A RTP crystal electro-optic modulator for next generation gravitational wave detector

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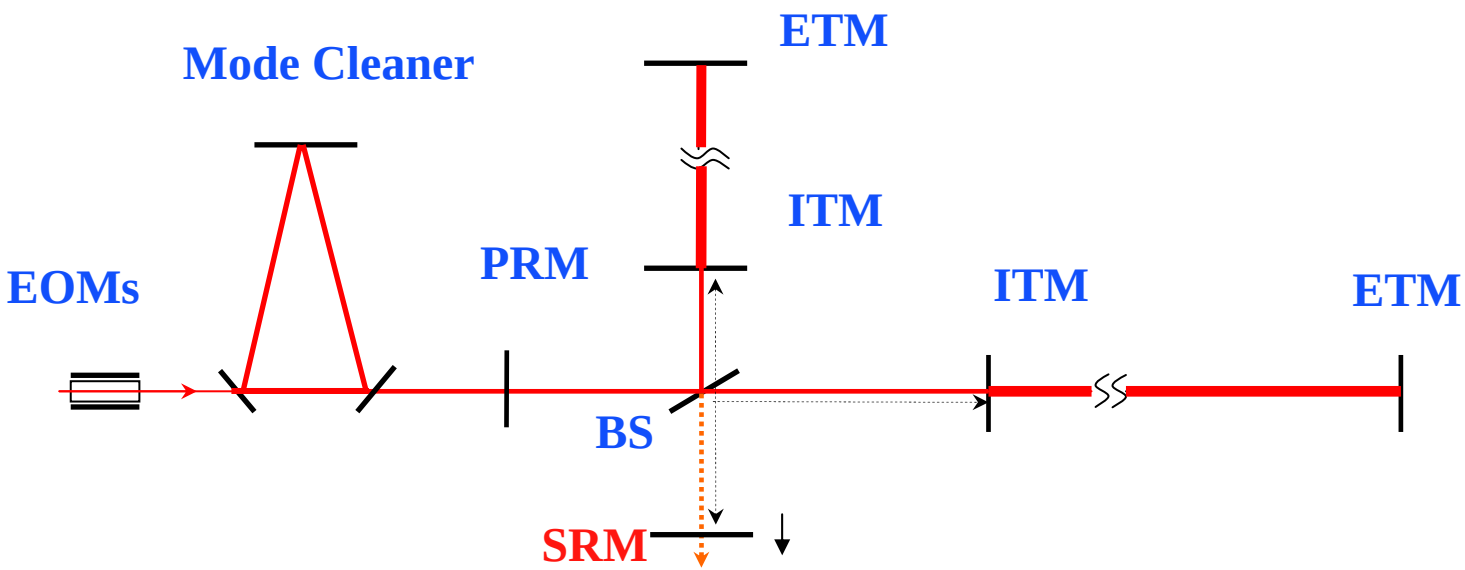
EOMs in Advanced LIGO

Part of the technical concerns for Advanced LIGO
- Potential 'thermal lensing' headaches due to the application of 180W laser
- Stringent requirement on the laser amplitude and frequency noise

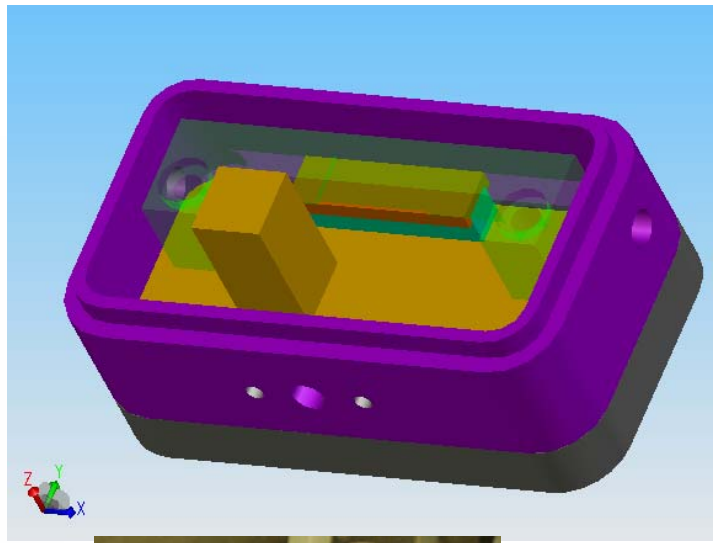
Demanding requirements on EOMs:
- Ultra-low optical absorption on the 1064nm laser
- Negligible residual amplitude and phase noise associated with the phase modulation

