Advanced LIGO PSL Power Stabilisation

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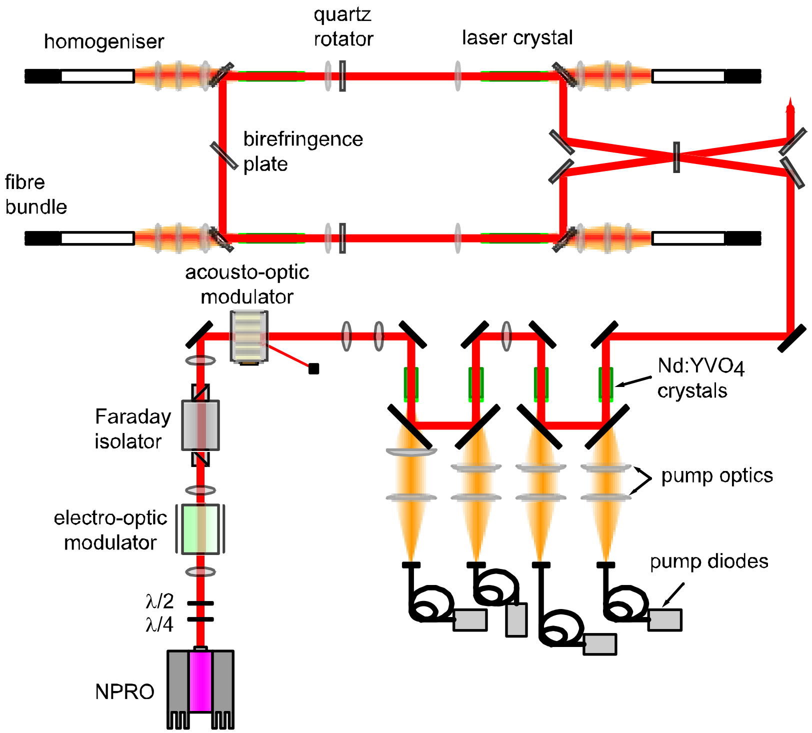
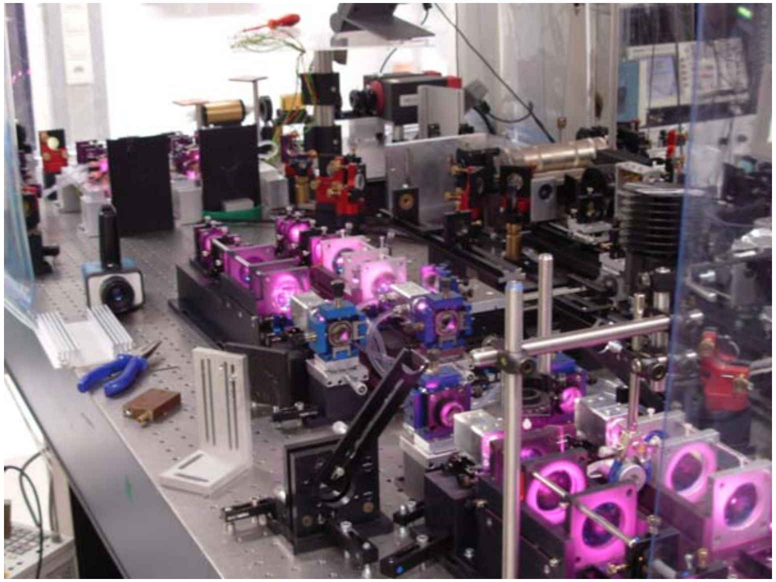
Credit

- Lots of hard work done by
  - Frank Seifert
  - Patrick Kwee

The Advanced LIGO Laser

- An injection-locked high power stage seeded by a 35-W four-stage MOPA front end with a 2-W NPRO master oscillator.

