New detection method for laser power fluctuations

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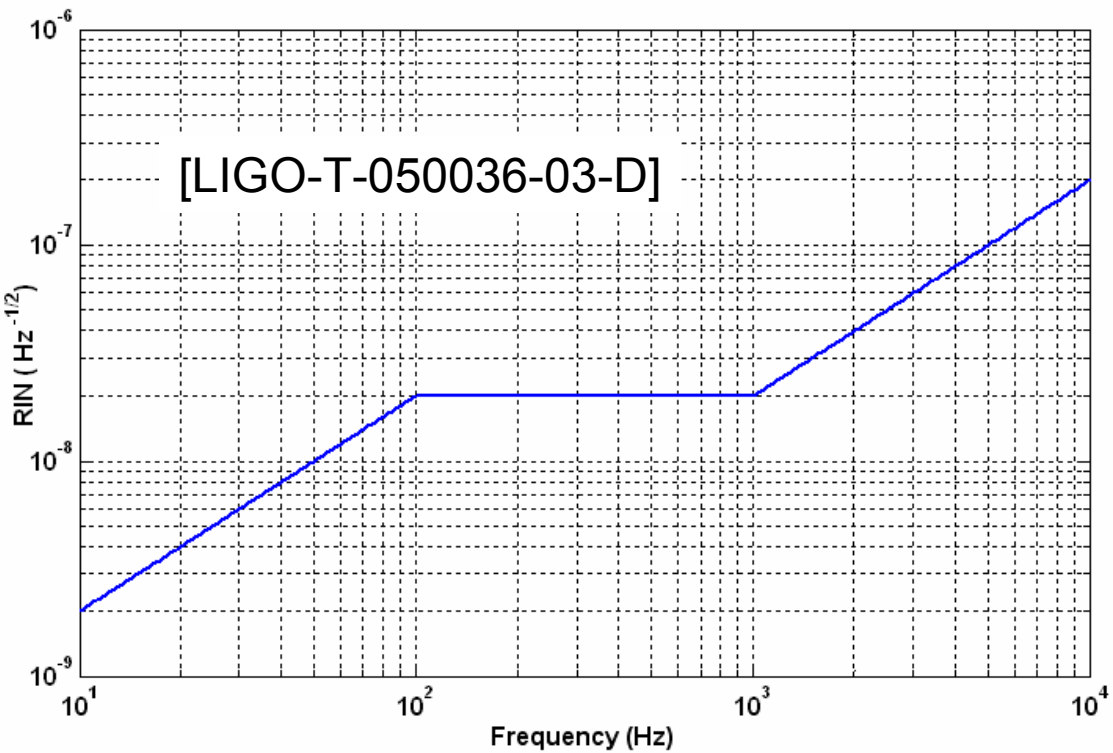
Motivation

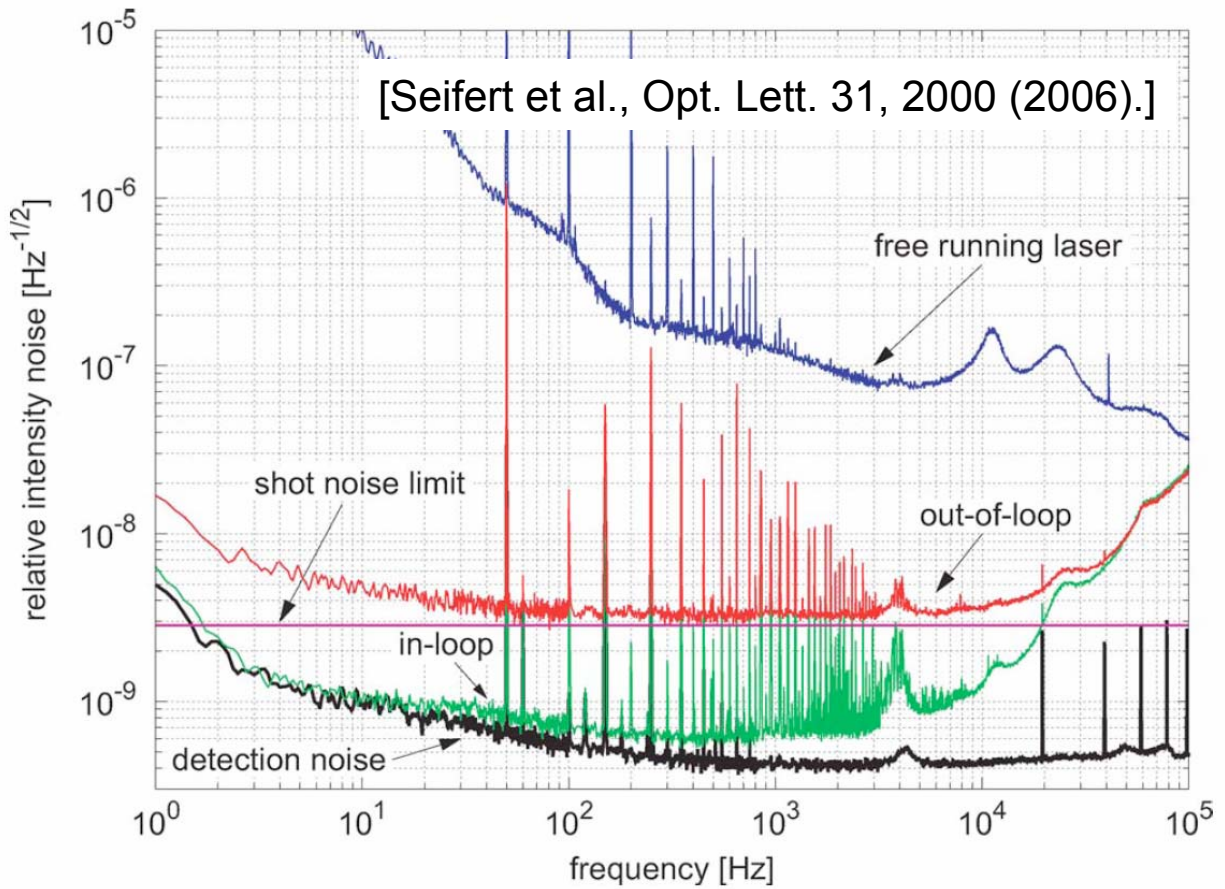
- Power fluctuations couple by radiation pressure to gravitational wave signal
- High sensitive power noise detectors necessary for power stabilization
- Quantum limit given by shot noise of photo current

