Advanced LIGO EOM Noise

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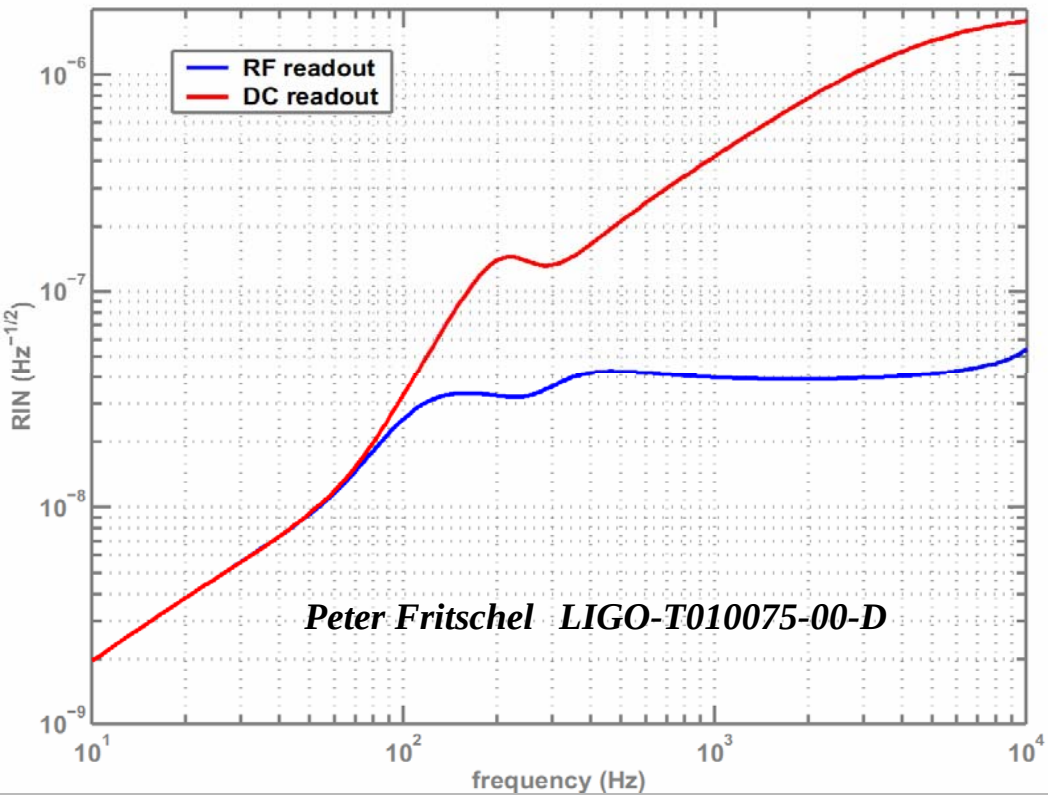
LIGO-G060480-00-Z

