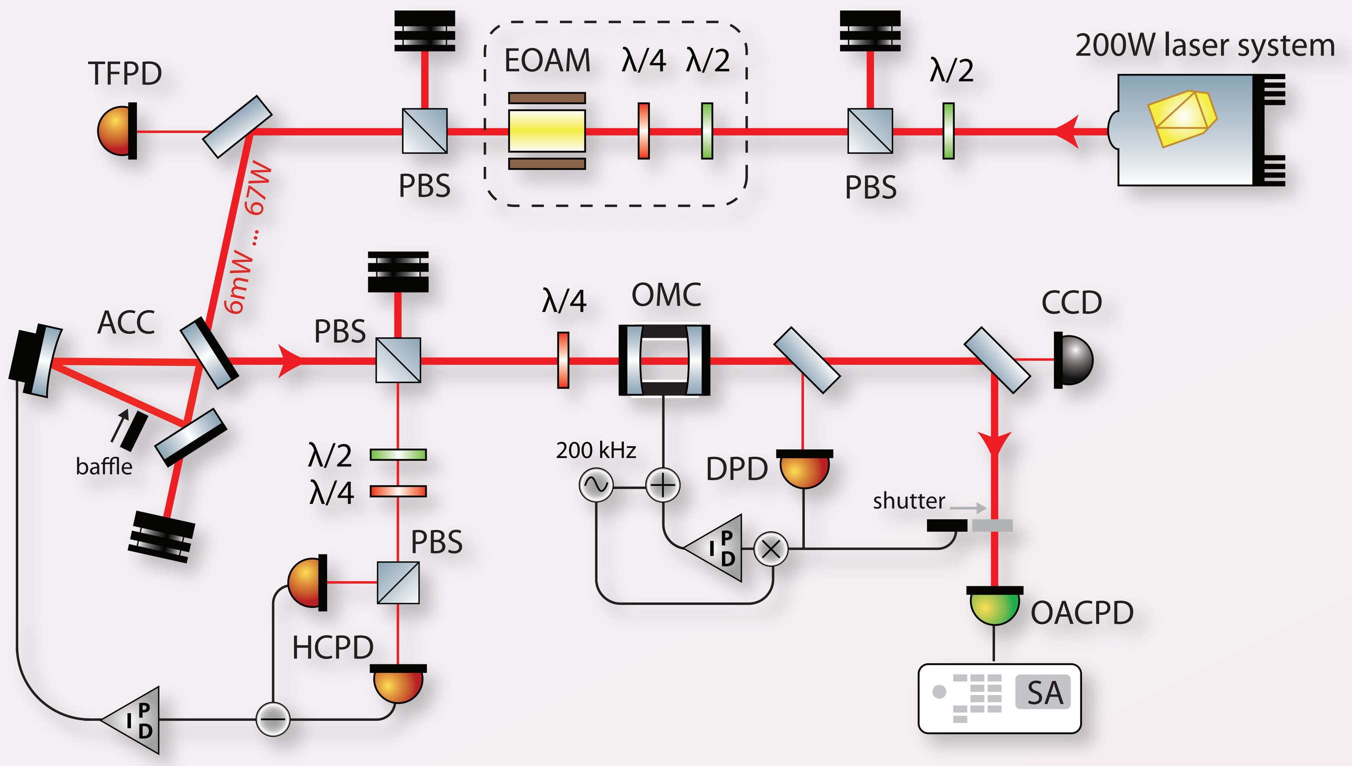
- Photodiode in reflection of optical resonator
- Power fluctuation sidebands are reflected
- Carrier is almost completely transmitted
- Transfer function for relative power fluctuations given by G(f)

