Optical AC Coupling

A new scheme for laser power stabilization

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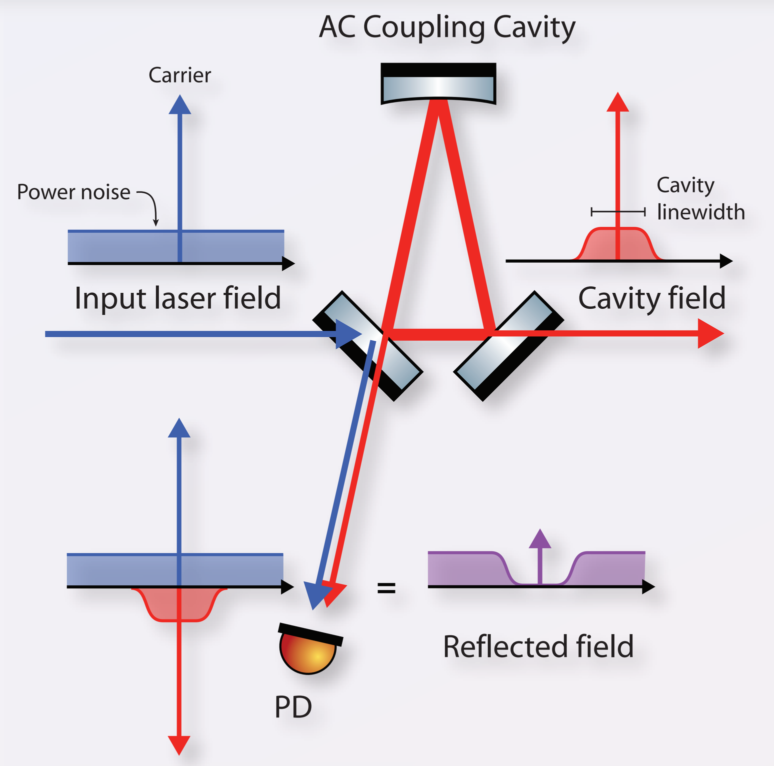
Problem

- Problems of traditional power stabilization schemes:
  - High power on photodiodes
  - Limited at 1e-9/sqrt(Hz) to 1e-8/sqrt(Hz)
  - Unknown noise source (presumably photodiode internal) associated with large photocurrent

Solution

- Optical ac coupling increases sensitivity of a photodetector by using an optical resonator
- Advantages of power stabilization with optical ac coupling:
  - Better stability compared to traditional schemes
  - Preserves more light for the main experiment



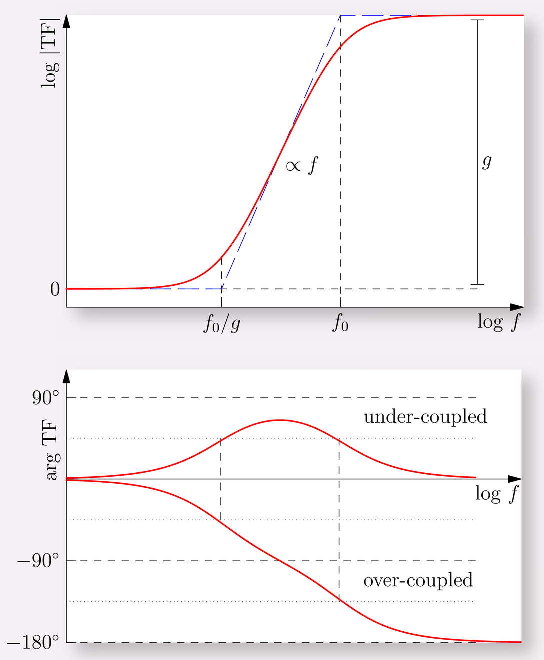
Functional Principle

- 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)