$$N_{SN} = \sqrt{\frac{2e}{I}}$$



- Relative shot noise of 80mA is $2 \times 10^{-9}/\sqrt{Hz}$

Photodiode limits



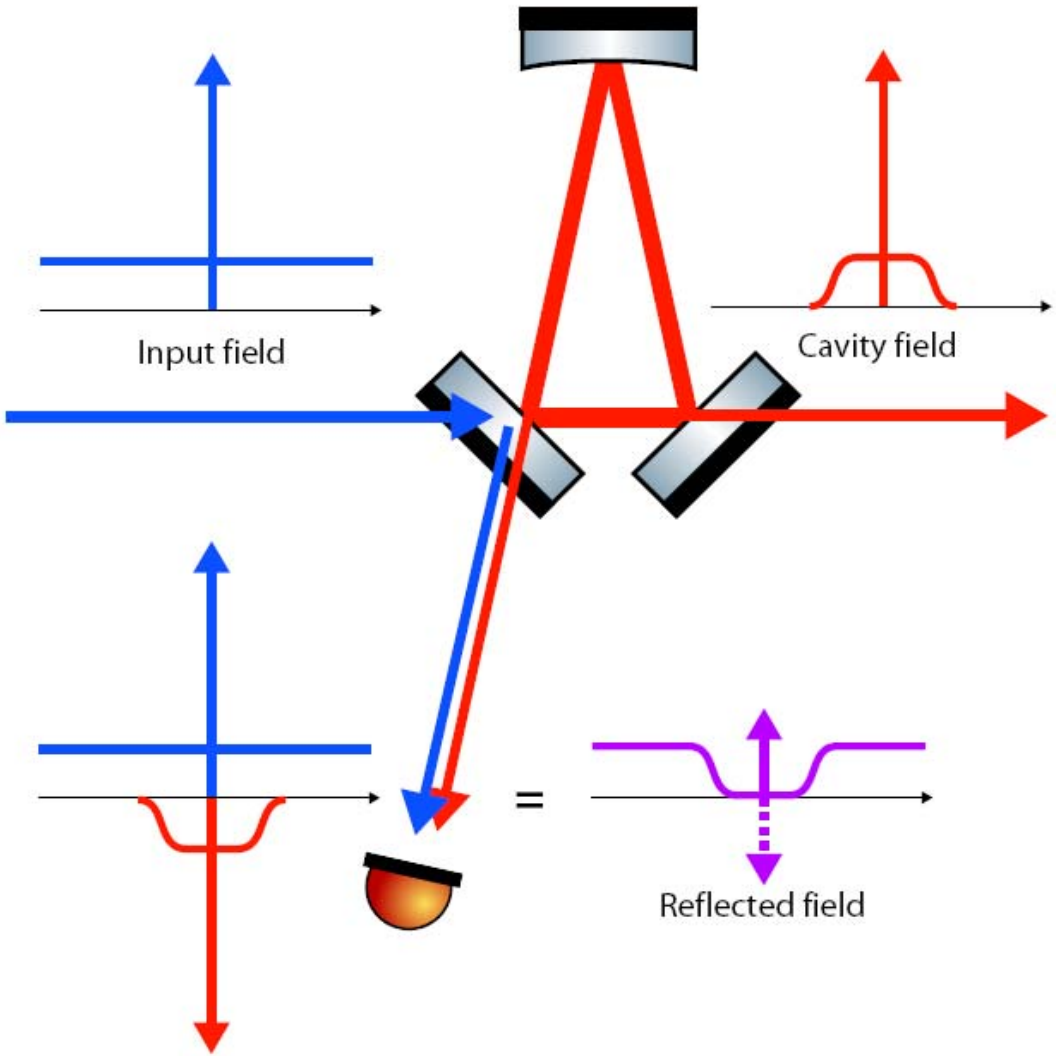
Most sensitive power detection at 10Hz is 3.5×10^{-9}/sqrt(Hz) (26mA)