$$|G(f)| = \sqrt{\frac{1 + g^2 \cdot f^2/f_0^2}{1 + f^2/f_0^2}}$$



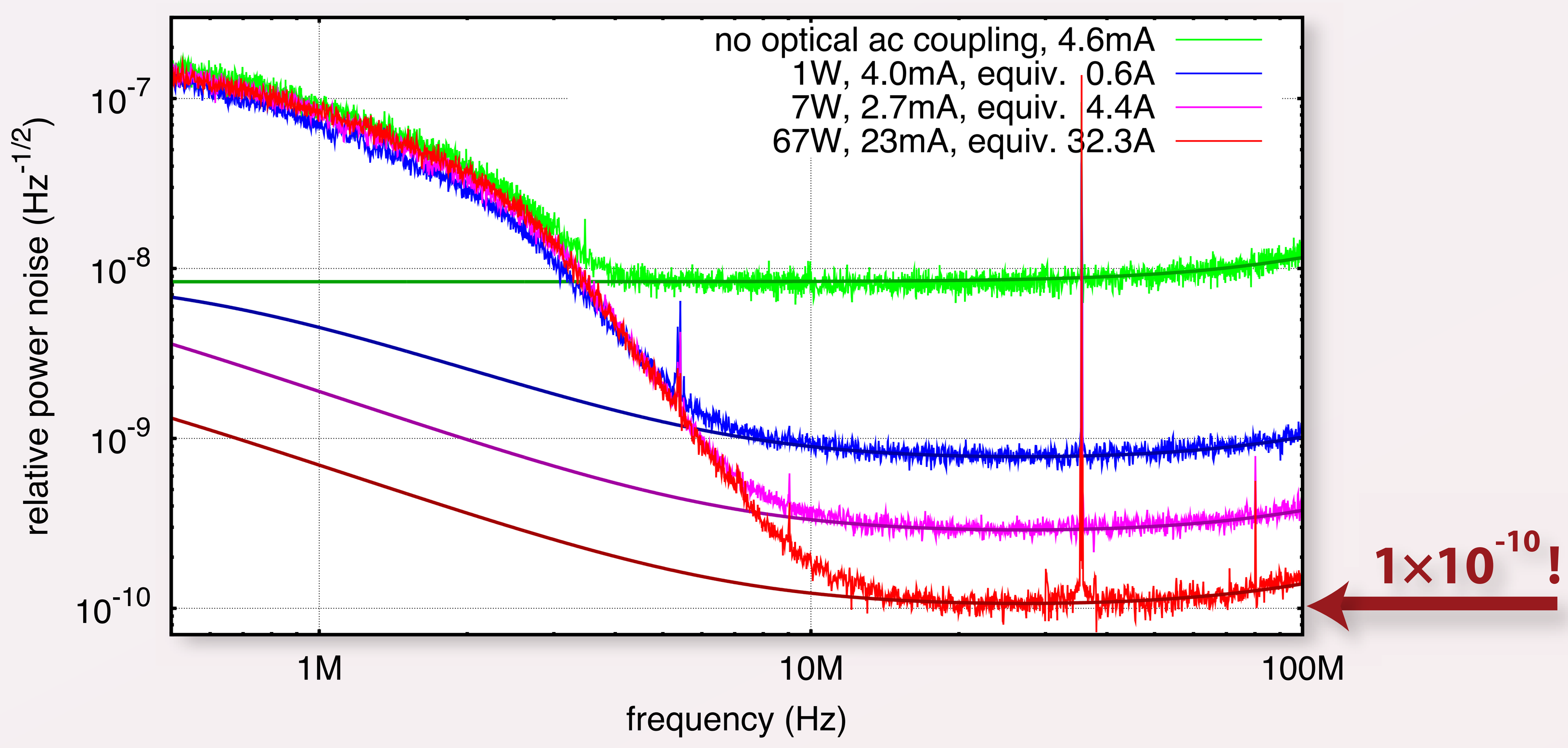
Experimental Setup

- Relative power noise of 200W laser system [4] measured (continuous-wave laser at 1064nm)
- Optical resonator (ACC) increased sensitivity of photodetector OACPD
- Output mode-cleaner (OMC) necessary to suppress parasitic higher-order modes
- Hänsch-Couillaud locking for ACC, dither lock for OMC used
- Two-stage µs-shutter system to protect OACPD from too much laser power