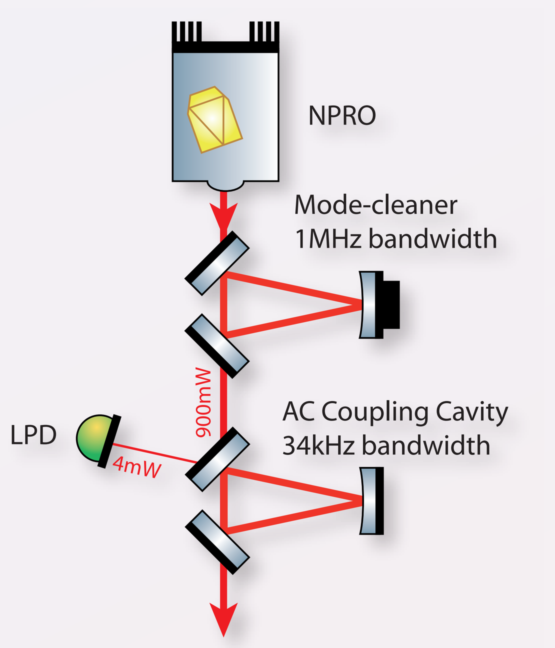
$$|G(f)| = \sqrt{\frac{1+g^2\cdot f^2/f_0^2}{1+f^2/f_0^2}}$$