Not limited by shot noise, probably by 1/f noise in the photodiodes

Future limits

- Saturation limit of 2mm InGaAs photodiodes ~250mA
- Dynamic range of electronics ~ $10^9..10^{10}$

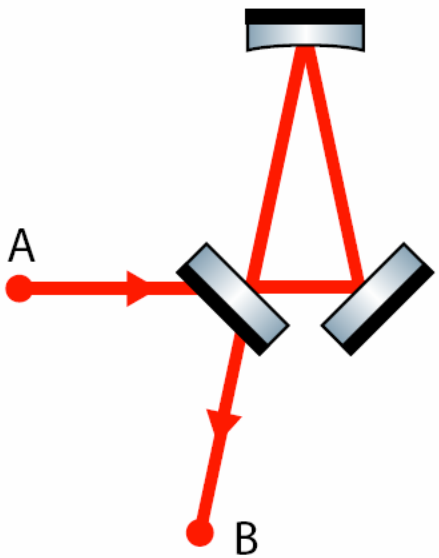
Optical AC coupling



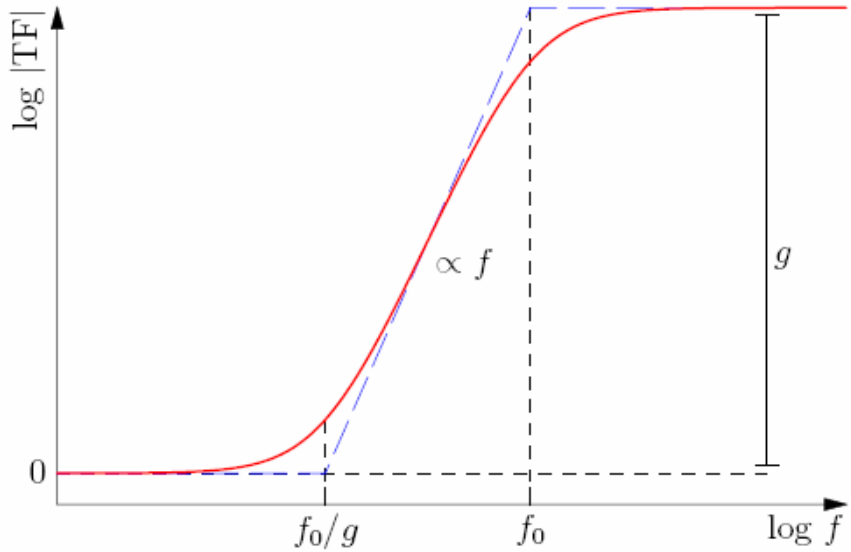
- Slightly over- or under-coupled cavity
- Reduction of carrier power
- Photodetector in reflection