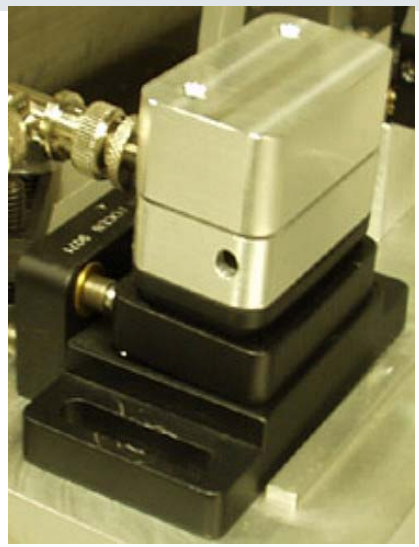


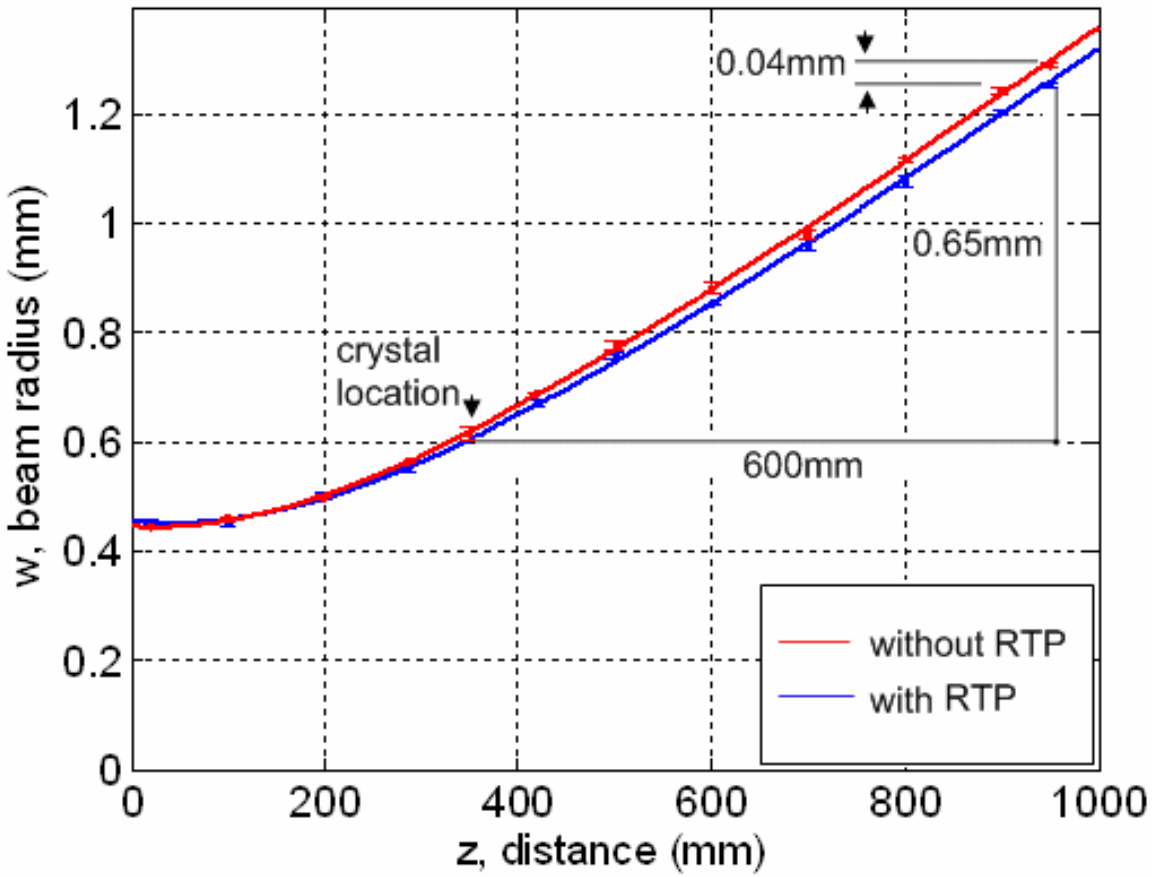
RTP crystal EOM

A novel RTP ($RbTiOPO_4$) crystal EOM is developed for Advanced LIGO

- Optical absorption coefficient < 1000 ppm/cm
  (upper limit according to our measurement)
- Maximum power loss of 00-mode ~ 1.4%