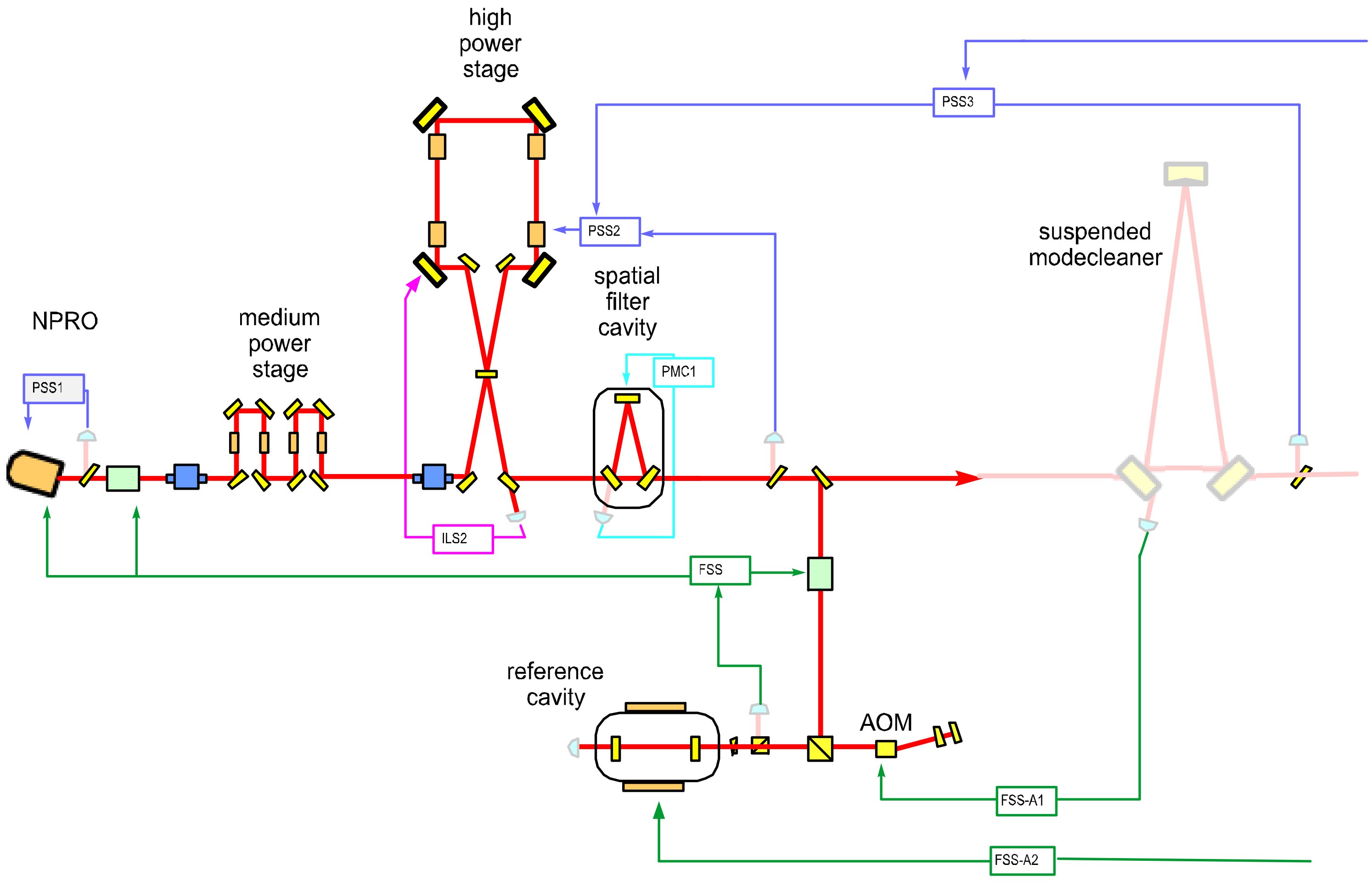




The Advanced LIGO Laser (cont.)