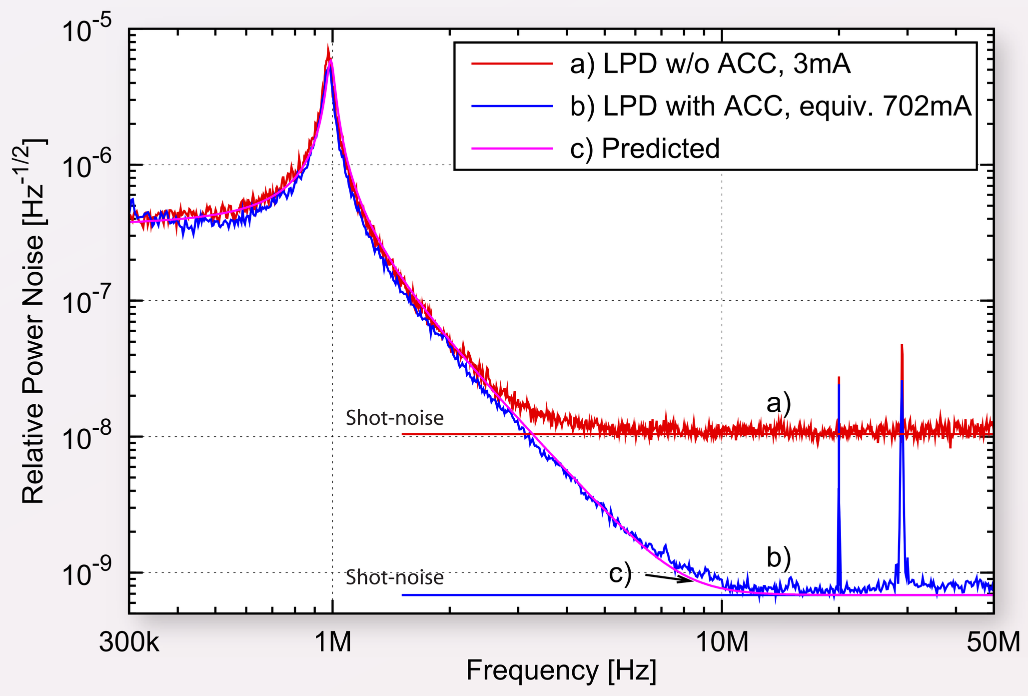
Optical AC Coupling Transfer Function



Power Noise Sensing

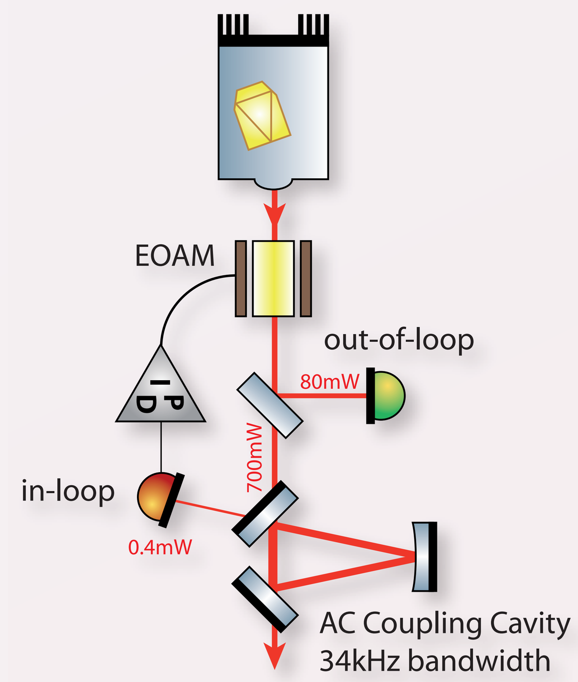
- Relative power noise of nonplanar ring oscillator (NPRO, continous-wave laser at 1064nm)
- Photodiode sensitivity ability increased by g=15 due to optical ac coupling
- Achieved 7e-10/sqrt(Hz) for relative power fluctuations
- Detected only 3 mA of photocurrent (equivalent to 700mA in a traditional setup)
- Measurements agree very well with prediction, including the relaxation oscillation at 1MHz



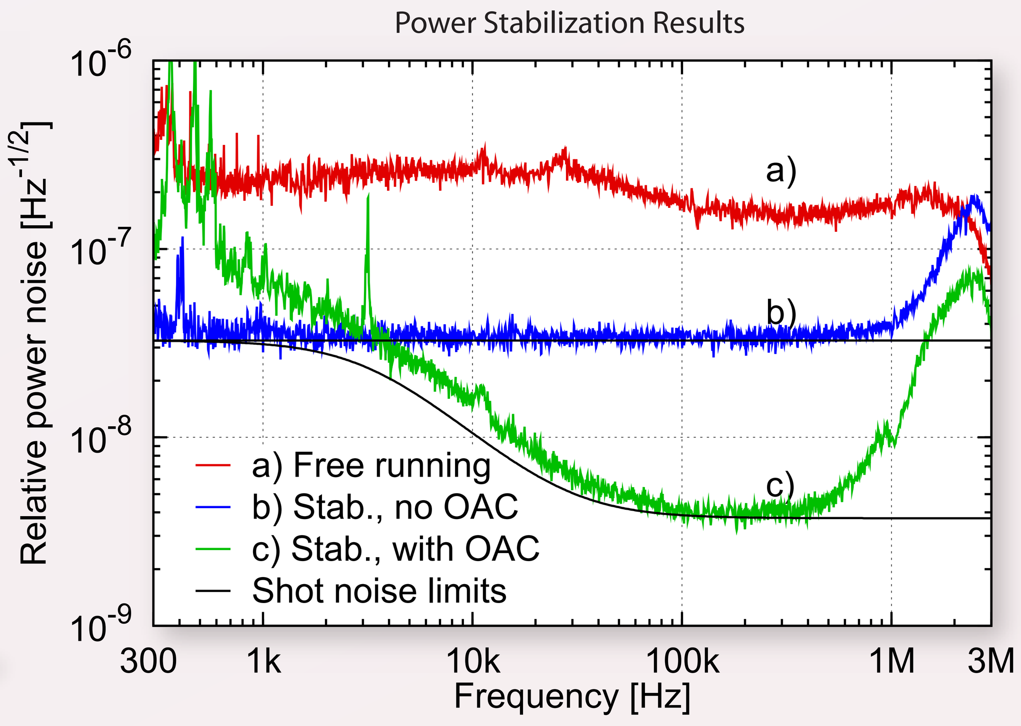


Power Stabilization

- Realized power stabilization of an NPRO laser with optical ac coupling scheme
- Optical ac coupling improved sensitivity of the stabilization PD (in-loop) by g=11
- Out-of-loop power stability of 3.7e-9/sqrt(Hz) at frequencies around 200 kHz (c)
- Significantly better result compared to equivalent traditional stabilization scheme (b)