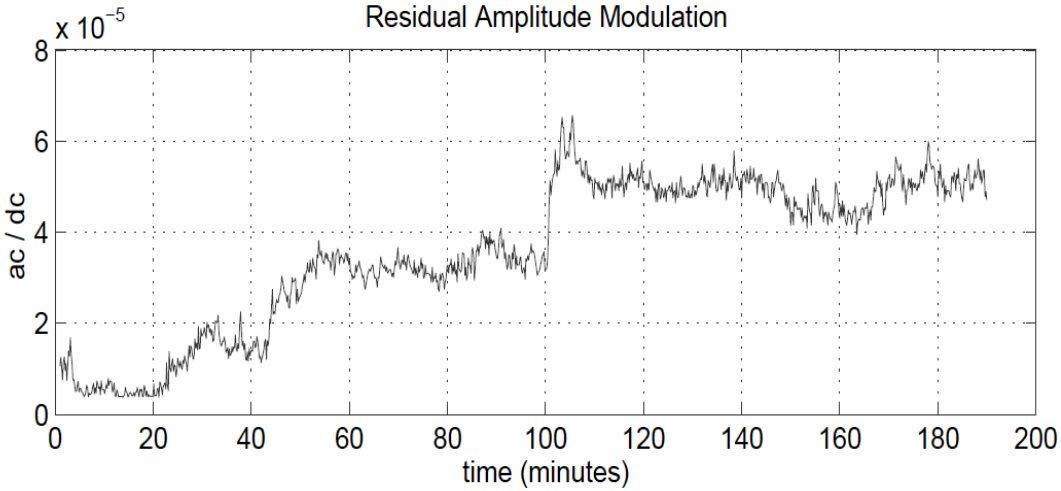


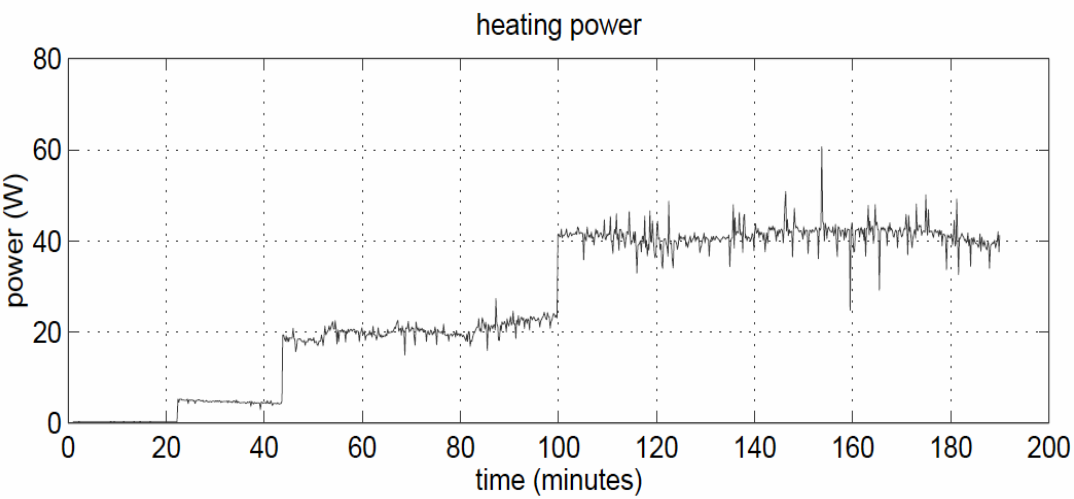


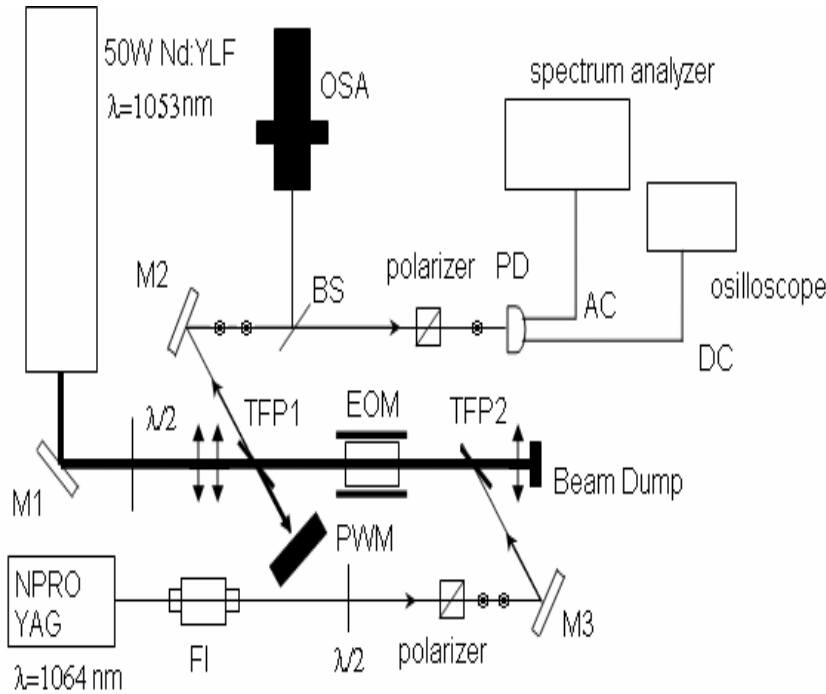


RFAM

RFAM creates unwanted offsets in the length sensing and control signals







Measured RFAM produced by RTP EOMs under high power laser heating

$\Delta I_{\Omega} / I_{DC} \sim$ 10e-5

Noise associated with EOM

- EOM imposes the additional noise on the transmitted light

  - Creates intensity noise of both the carrier and the sidebands

  - Introduces sidebands phase noise

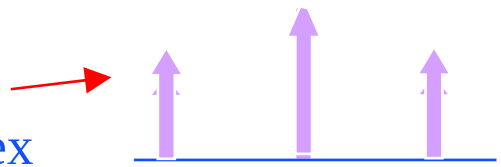
  (The phase fluctuation between the carrier and the sidebands causes laser frequency noise via the feed back loop)