- Power actuators available:
  - » NPRO pump diode current
  - » AOM located between master oscillator and power amplifier
  - » Power amplifier pump diode current
    - – Possibly via a current shunt
  - » High power stage pump diode current
    - – Possibly via a current shunt

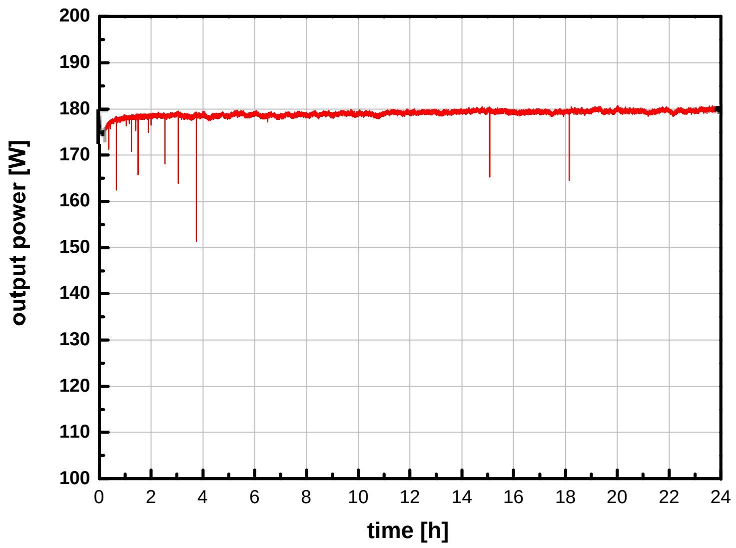
The Advanced LIGO PSL



Intensity Noise Requirements

- Low frequency variations over 24 hours, less than 1% peak to peak
- Control band
  - » 0.1 to 0.4 Hz $< 10^{-3}$
  - » 0.4 to 10 Hz $< 10^{-4}$

- software routine to vary pump diode current



free running

GW Band

-

Frequency [Hz]	Relative Intensity Noise [1/Sqrt[Hz]]
10	2×10^{-9}
$10 < f < 500$	$2 \times 10^{-10} f$
$f >= 500$	1×10^{-7}

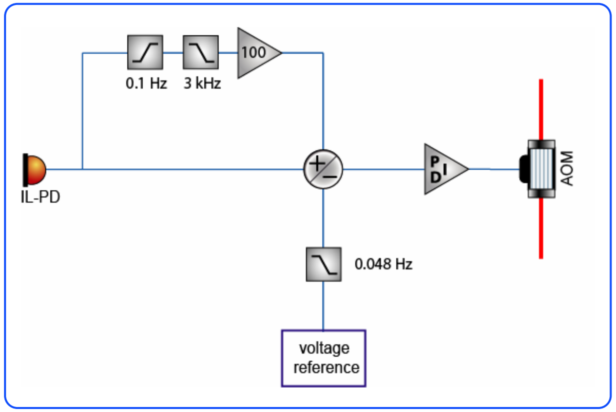
- The requirement at 10 Hz is very tough due to the combination of:
  - low noise level
  - low frequency specified

The Challenge

- What limits the power stabilisation performance?
  - » Typically more than enough servo gain to suppress the relative intensity noise to the required level.
    - – Observe a difference between an in-the-loop photodetector and an out-of-the-loop photodetector.
- Is there a fundamental limit? Or are there noise mechanisms not found yet?
  - » Photodiode performance?
    - – Uniformity of the diode response
    - – Temperature effects
  - » Beam pointing?
  - » Acoustics