Noise requirement on the modulation index



Modulation index variation δm

▼

Intensity fluctuation of the carrier light

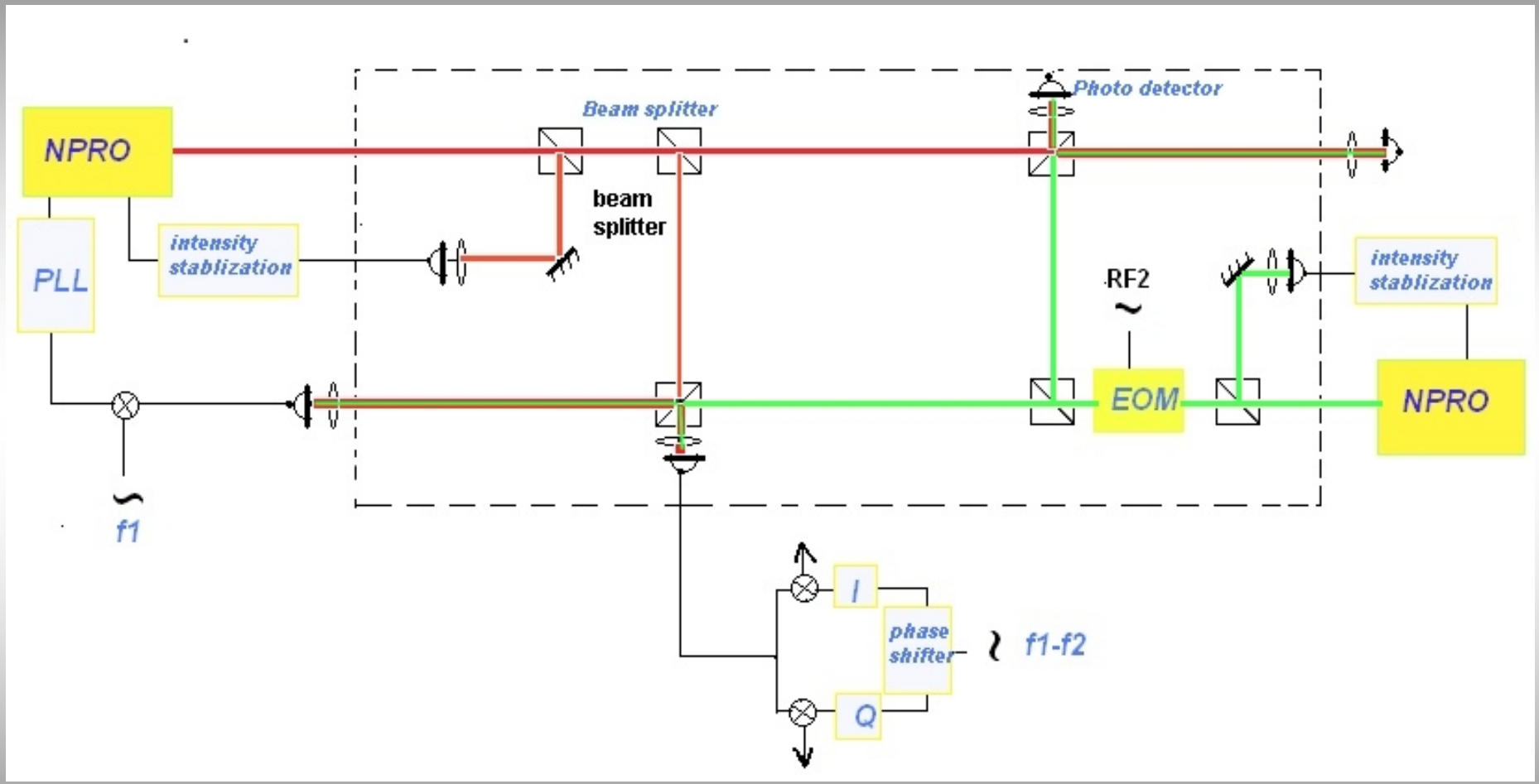
▼

Radiation pressure noise

$$E = E_0 e^{i[\varpi t + m\sin(\Omega t+\phi)]} \approx J_0(m)E_0 e^{i\varpi t} + J_1(m)E_0 e^{i[(\varpi+\Omega)t+\phi]} - J_1(m)E_0 e^{i[(\varpi-\Omega)t-\phi]} + \cdots$$

For m = 0.1, δm **must <** $10^{-8}/\sqrt{Hz}$ **at 10 Hz !**

Experiment setup



- **Phase locking two lasers with a frequency offset**
- **Intensity stabilization for both lasers**
- **Measure the beat signal –** *Carrier-Carrier, Carrier-Sideband*

Signals we measure

Carrier-sideband beat note ~

$$J_1(m+\delta m(f))E_1E_2(1+\tilde{A}(f))\cos(\phi+\delta\phi_{pll}(f)+\delta\phi_{SB}(f))$$

I/Q demodulation to get:

Relative amplitude noise ~ $\dfrac{\delta m(f)}{m}+\tilde{A}(f)+\tilde{A}_{\Omega}(f)+\Delta\phi(\delta\phi_{\Omega}(f)+\delta\phi_{pll}(f)+\delta\phi_{SB}(f))$