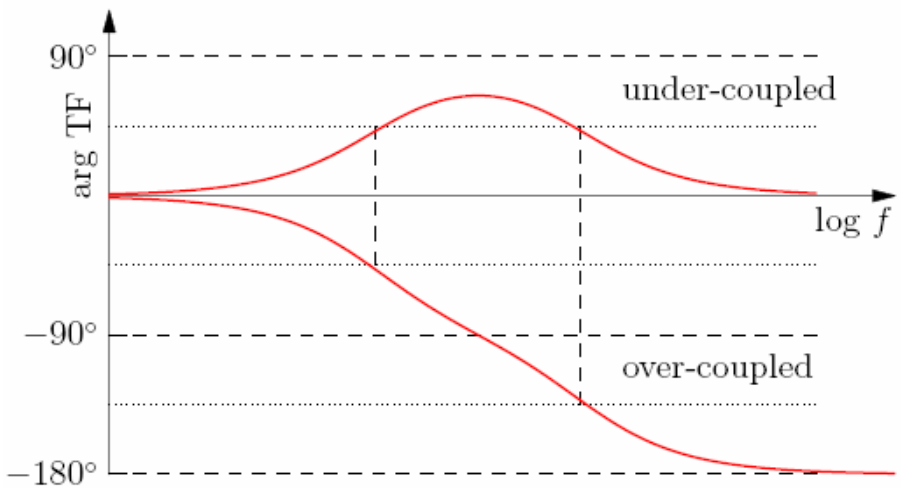
Transfer function

Transfer function of relative power fluctuations from A to B: G = B/A

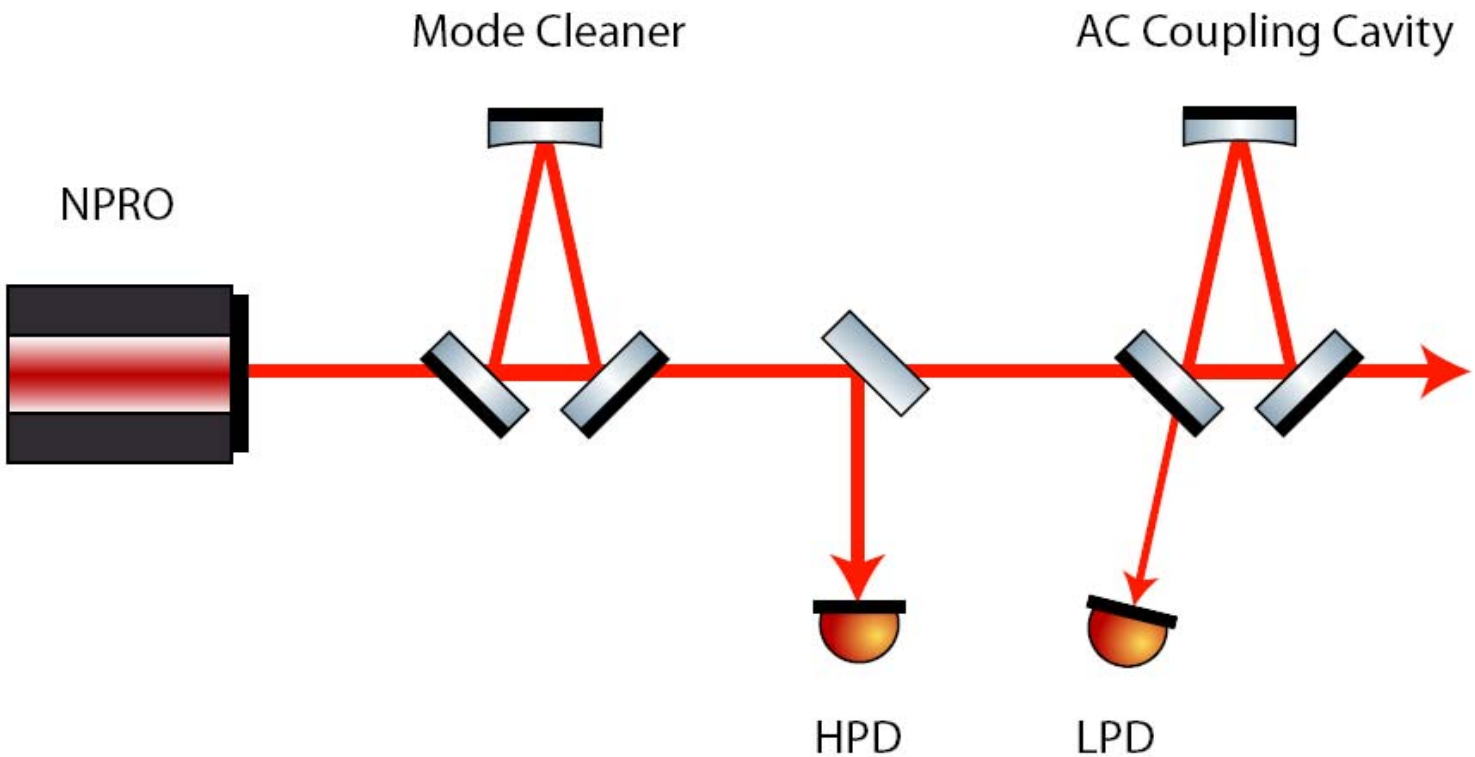


$$|G(f)| = \sqrt{\frac{1 + g^2 \cdot f^2/f_0^2}{1 + f^2/f_0^2}}$$

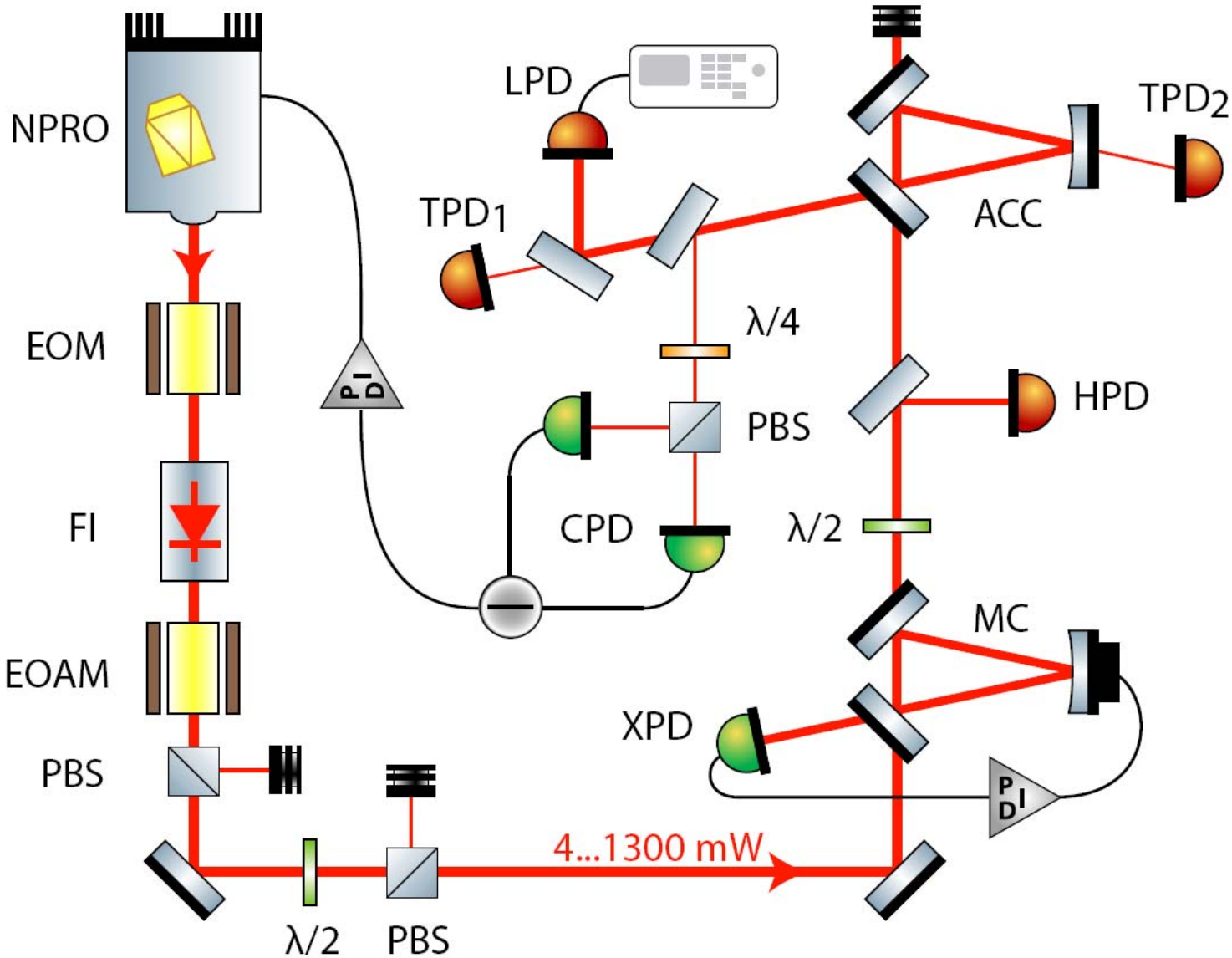




Experimental setup

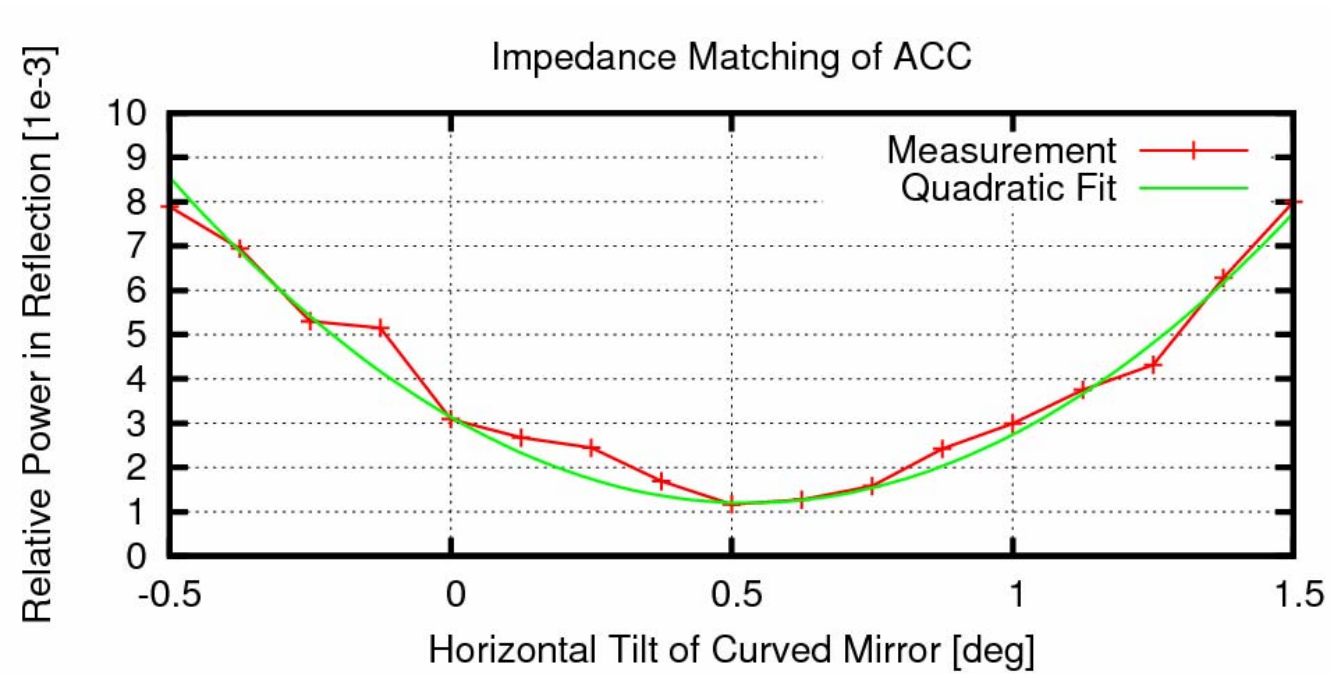


Experimental setup

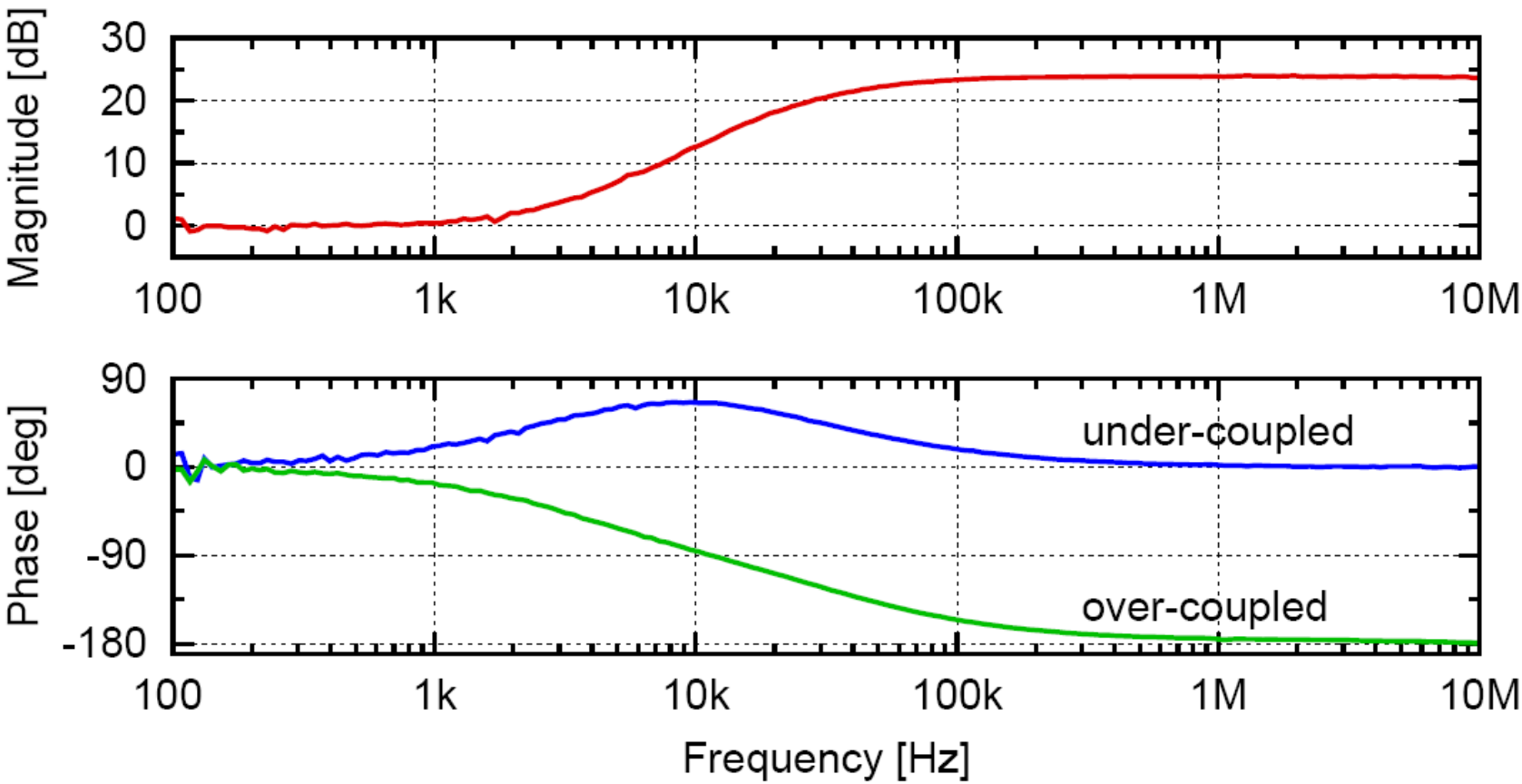


Experimental challenges

- Mode matching > 99.96%
- Impedance mis-matching of 0.4%
- High finesse cavity (F=10000) and high power (P=1W)
  → 3kW circulating power
- High bandwidth locking of the cavity