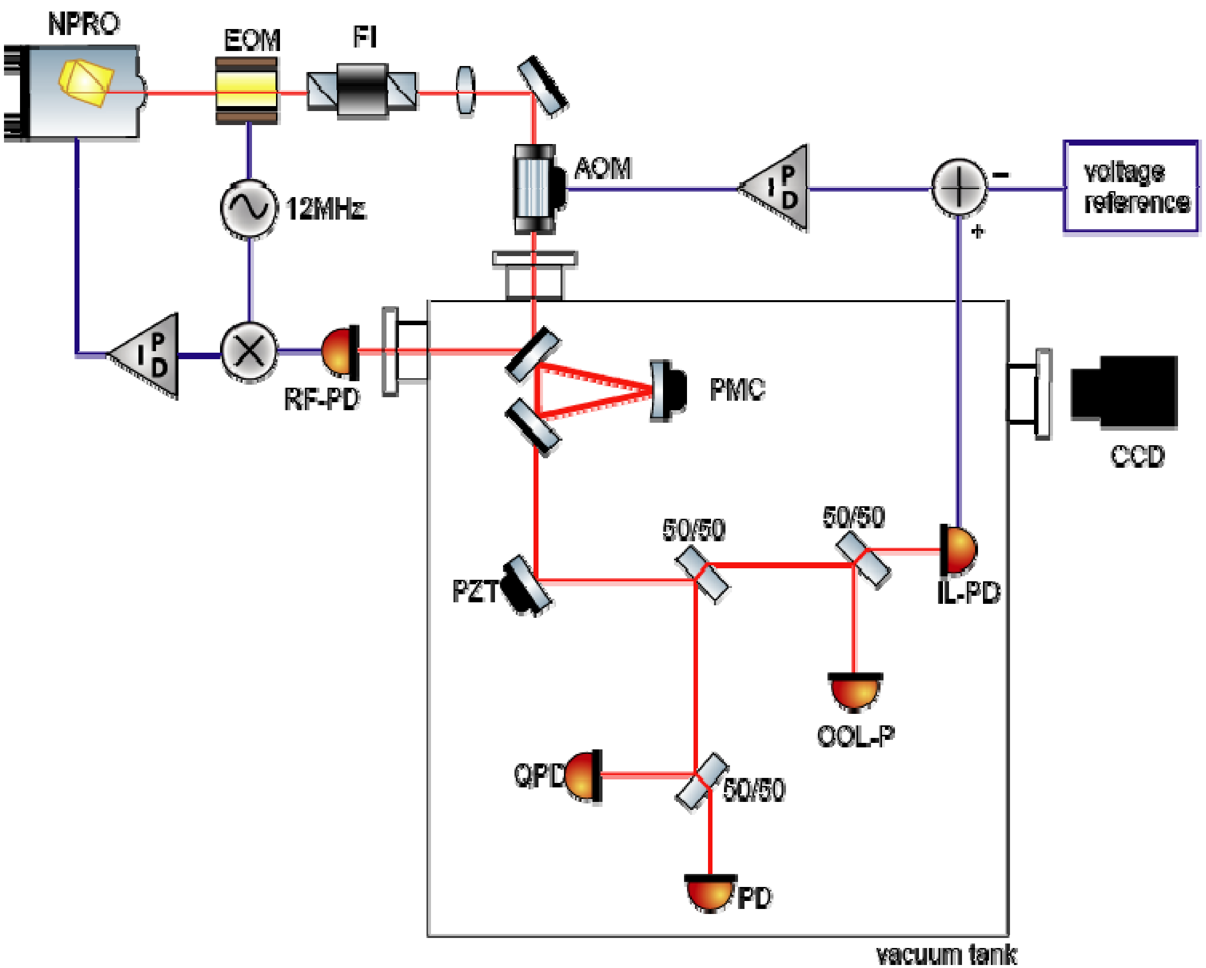
Power Stabilisation Setup

- Uses an AOM
  - » Power actuator independent of laser
- Beam pointing filtered by a pre-modecleaner (*F* ~ 4100)
- Active temperature stabilisation of the photodetector
  - » With 130 mW on photodetector, temperature rises ~ 10 K
- Optimisation of stabilisation loop shape
  - » AC-coupled loop for lowest noise
  - » DC-coupled loop for a stable operating point