Phase noise ~ $\delta\phi_{\Omega}(f)+\delta\phi_{pll}(f)+\delta\phi_{SB}(f)$

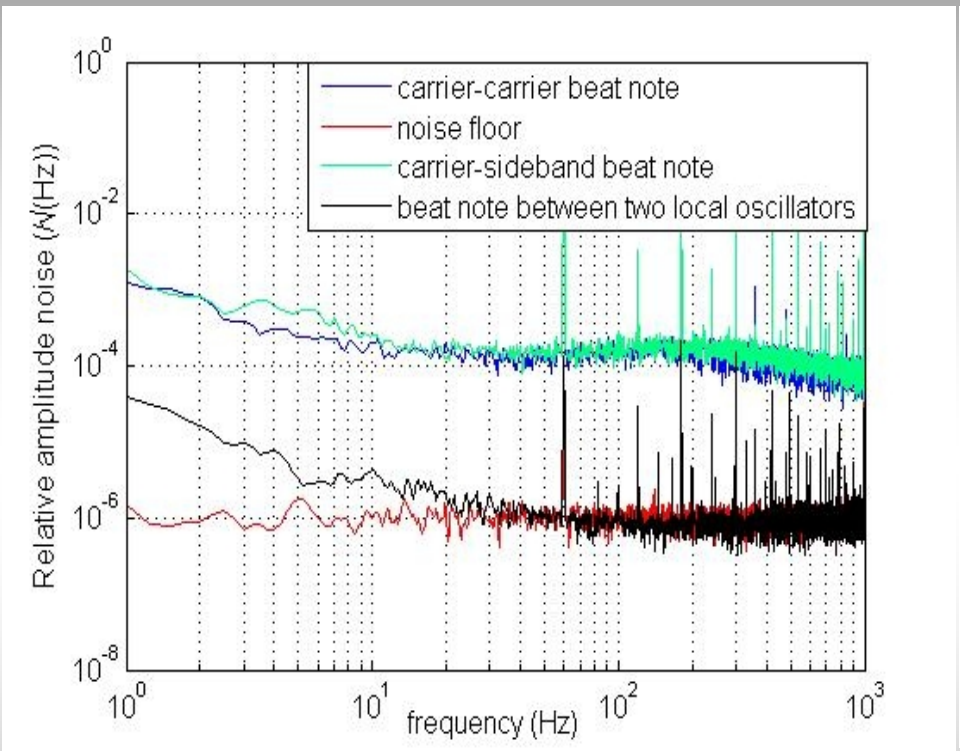
δm

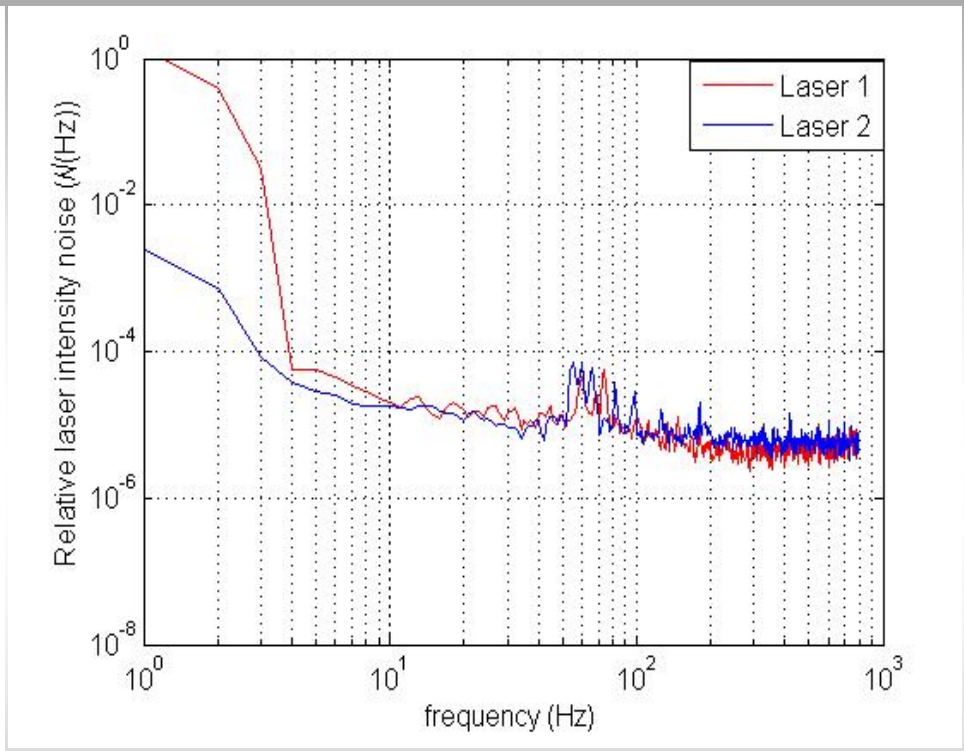
Noise that limits the measurement sensitivity

- **Amplitude noise**
  - ***Laser intensity noise*** A
  - ***Mode mismatching noise due to beam jitter***
  - ***Amplitude noise of the local oscillator*** A_{Ω}