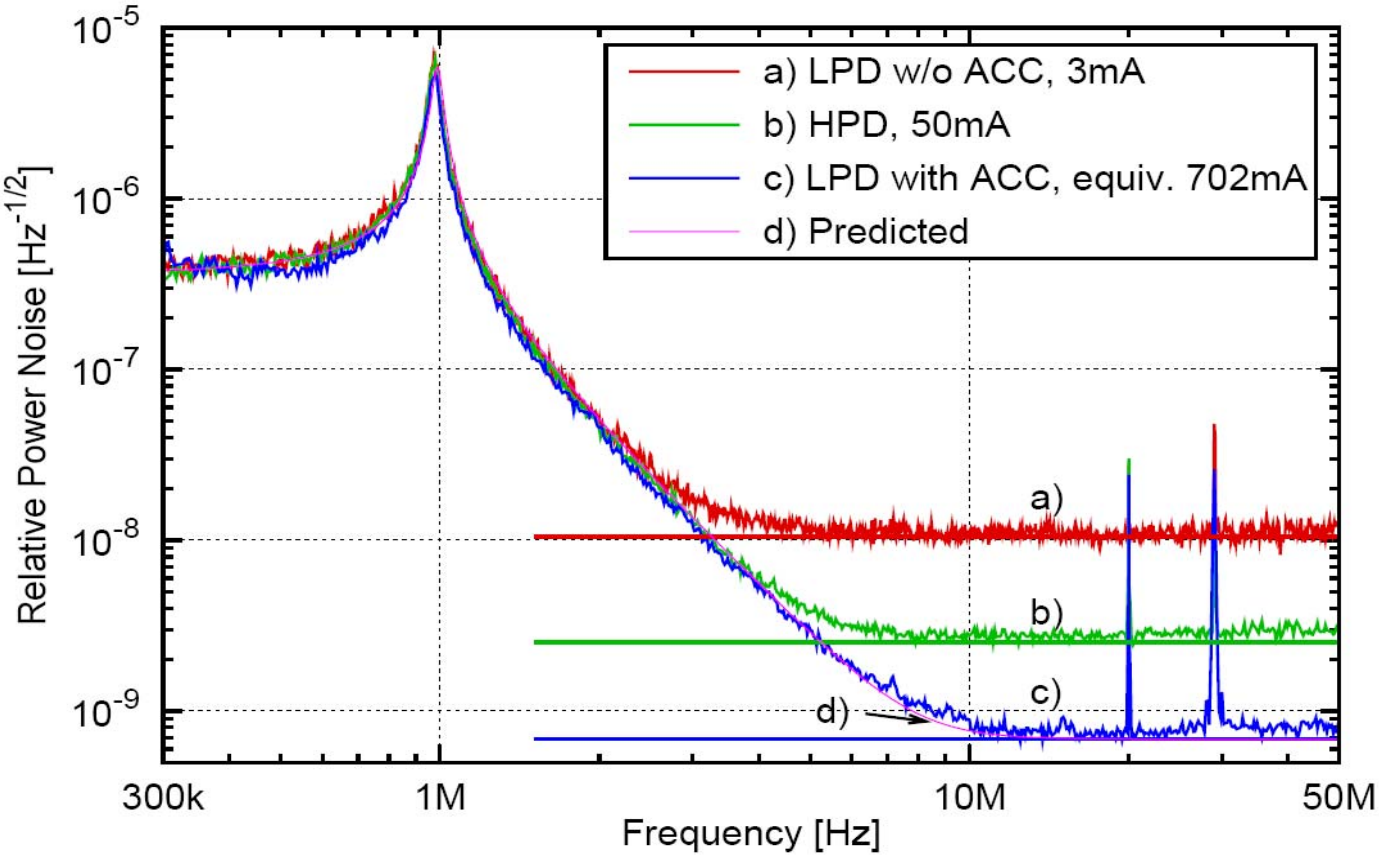


Measured transfer function



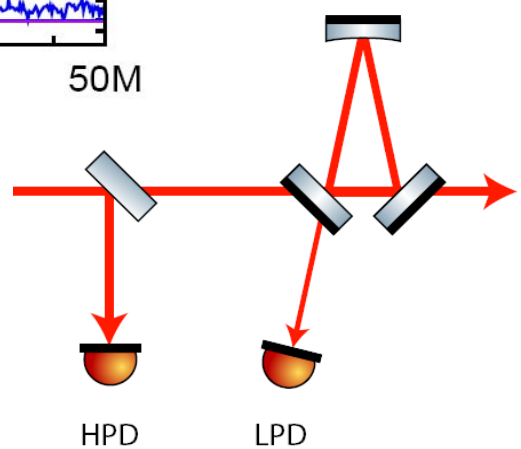
g = 15.3, f_0 = 34 kHz, carrier reduction: 0.4% = 1 / 250