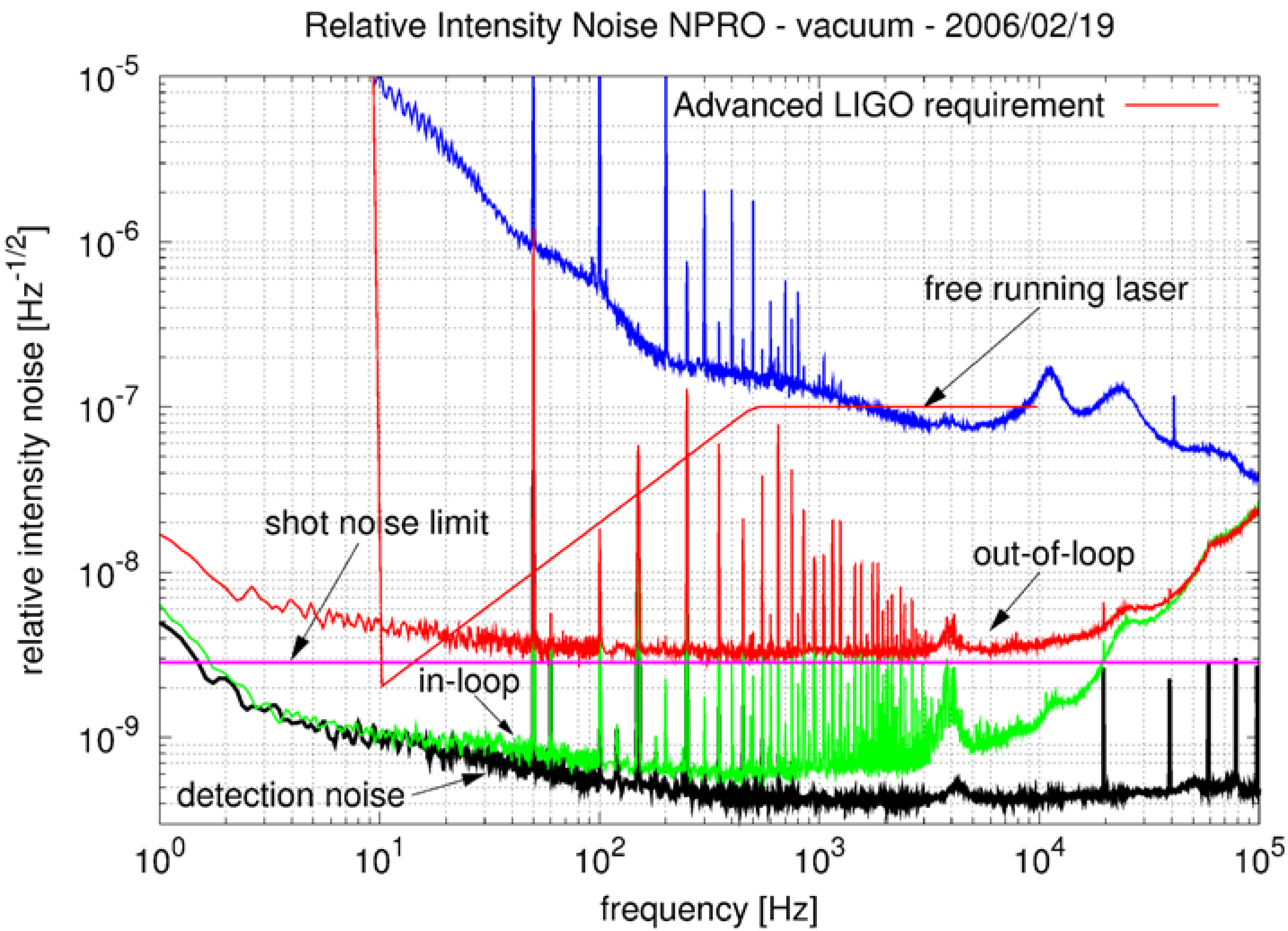


LIGO

Power Stabilisation Setup (cont.)