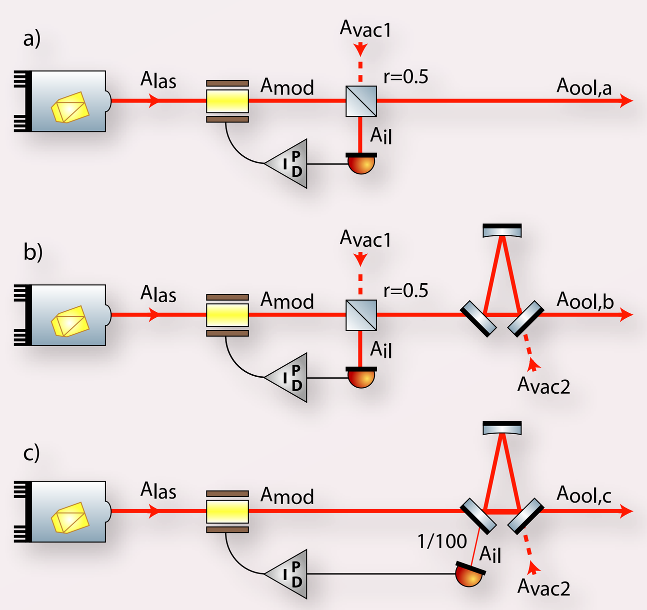
Power Stabilization Results

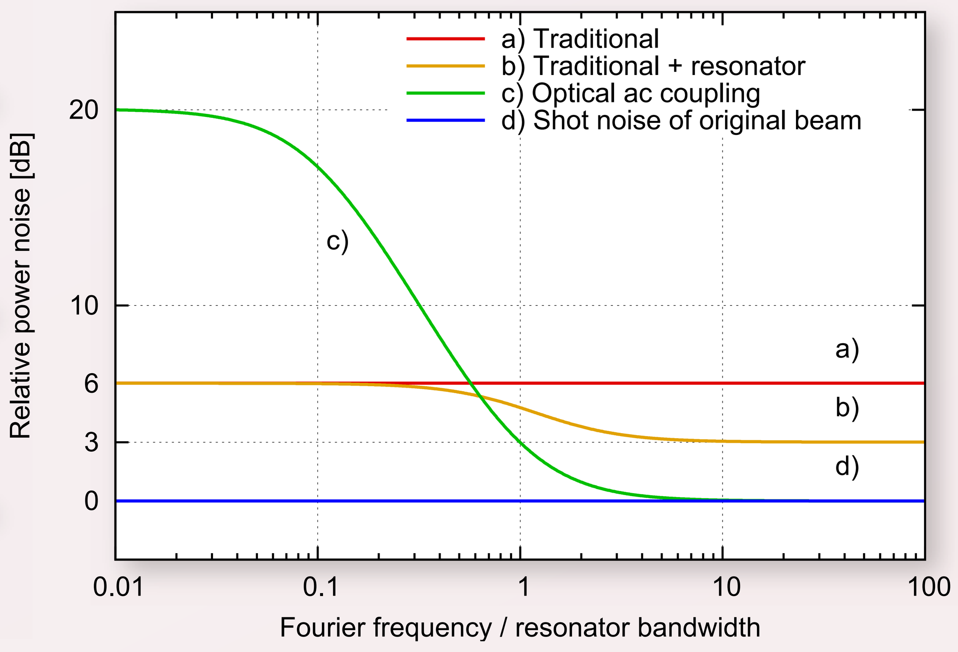


Quantum Noise Limit

- Quantum noise limit of three power stabilization schemes:
  - Traditional power stabilization (a)
  - Traditional power stabilization with passive filtering resonator (b)
  - Power stabilization with optical ac coupling (c)

In a traditional power stabilization (a) the achieveable ool power noise is 6 dB, with resonator (b) 3 dB, and with optical ac coupling (c) 0.04 dB above the relative shot noise of the original beam.



