Basics of Interferometer Response and Calibration Considerations

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Laser beams

- Electric fields can be written as

$$E = E_0 e^{i(\omega t - \phi)}$$

amplitude

laser frequency

phase

$$\phi = \frac{2\pi L}{\lambda}$$

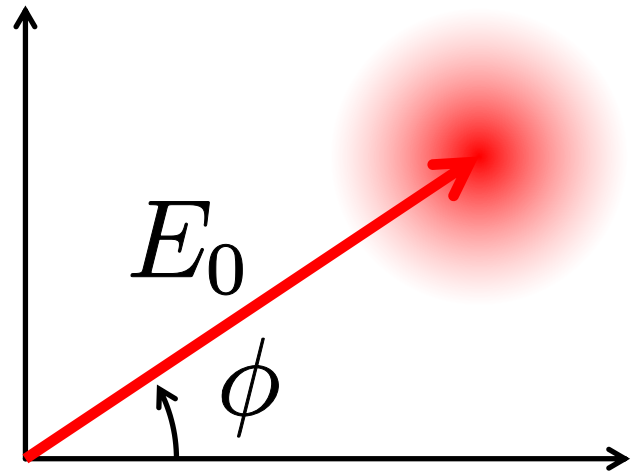
$$\omega = \frac{2\pi c}{\lambda}$$

- Photo diodes detect “power”

$$P = |E|^2 = E_0^2$$

- Amplitude and phase fluctuates by quantum mechanics

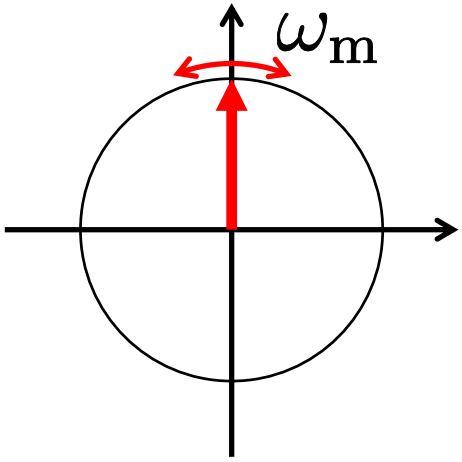
$$\delta P_{\mathrm{shot}} \propto \sqrt{P}$$



Phase Modulation & Sidebands

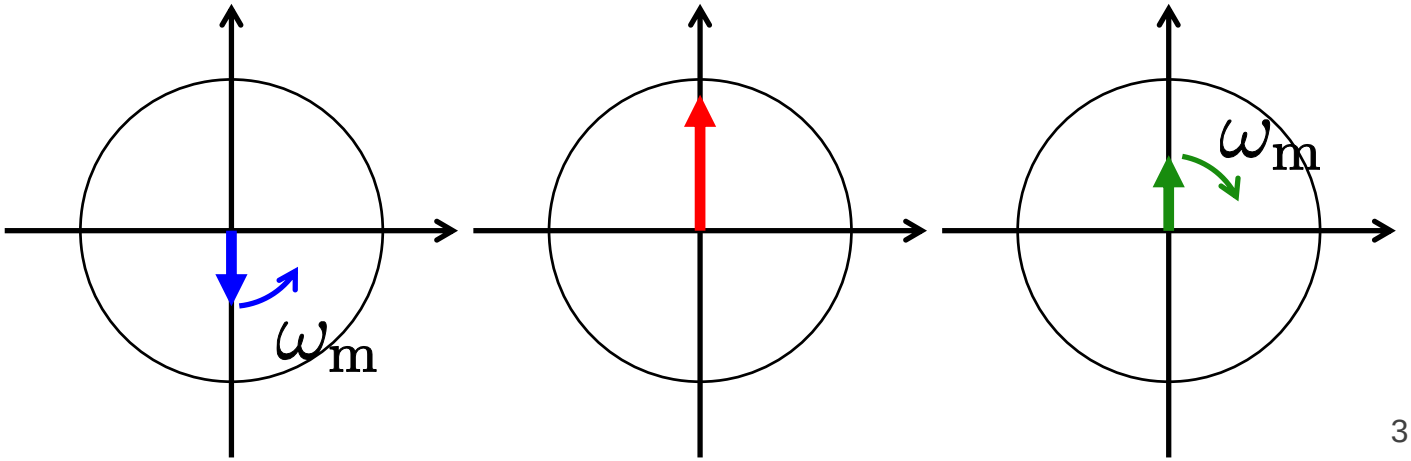
- phase modulation makes two sidebands
- GW signals are sidebands