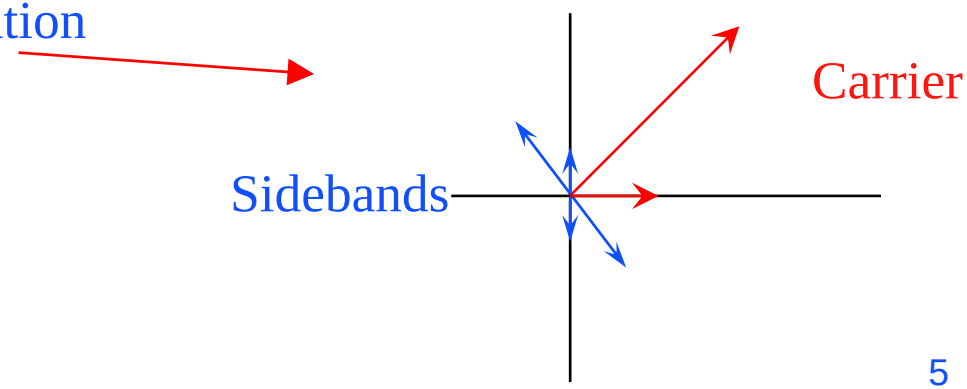
- Noise generation mechanism

  - Variation of the modulation index

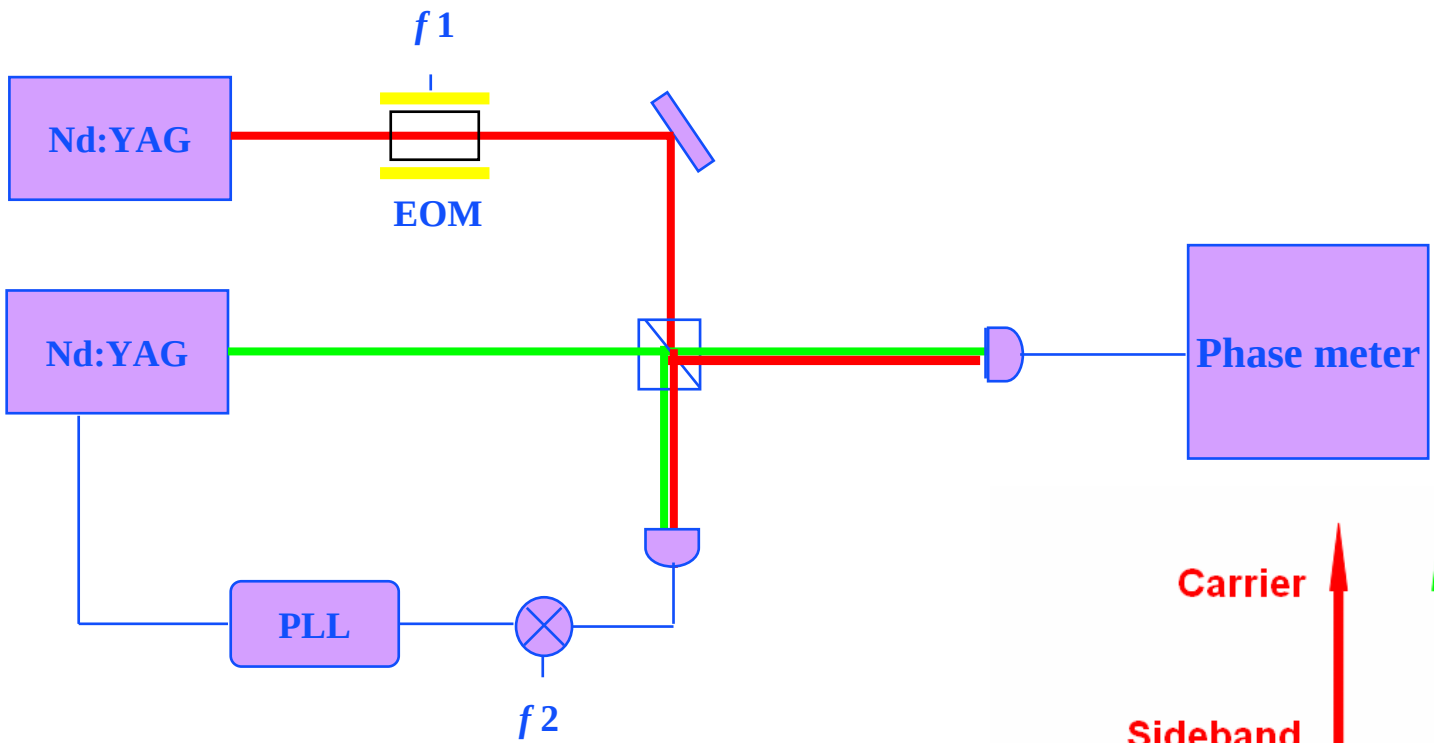
  - Variation of the phase retardation