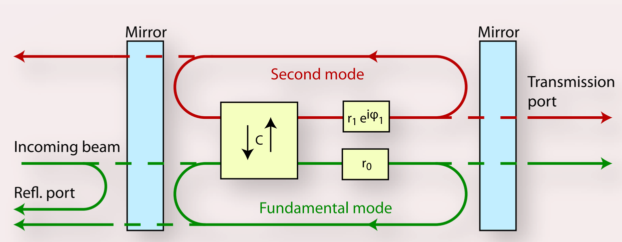


Scattering Noise

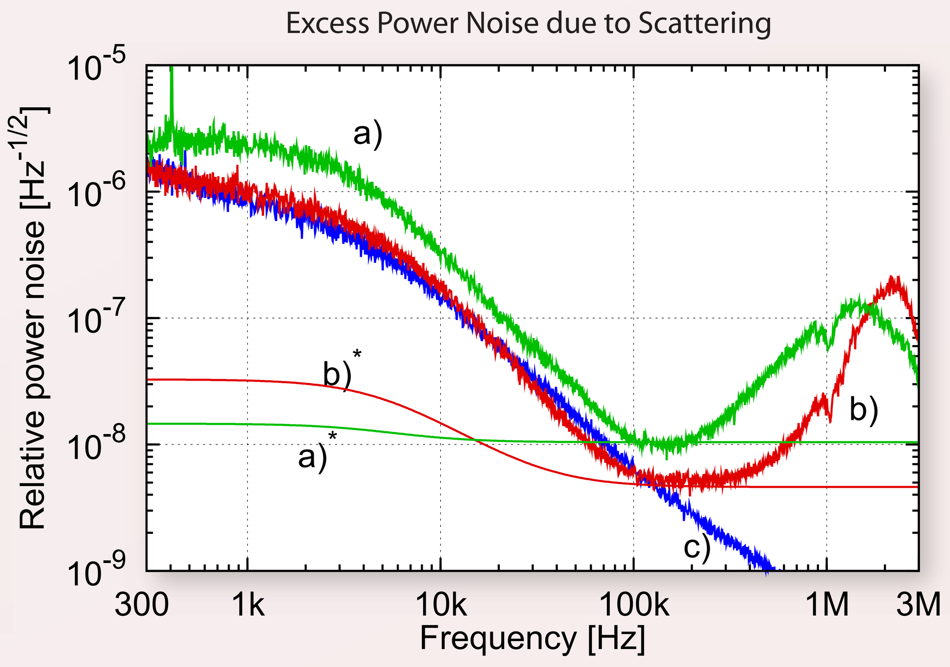
- First experiments limited by resonator-internal scattering
- Higher-order TEM modes and counter-circulating fundamental mode excited by scattered light
- Scattering caused power fluctuations of the fundamental mode used for optical ac coupling
- Typical out-of-loop power noise measurements with scattering:
  - Scattering into higher-order modes (a)
  - Scattering into counter-circulating fundamental mode (b), projection (c)

Noise Source

- Scattering strength was fluctuating
- Cause of coupling factor fluctuations unknown.



Excess Power Noise due to Scattering



Application

- Application could be power stabilization for next generation gravitational wave detectors, as e.g. Advanced LIGO
- These GW detectors require very high power stabilities (~ 2e-9/sqrt(Hz) @ 10 Hz)
- Problematic to reach this with traditional techniques [3]
- Power recycling cavity with a bandwidth of 1 Hz could be used as ac coupling cavity
- Advanced LIGO requirements so far not achieved - optical ac coupling could help

References

1) P. Kwee, B. Willke, and K. Danzmann, "Optical ac coupling to overcome limitations in the detection of optical power fluctuations," Opt. Lett. 33, 1509-1511 (2008).

2) P. Kwee, B. Willke, and K. Danzmann, "Laser power stabilization using optical ac coupling," In preparation, 2009 (LIGO-P080128-00).

3) F. Seifert, P. Kwee, M. Heurs, B. Willke, and K. Danzmann, "Laser power stabilization for second-generation gravitational wave detectors," Opt. Lett. 31, 2000-2002 (2006).

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