Results



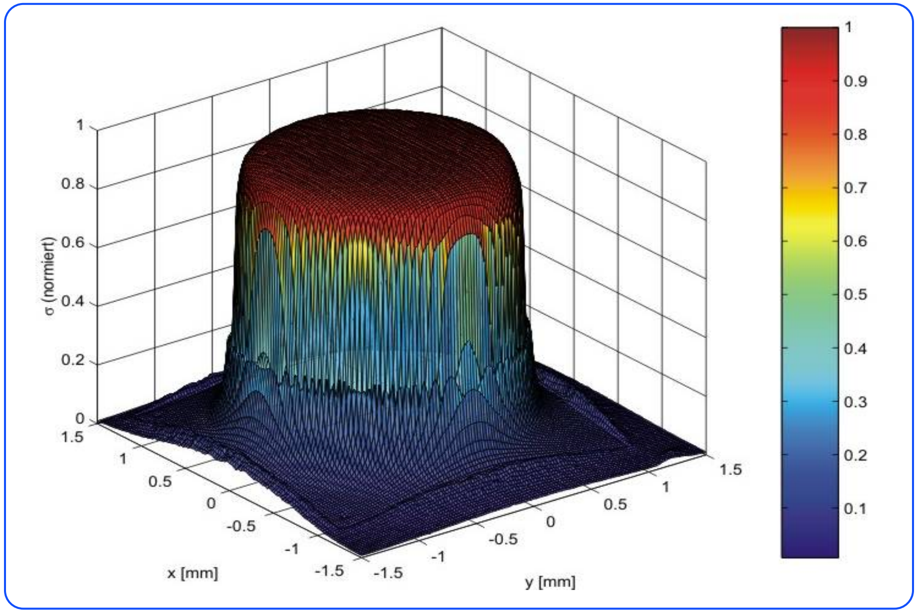
Relative Intensity Noise NPRO - vacuum - 2006/02/19
Advanced LIGO requirement
free running laser
shot noise limit
out-of-loop
in-loop
detection noise
relative intensity noise [Hz^-1/2]
frequency [Hz]
10^-5
10^-6
10^-7
10^-8
10^-9
10^0
10^1
10^2
10^3
10^4
10^5

Important Considerations

- Avoid ground loops, even at RF frequencies
  - » Use battery powered devices
  - » Separate power supplies for components
- Beam pointing
  - » Use pre-modecleaner
  - » Adjustment of photodetectors
- Acoustics
  - » Quiet environment
  - » Proper mechanical design
- Convection currents
  - » Place components in vacuum

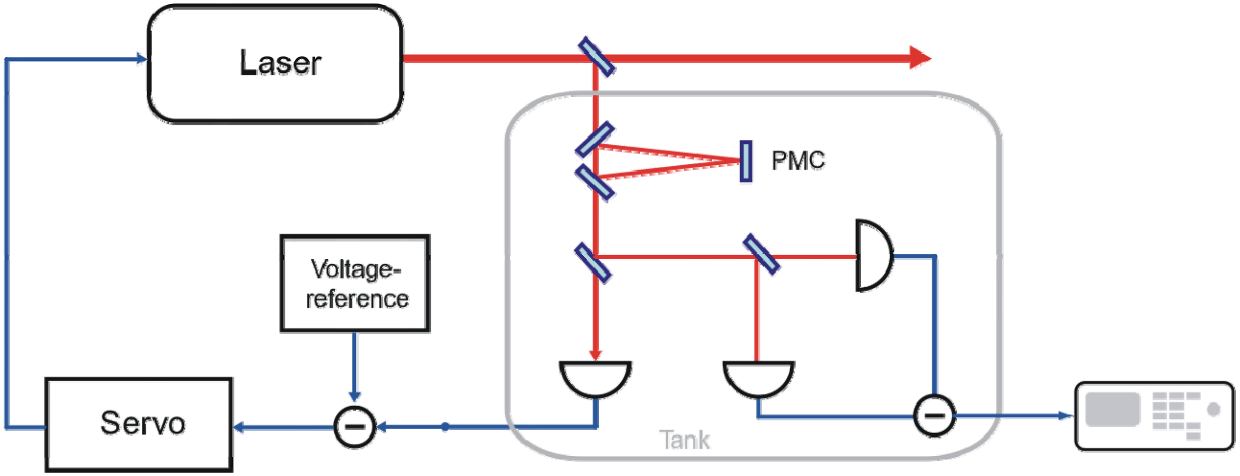
Photodiode Uniformity

- There is a “sweet spot” on a photodiode.
  - Not necessarily at the centre!
  - Minimises the coupling between pointing and intensity noise.