Power noise measurement



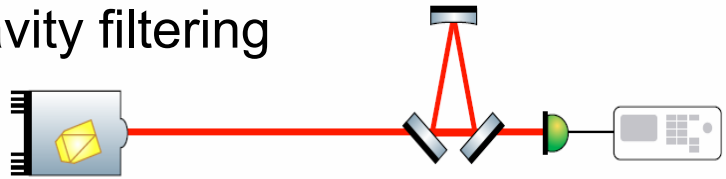
Detected photo current: 3mA

Equivalent photo current: 702mA

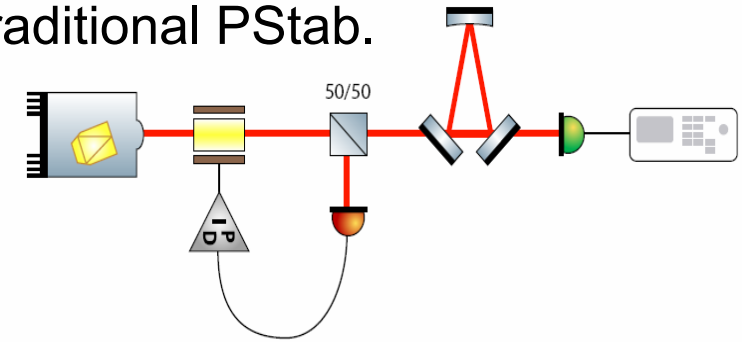


Power stabilization concepts

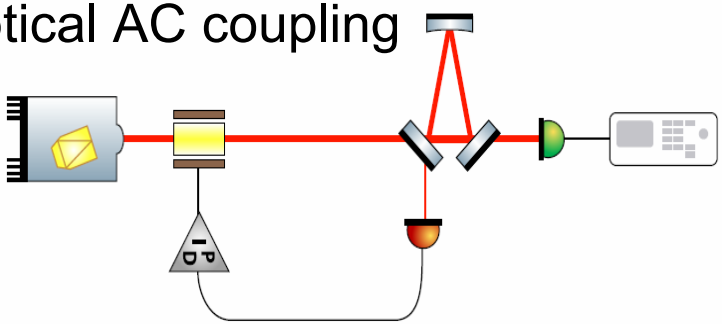
Cavity filtering

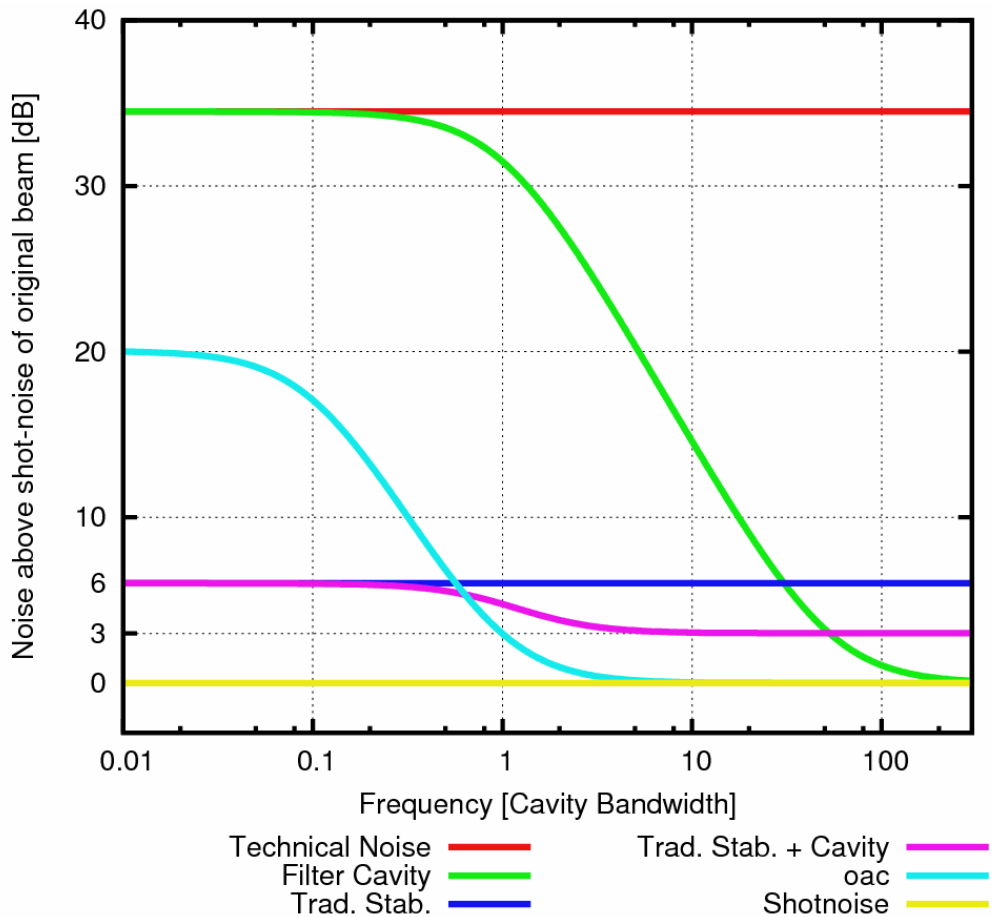


Traditional PStab.



Optical AC coupling





Optical AC coupling can beat the theoretical limit of power stabilizations by 3dB

Next Steps & Summary

Next Steps

- Power stabilization for frequencies 1kHz .. 100kHz
- Out-of-loop verification with high power photodetector

Summary

- Optical AC coupling can improve sensitivity of a photodetector by one order of magnitude
- Power recycling cavity of GWDs could be used as AC coupling cavity
- Optical AC coupling can beat theoretical limit of power stabilization by 3dB