$$Ee^{i(\omega t+\beta \sin \omega_{\mathrm{m}} t)}$$

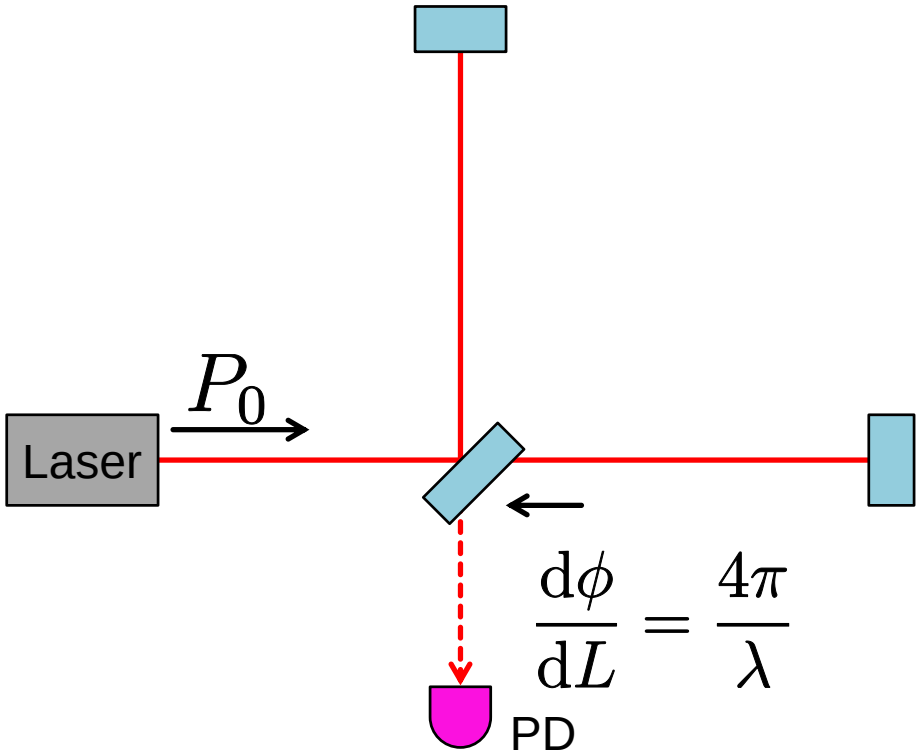


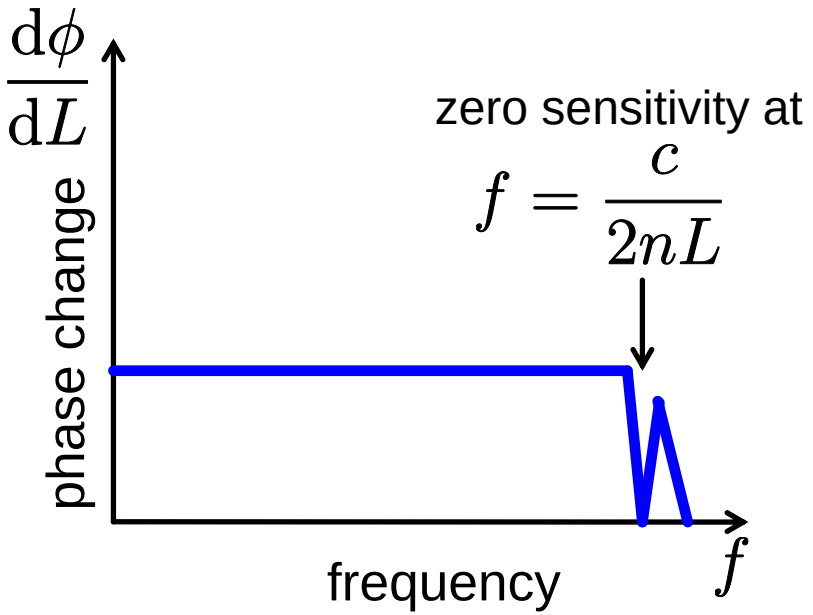
Approximation with Bessel functions

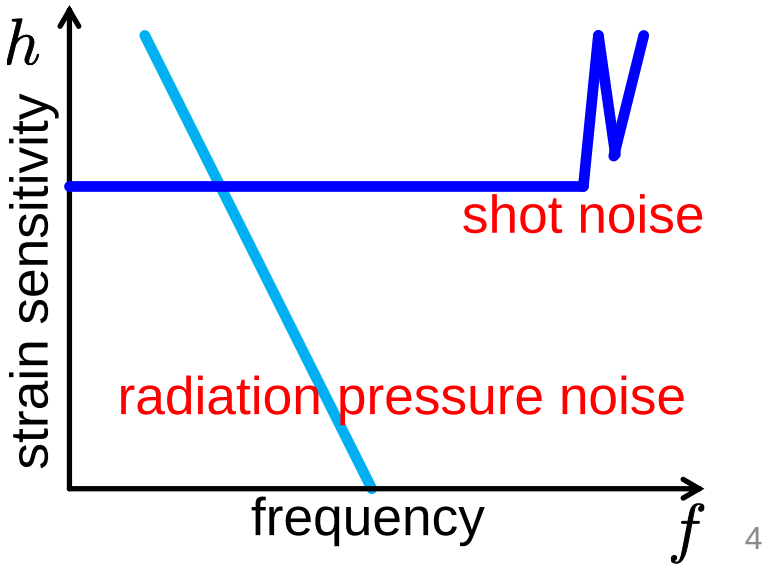
$$E[J_0(\beta)e^{i\omega t} + J_1(\beta)e^{i(\omega+\omega_{\mathrm{m}})t} - J_1(\beta)e^{i(\omega-\omega_{\mathrm{m}})t}]$$