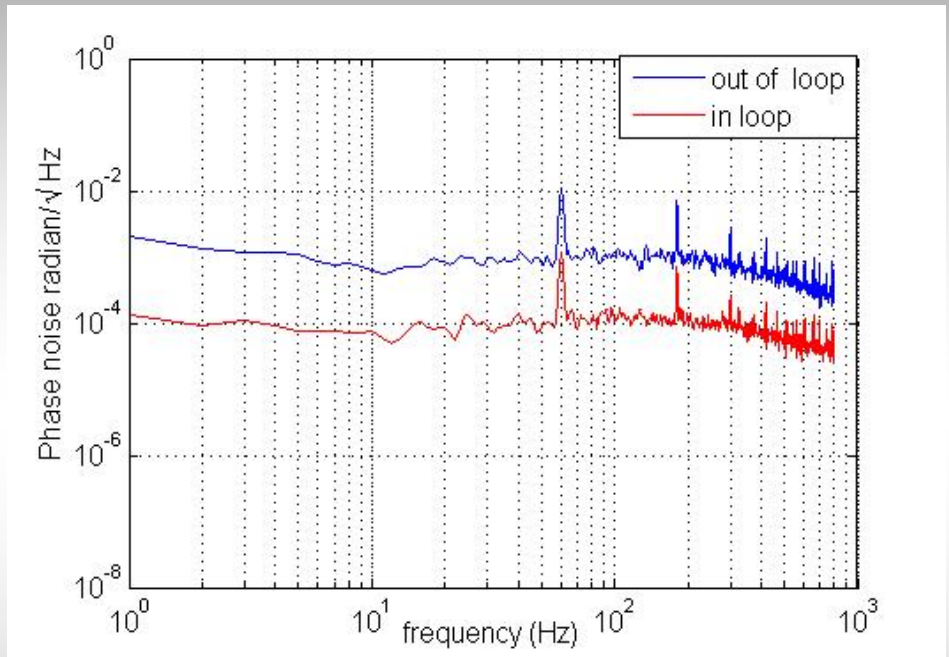
- **Phase noise**
  - ***Local oscillator phase noise*** $\delta\phi_{\Omega}$,
  - ***Phase locking noise between two lasers*** $\delta\phi_{PLL}$,
  - ***Sideband phase noise*** $\delta\phi_{SB}$

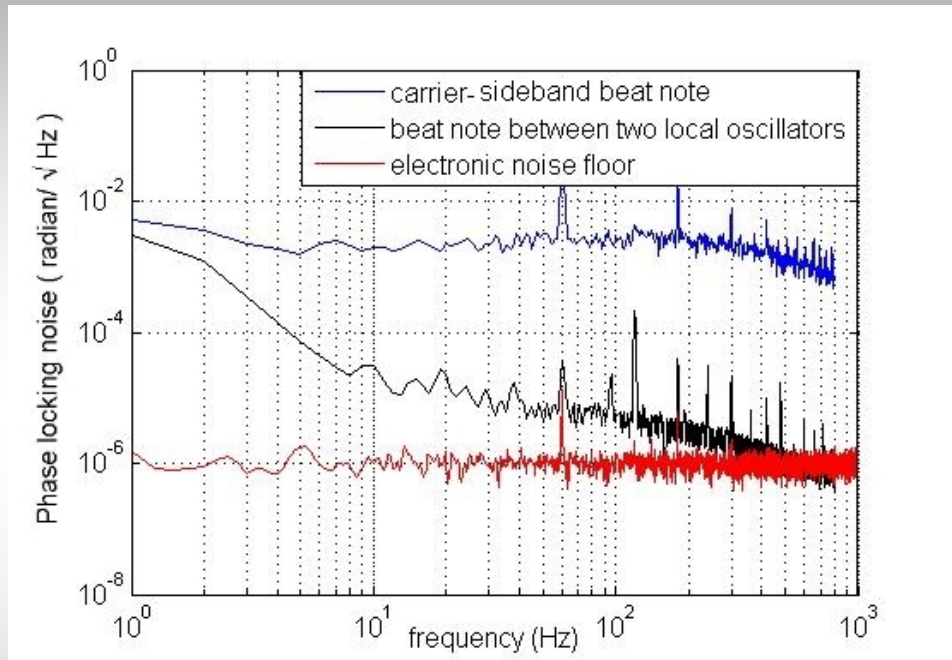
Amplitude noise





Phase noise



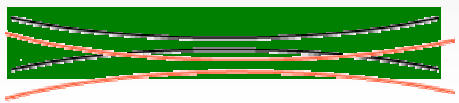


The phase noise – amplitude noise coupling is determined by the demodulation phase offset $\Delta\phi\,\delta\phi(f)$