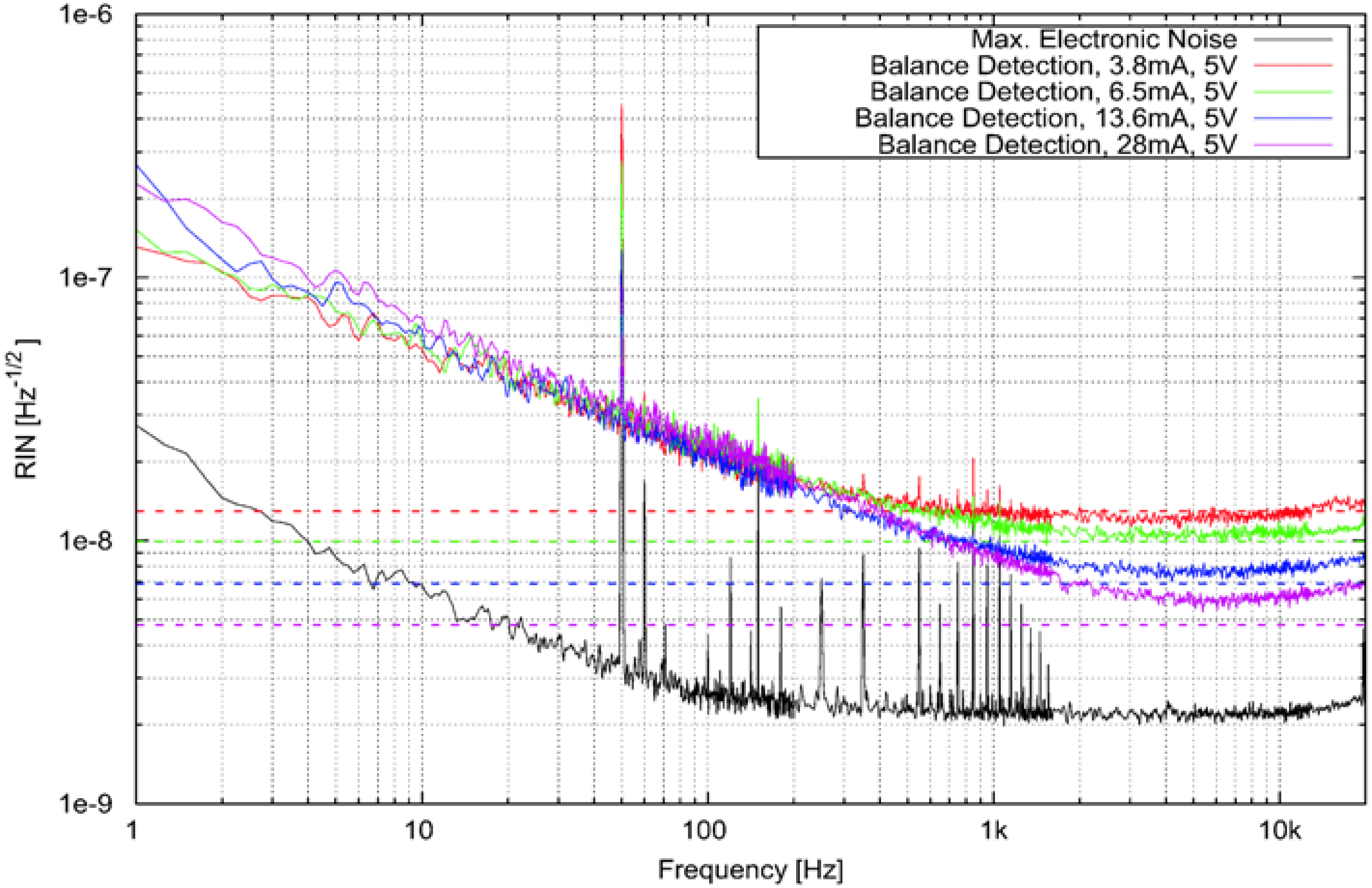
spatial uniformity measurement

Balanced Detection



- Is excess noise at low frequencies due to the photodetectors?
- laser stabilised below 10^{-8}
- amplification *after* subtraction of photocurrents