Michelson Interferometer



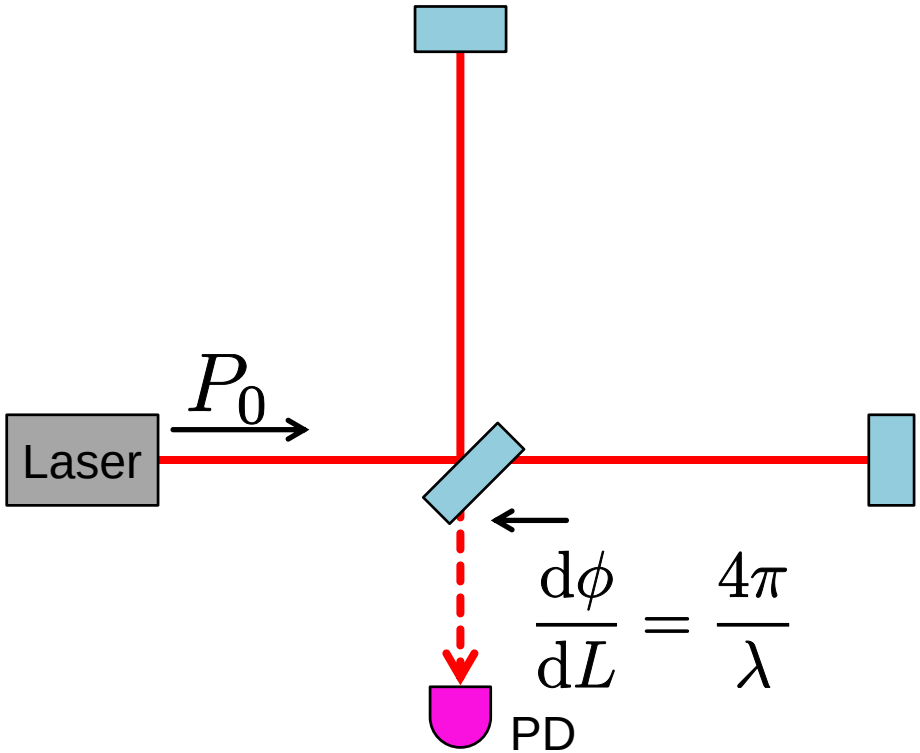


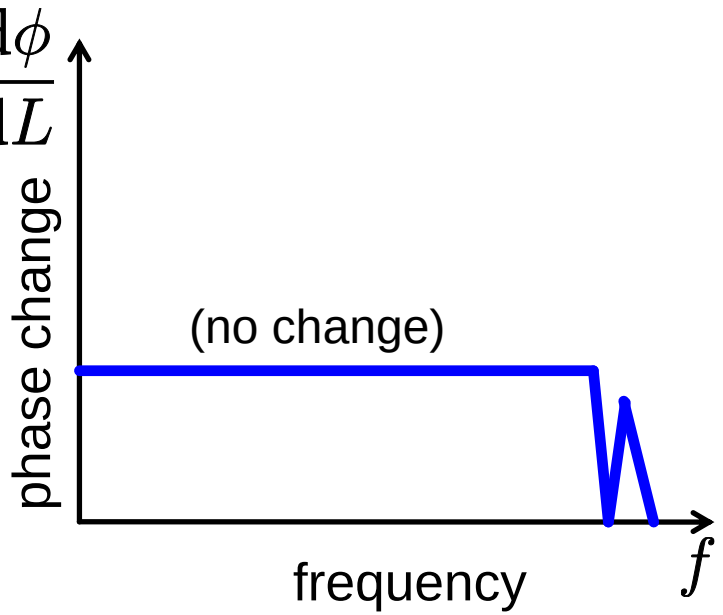


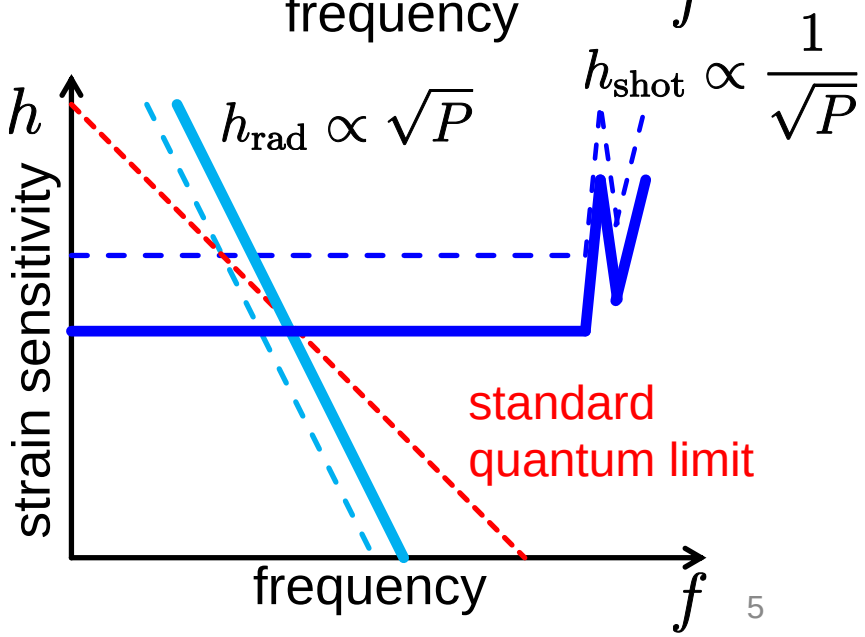
$$P_{\mathrm{PD}} = \frac{1}{2} P_0 \left(1 - \cos \frac{4\pi L_-}{\lambda}\right)$$

(at mid-fringe)