Phase offset drift need to be investigated

$$U_{00} = \hat{U}_{00} - \left(\frac{\Delta x}{\omega_0} + i\frac{\pi\omega_0}{\lambda}\Delta\theta\right)\left(\hat{U}_{10} + \hat{U}_{01}\right)$$

$$\text{RIN} \sim 4\left(\frac{\pi\omega_0}{\lambda}\right)^2 \Delta\theta\,\delta\theta + 4\frac{\Delta x}{\omega_0^{\,2}}\delta x$$



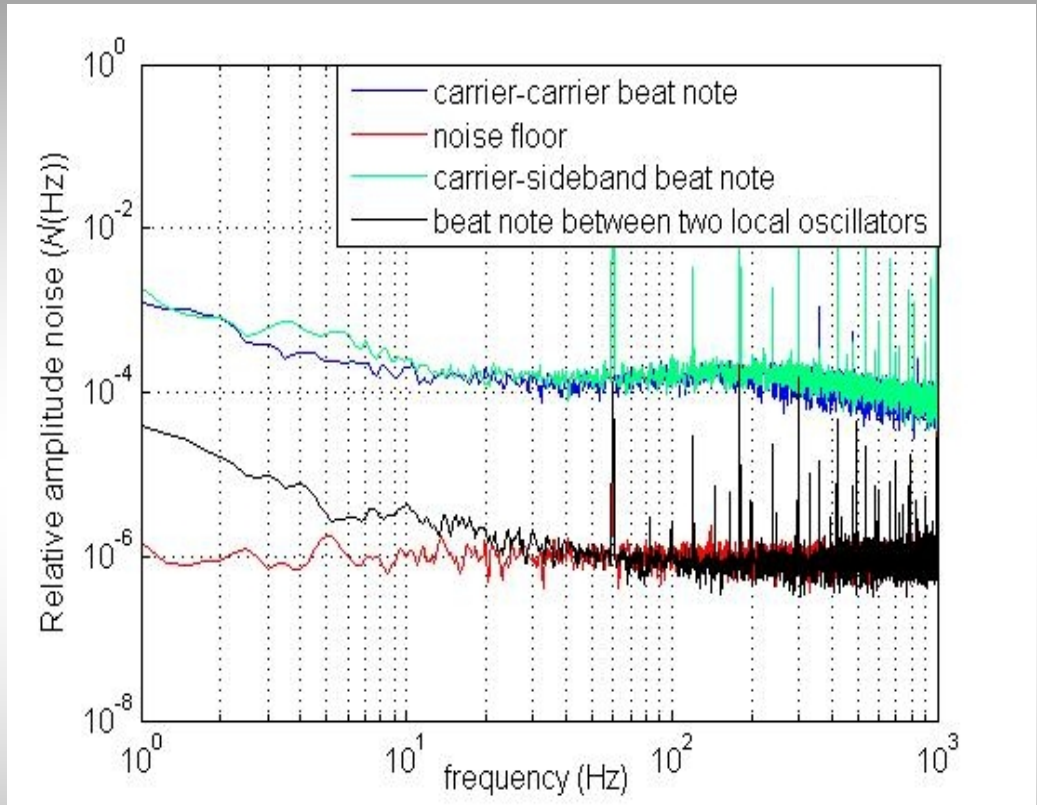
$\Delta x'$

$\Delta\theta'$

For a 0.1 mm waist,
1 μm displacement offset plus $1\mu m/\sqrt{Hz}$ ***displacement noise***
OR
0.1 mrad tilt angle offset plus $10^{-5}\,radian/\sqrt{Hz}$ ***tilt noise***

$10^{-4}/\sqrt{Hz}$ **Relative amplitude noise**

Common mode noise



Common mode noise rejection :

Phase meter $\dfrac{\textit{Carrier-sideband}}{\textit{Carrier-Carrier}} \rightarrow m(t) \xrightarrow{FFT} \delta m(f)$

Difficulties to be overcame

- **Electronic noise (mixer, phase shifter, etc) hunting**
- **Phase offset drift, phase locking**
- **Laser intensity stabilization**

Feedback control using the power adjustment port of the Light Wave NPRO will strongly affect the laser frequency and break the phase locking

Solution: ***Control the laser power through the AOM***

- **Beam jitter reduction**
  Solution: ***Characterize the beam jitter and feedback control using prism deflector***
- **Application of low noise local oscillators**
  Relative amplitude noise $< 10^{-8}/\sqrt{Hz}$

Summary

- ***Experiment has been set up. Noise sources are analyzed.***
- ***Need more precise noise characterization***
- ***Need further test to verify the solutions for noise reduction***