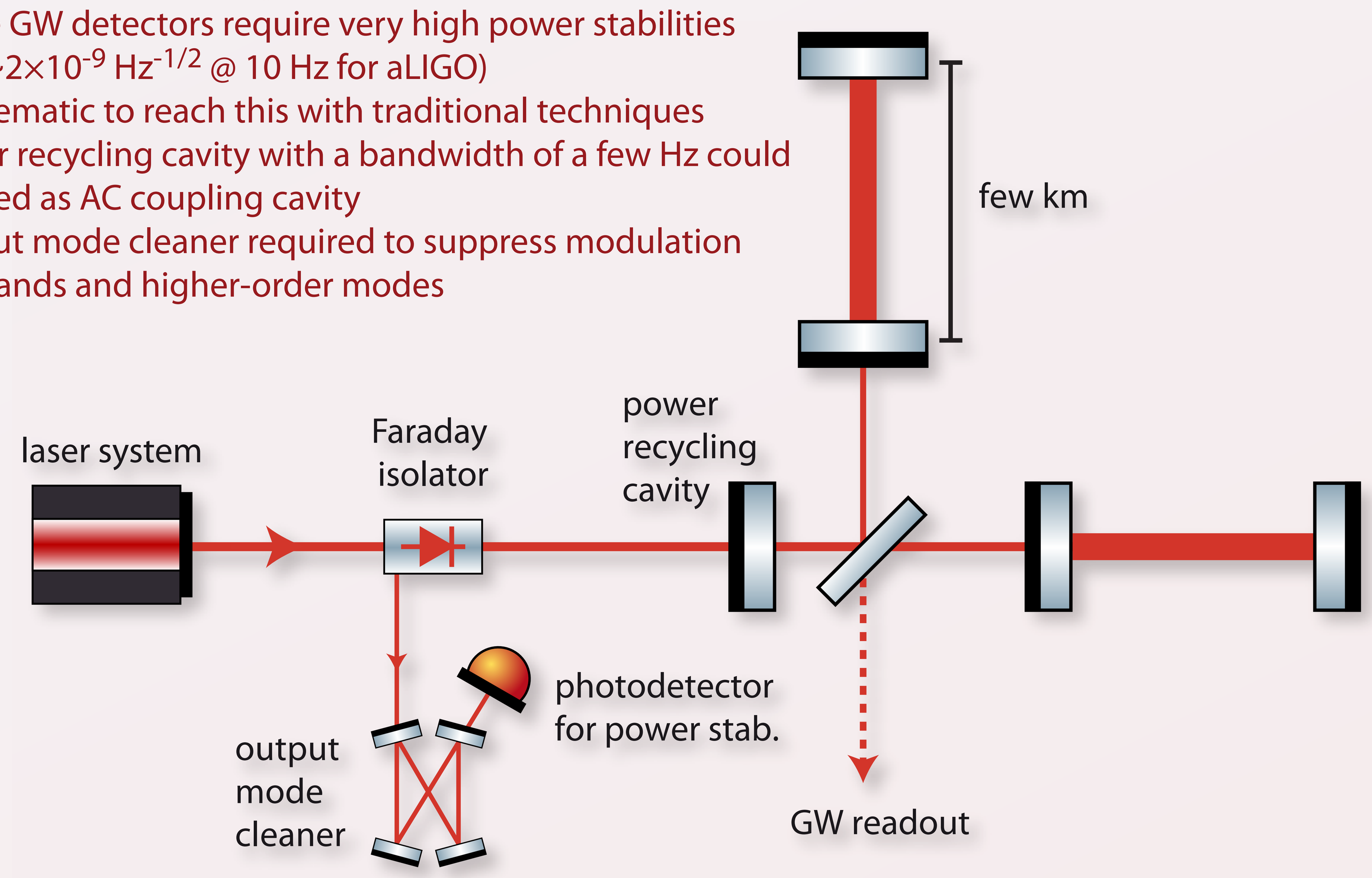
Sensitivity

- Photodetector sensitivity increased by up to g=62 due to optical AC coupling
- Increased laser power step by step from 1W to 67W
- Achieved $1.1{\times}10^{-10}\,\mathrm{Hz}^{-1/2}$ for relative power fluctuations
- Detected only 23 mA of photocurrent (equivalent to 32A in a traditional setup)