Higher Power



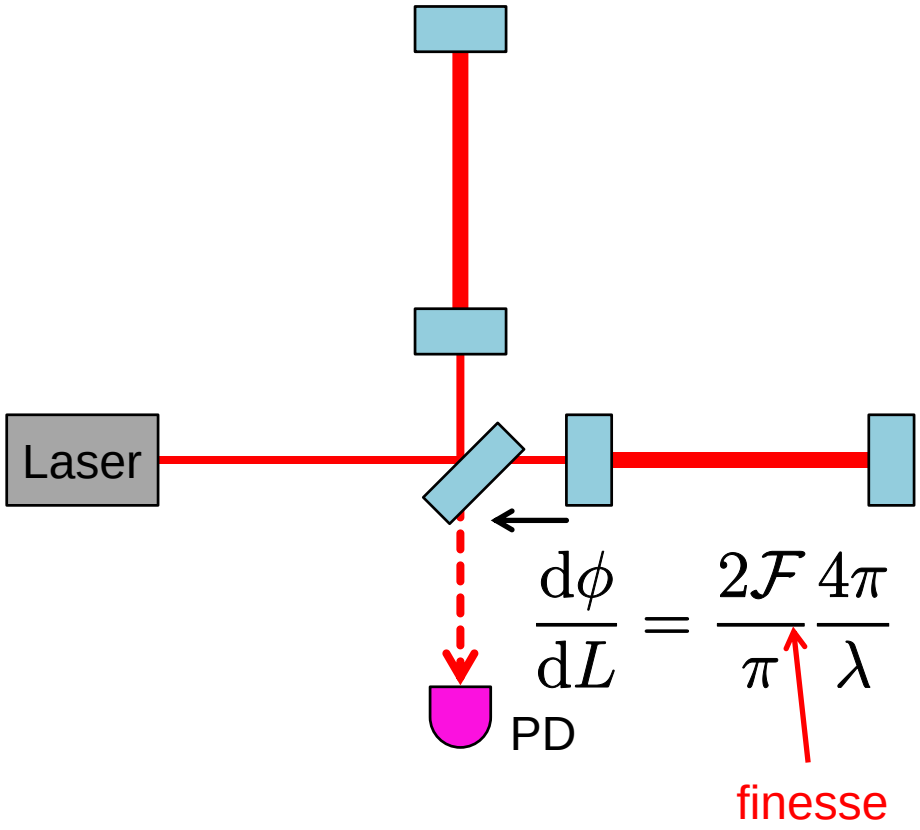


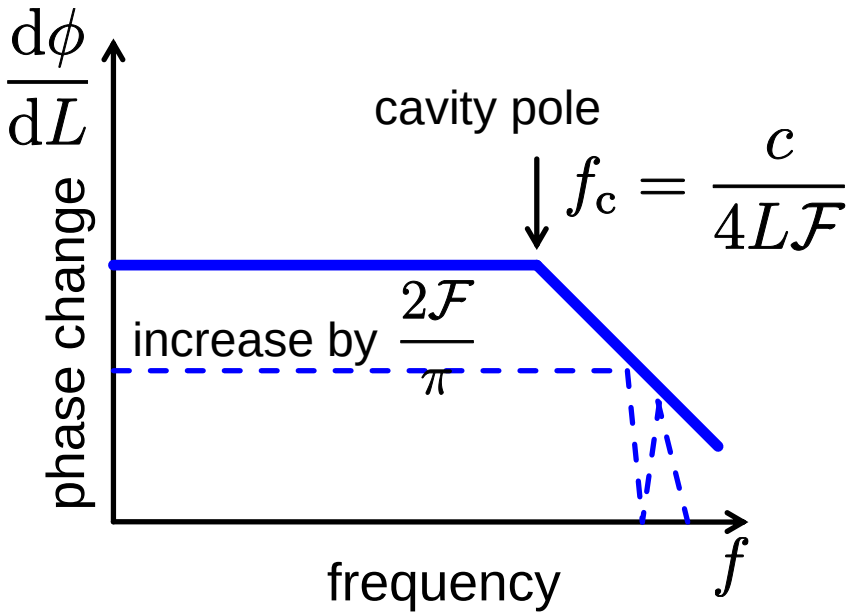


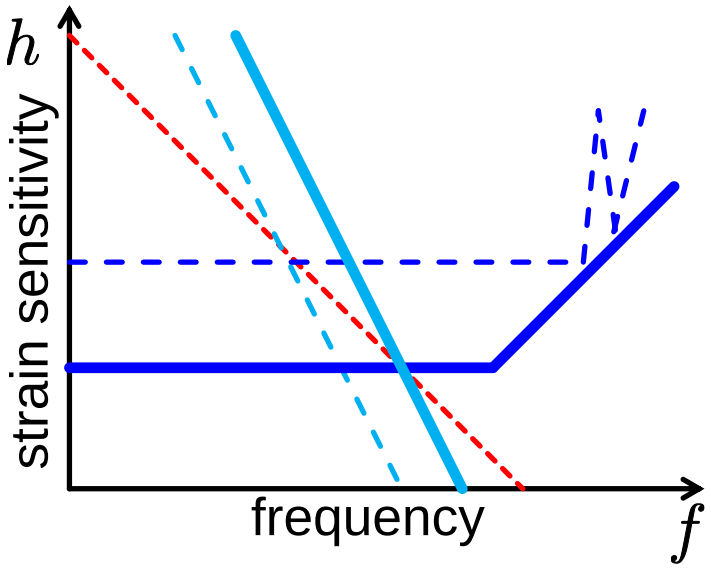
$$P_{\rm PD} = \frac{1}{2} P_0 \left(1 - \cos \frac{4\pi L_-}{\lambda}\right)$$

(at mid-fringe)