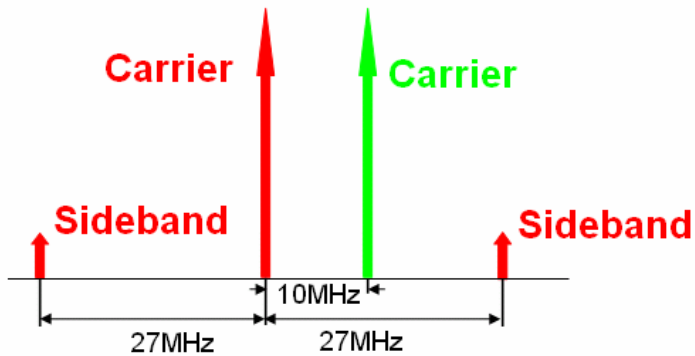
  - Fabry-Perot cavity effect





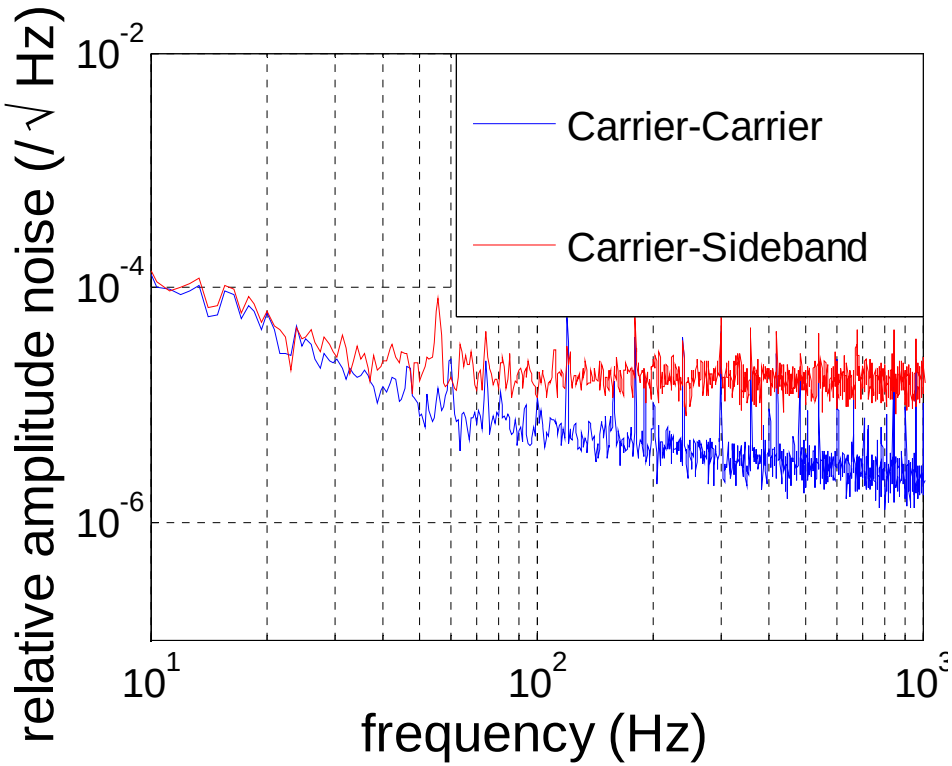
Measurement of the intrinsic EOM noise

