LIGO

Sensing and control of the Advanced LIGO optical configuration

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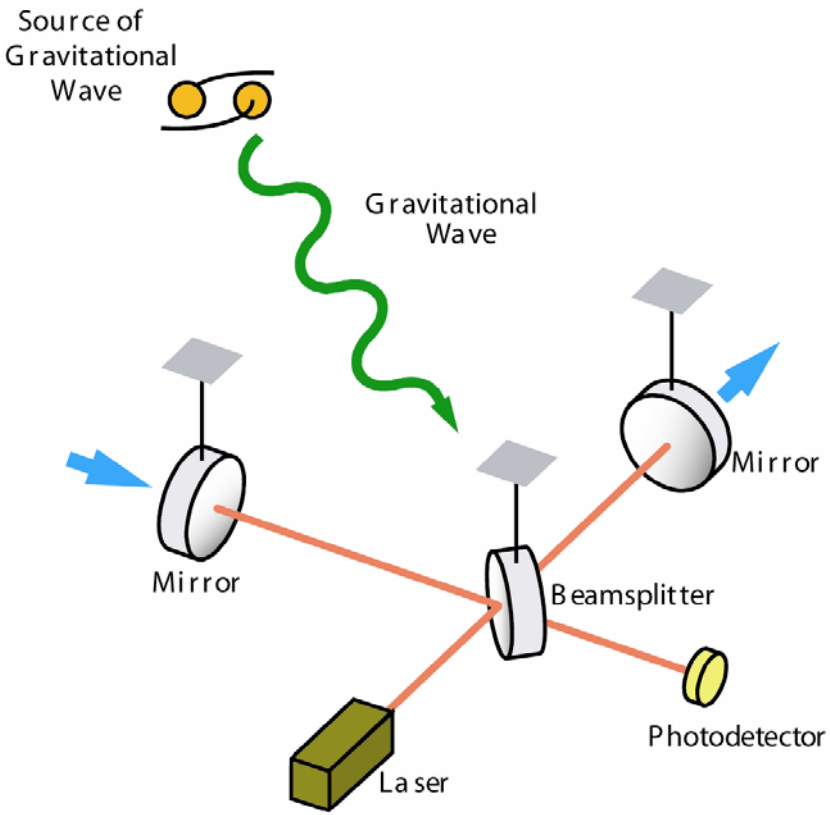
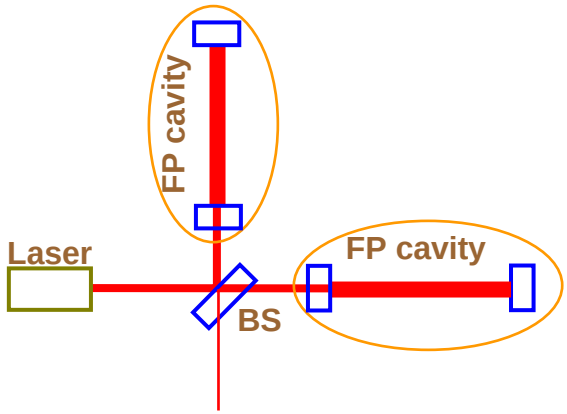
Optical configuration for Gravitational wave interferometer

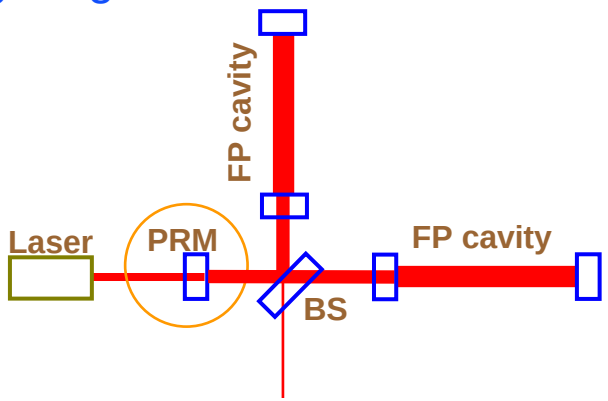
- Gravitational wave detection using Michelson interferometer