Fabry-Perot Cavity

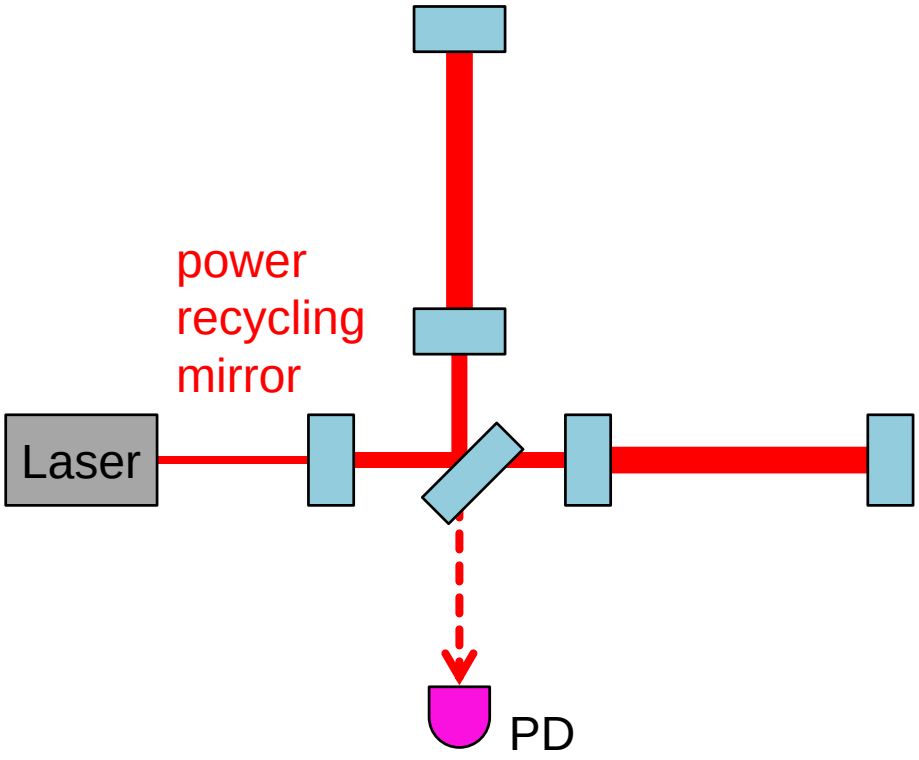


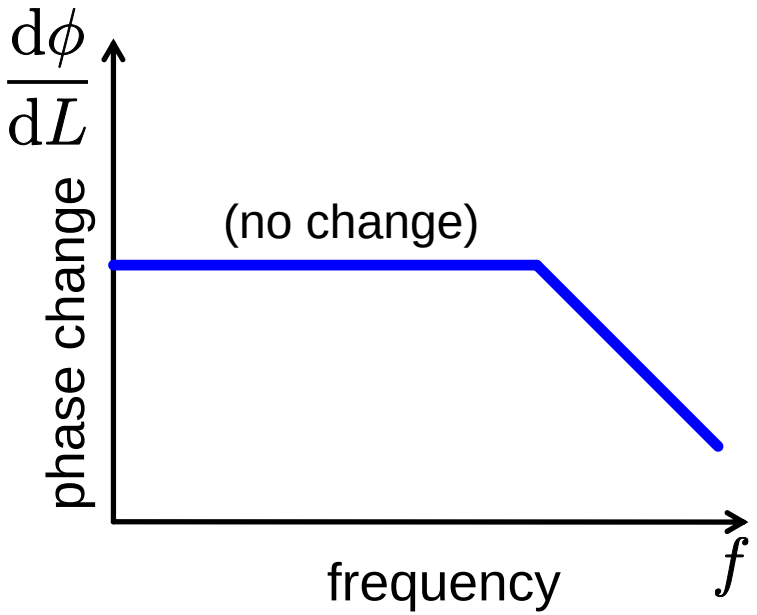


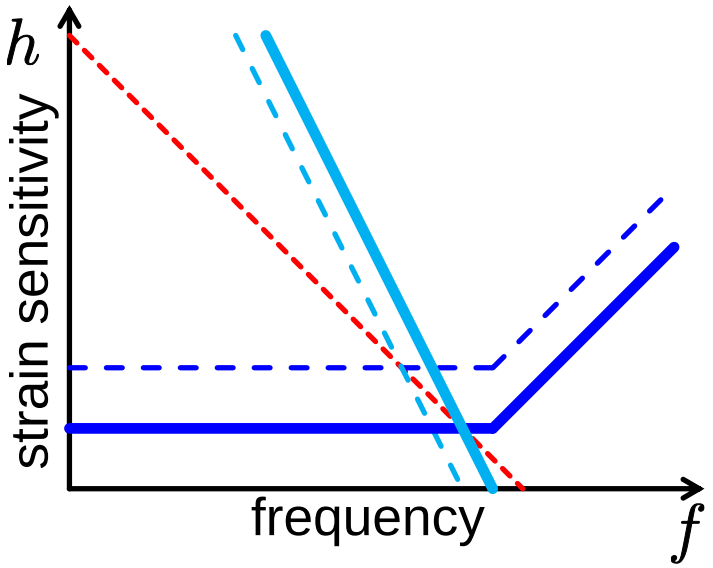


Phase change is increased by multiple reflections between ITM and ETM

Power Recycling