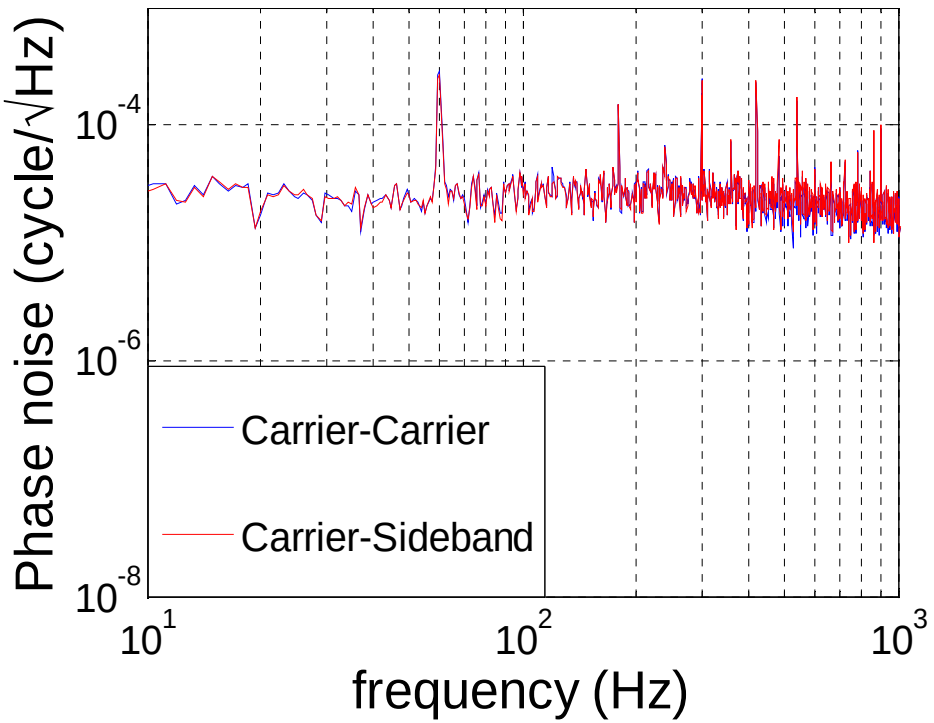




- **Phase lock two lasers with a frequency offset**
- **Measure the beat signals –** Carrier-Carrier (C-C), Carrier-Sidebands (C-S)