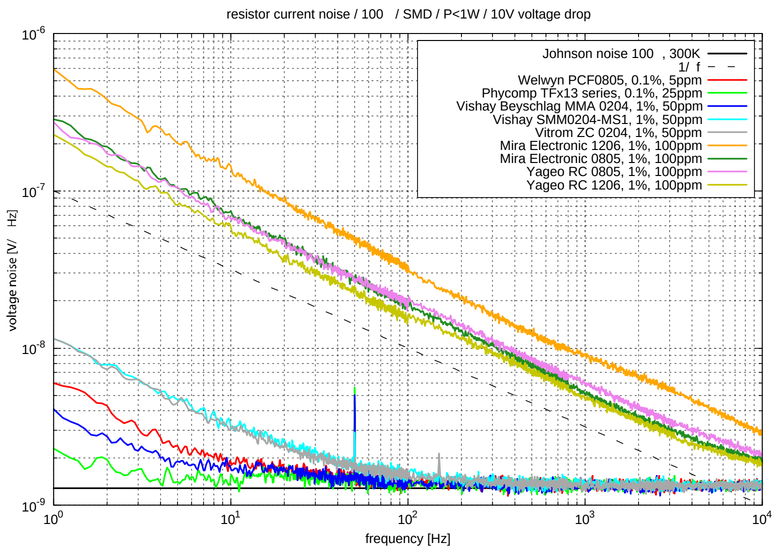
Balanced Detection Results

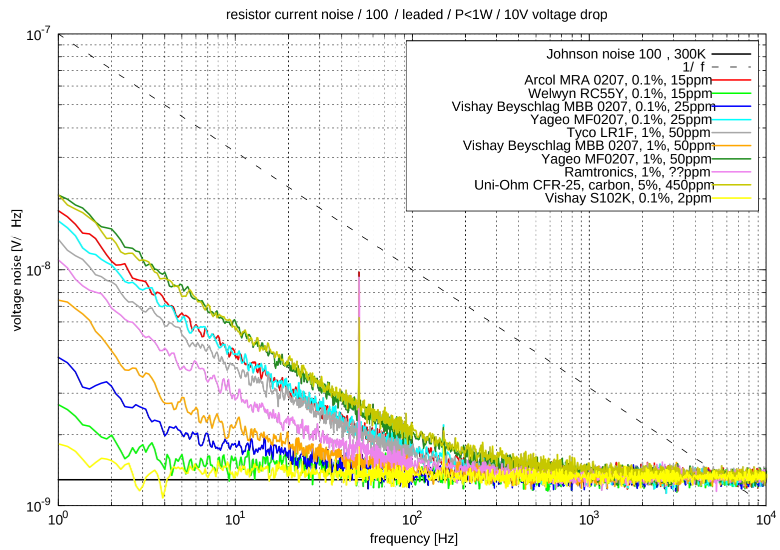


Low Frequency Noise

- What is the source of the ~1/Sqrt[f] noise at low frequencies?
  - » Beam pointing introduced by the beamsplitter after the pre-modecleaner cavity.
  - » Photodiode material
    - – Noise when holes and electrons re-combine
  - » Resistor current noise

Resistor Current Noise





Work In Progress

- Further reduction of beam pointing
  - » Elimination of the beamsplitter
  - » Use of modecleaner cavity as the beamsplitter
- Influence of photodetector temperature fluctuations

Conclusions

- Minimise beam pointing
- Careful selection of photodiodes
- Use metal foil resistors for best performance at low frequencies