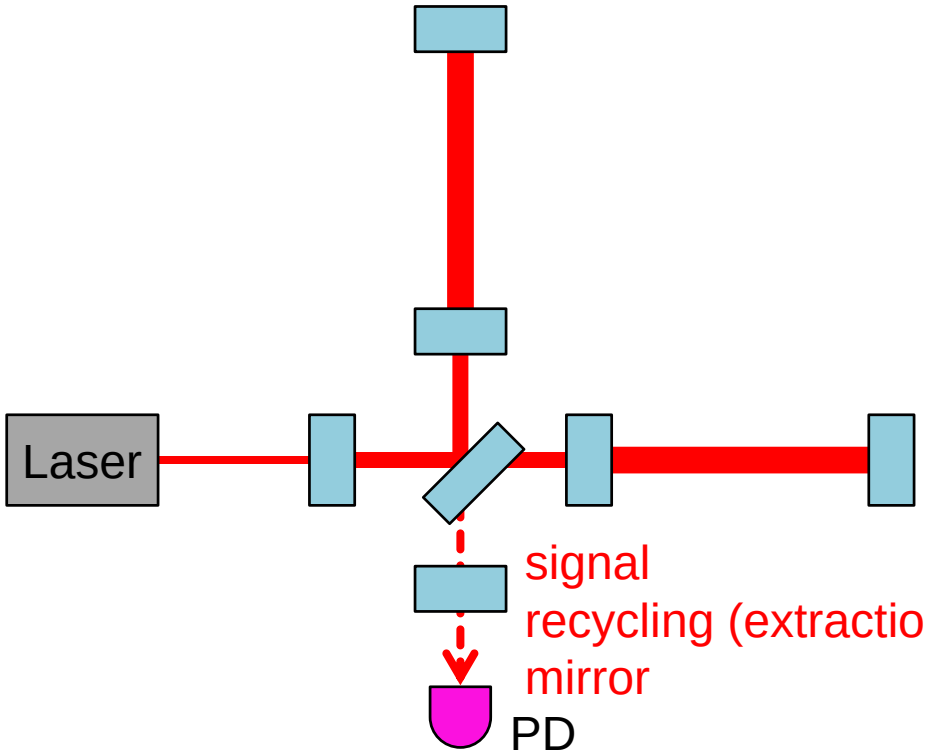


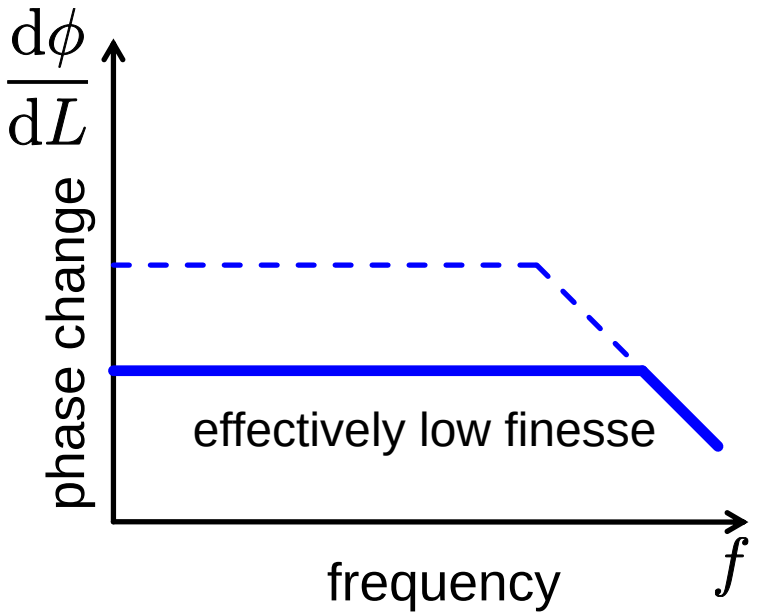


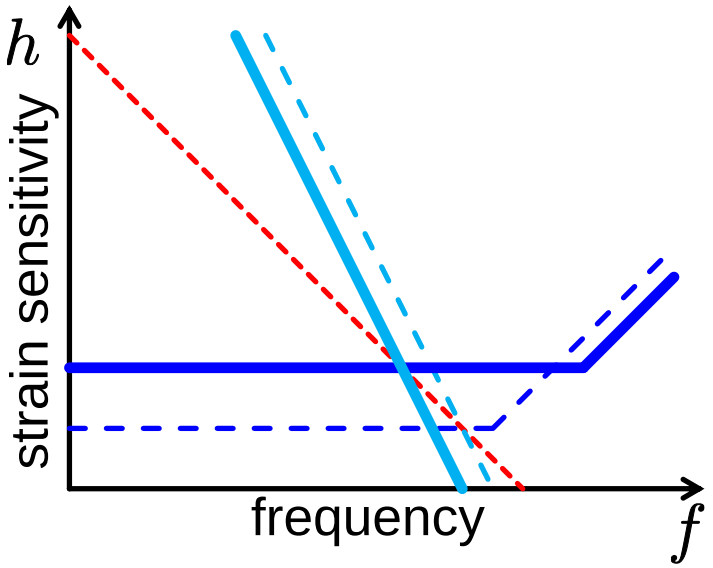


Reflected beam is returned back into the interferometer and effective laser power is increased