Amplitude noise & phase noise





Noise in the beat notes

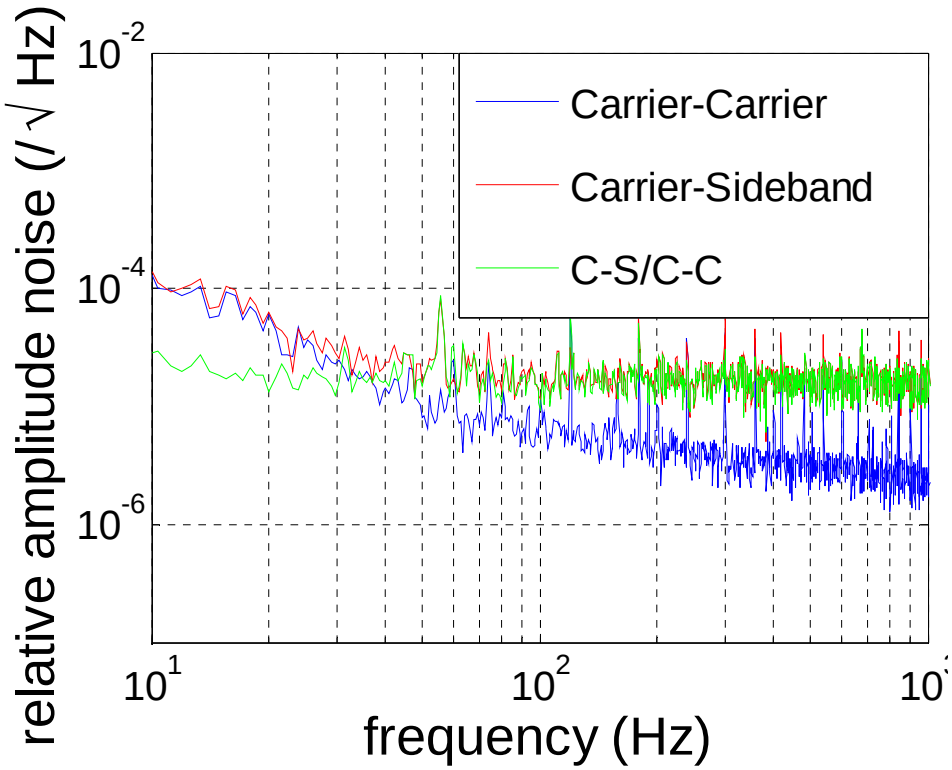
- Noise in two beat signals (C-C, C-S) in common mode
  - Beam jitter between two laser beams
  - Laser intensity noise
- Noise in two beat signals in differential mode (amplitude & phase noise)
  - produced by the EOM