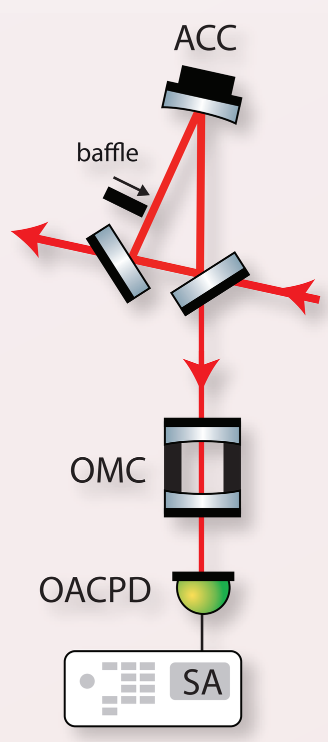
Gravitational Wave Detector

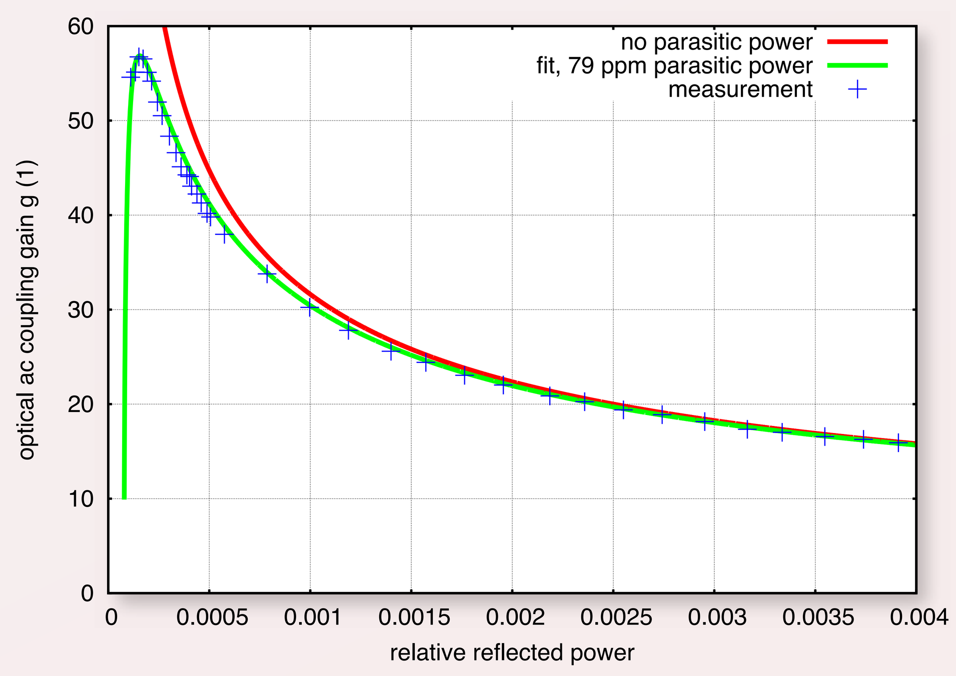
- Power stabilization for gravitational wave detectors
- These GW detectors require very high power stabilities (e.g. $\sim 2{\times}10^{-9}\,\mathrm{Hz}^{-1/2}$ @ 10 Hz for aLIGO)
- Problematic to reach this with traditional techniques
- Power recycling cavity with a bandwidth of a few Hz could be used as AC coupling cavity
- Output mode cleaner required to suppress modulation sidebands and higher-order modes



Impedance Matching & Output Mode Cleaner

- Specific impedance matching crucial, adjusted with resonator internal baffle
- Parasitic higher-order TEM modes suppressed by output mode-cleaner (OMC)
  - Linear optical resonator stabilized to TEM_{00} mode
- OMC reduced total parasitic mode power down to 79ppm of total input power
  - Measured optical AC coupling gain g as function of impedance matching
  - Fitted model to determine parasitic power





Application

- Application could be power stabilization for gravitational wave detectors, as e.g. Advanced LIGO or third generation detectors [5].
- Power stabilizations for experiments requiring most of the available power for the actual experiment.
- Fast and at the same time high-power photodetectors [5].
- Sensing at the $10^{-10}\,\mathrm{Hz}^{-1/2}$ level which is almost impossible due to technical limits with traditional detection schemes.

References

1. Email: patrick.kwee@aei.mpg.de, homepage: http://www.patrick-kwee.de
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3. P. Kwee, B. Willke, and K. Danzmann, "New concepts and results in laser power stabilization", App. Phys. B, 102:515-522 (2011)
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5. P. Kwee, "Laser Characterization and Stabilization for Precision Interferometry" Ph.D. thesis, Universität Hannover, 2010, http://www.patrick-kwee.de