Resonant Sideband Extraction



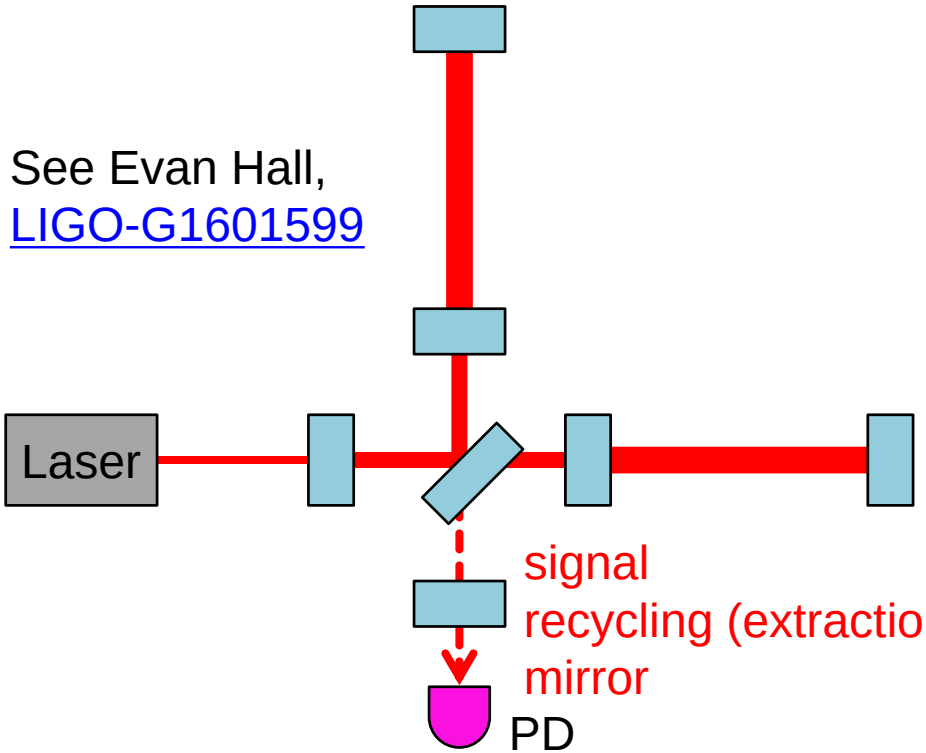


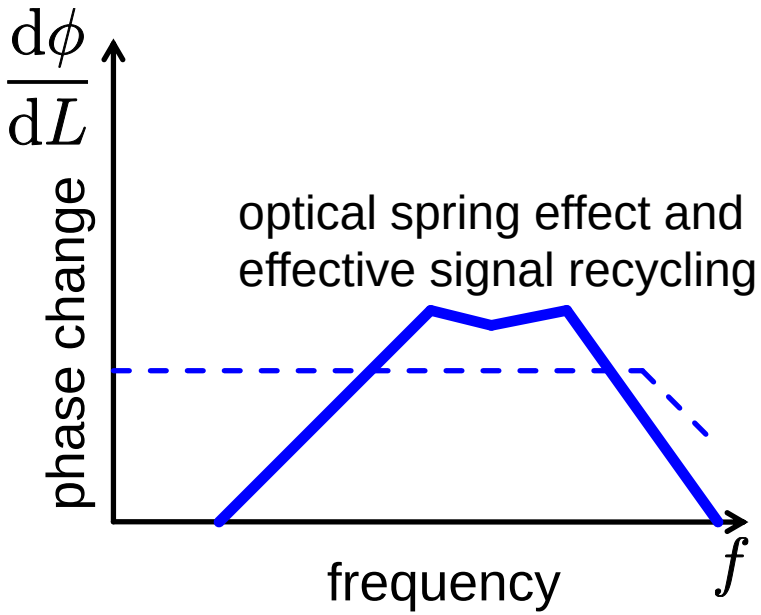


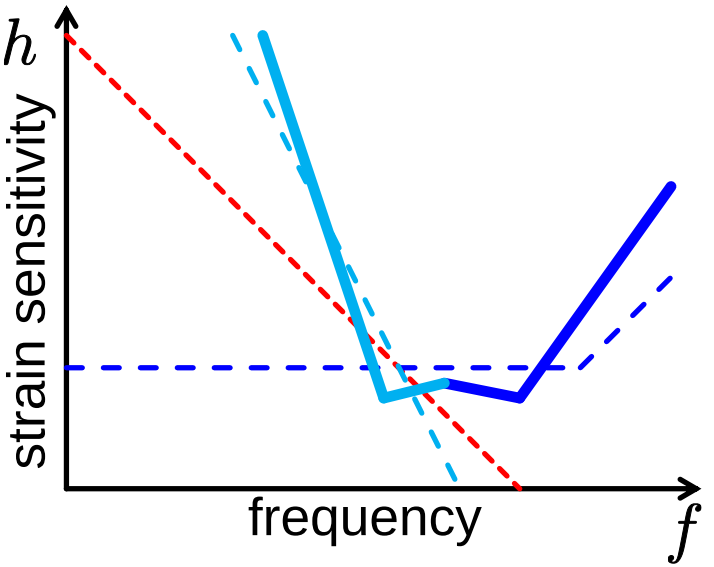
Make arm cavity finesse low for GW signal to extract signal before cancellation, without reducing arm cavity power

Detuned RSE

See Evan Hall,
LIGO-G1601599







Dip at low frequency from optical spring effect, dip at high frequency where SRC is resonant for GW signal

Calibration Considerations

iKAGRA Calibration

- Optical gain calibration using Michelson free-swing
- Actuator calibration using simple pendulum model
- Independent actuator calibration using laser sensor for sanity check in advance
- Calibration lines for openloop gain monitor and UGF servo
- Calibration lines for BS, ETMX, ETMY actuator monitor
- Random calibration line frequency, amplitude

New in bKAGRA Phase 1

- Multiple pendulum
- Actuator lines for upper stages
- Actuator calibration when room temperature and when cryogenic temperature
- Time variation of actuator gain due to cooling
- Somewhat “optimized” calibration line frequency and amplitude

New in bKAGRA Phase 2-3

- Calibration ladder from ITM to ETM
- Pcal
- Calibration line for cavity poles
- Calibration in detuned case
- Calibration in homodyne readout case

- Calibration in LVK network