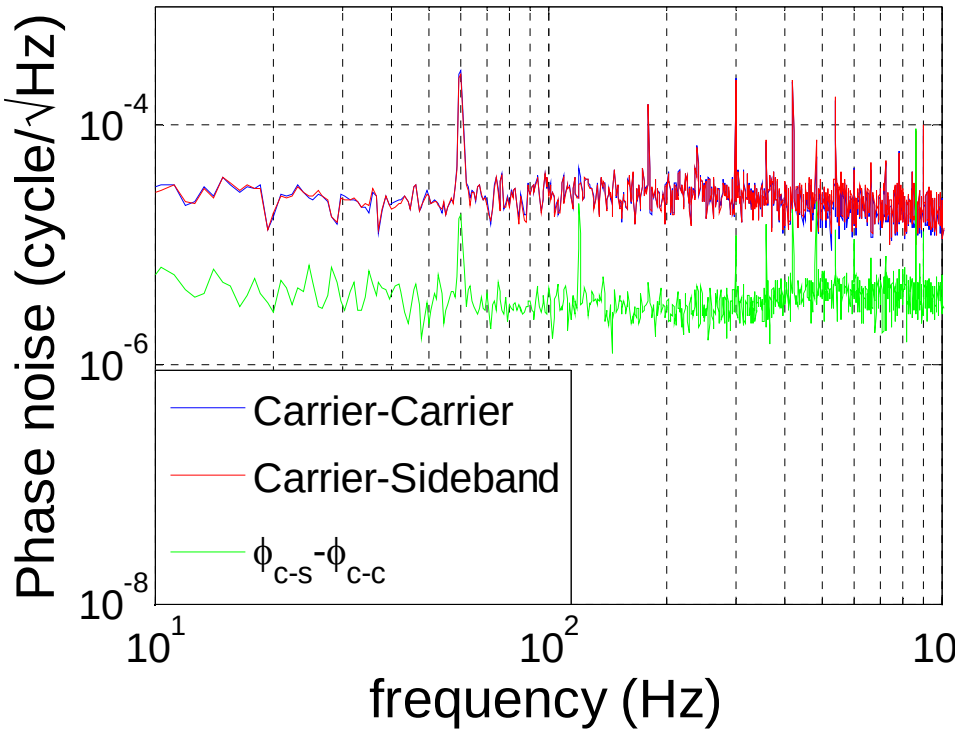
Common-mode noise rejection analysis

Amplitude $$fft\left\{\frac{amplitude\quad of\quad C-S}{amplitude\quad of\quad C-C}\right\}$$

Phase $$fft\left\{\phi_{C-S}-\phi_{C-C}\right\}$$

Data analysis





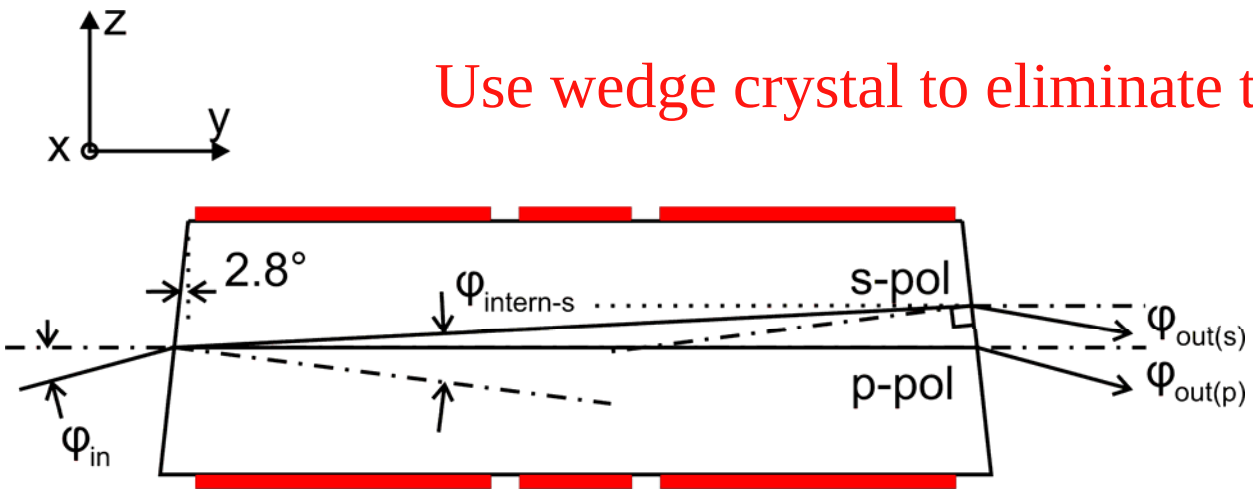
Future improvement

Modulation index $$m = \frac{\pi L}{\lambda} r_{33} n_z^3 \frac{V_z}{d}$$

Phase retardation $$\Delta\phi = \frac{2\pi}{\lambda}(n_z - n_y)L$$

Temperature stabilization is needed

$$L = L_0 + \kappa \Delta T \qquad n = n_0 + \frac{dn}{dT}\Delta T$$



Use wedge crystal to eliminate the cavity effect

Our ultimate goal

- Solving the noise problems associated with EOMs is a challenging task !

- Current estimation of the requirement on the amplitude and the phase noise:
  - Laser intensity noise ~ $2\times10^{-9}/\sqrt{\mathrm{Hz}}$
  - Sideband phase noise ~ $10^{-11}/\sqrt{\mathrm{Hz}}$ at 100 Hz

  Based on the calculation in (K. Somiya, Y. Chen, S. Kawamura, and N. Mio, PRD, 2006)