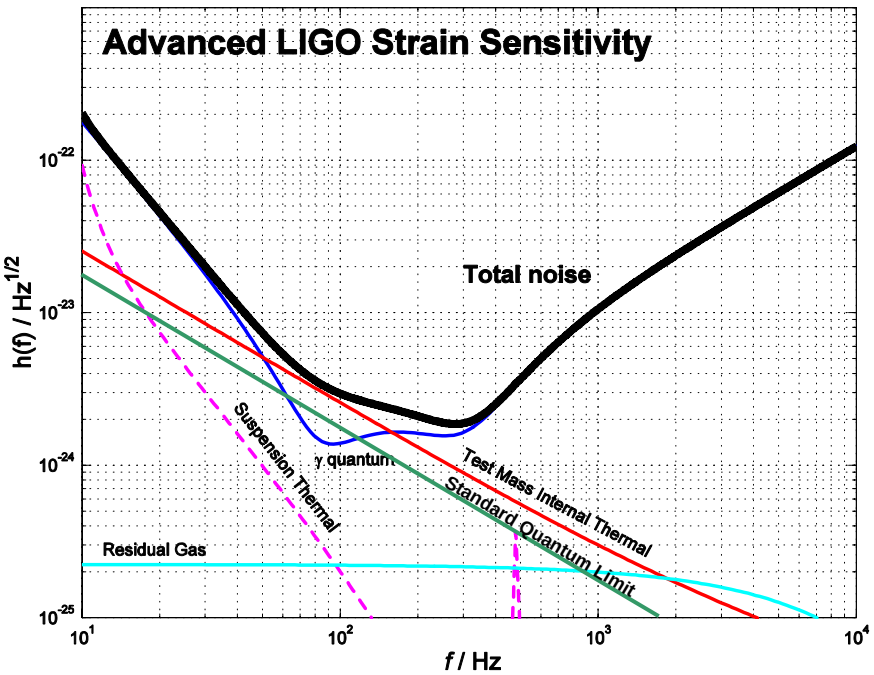
- Signal and power enhancement using Fabry-Perot cavity in each arm



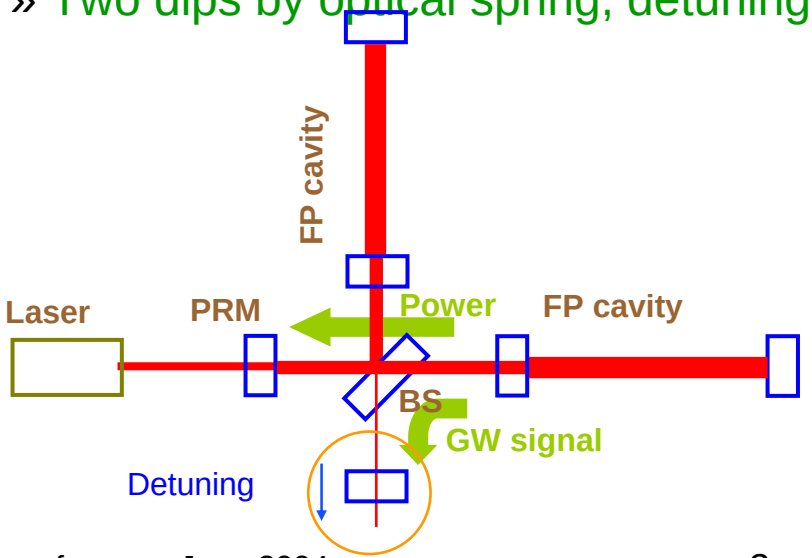
- Power enhancement using Power Recycling



Advanced LIGO optical configuratoin



- LIGO:Power recycled FPMI
  - » Optical noise is limited by Standard Quantum Limit (SQL)
- AdvLIGO:GW signal enhancement using Detuned Resonant Sideband Extraction
  - » Can overcome the SQL ➡ QND detector
  - » Two dips by optical spring, detuning

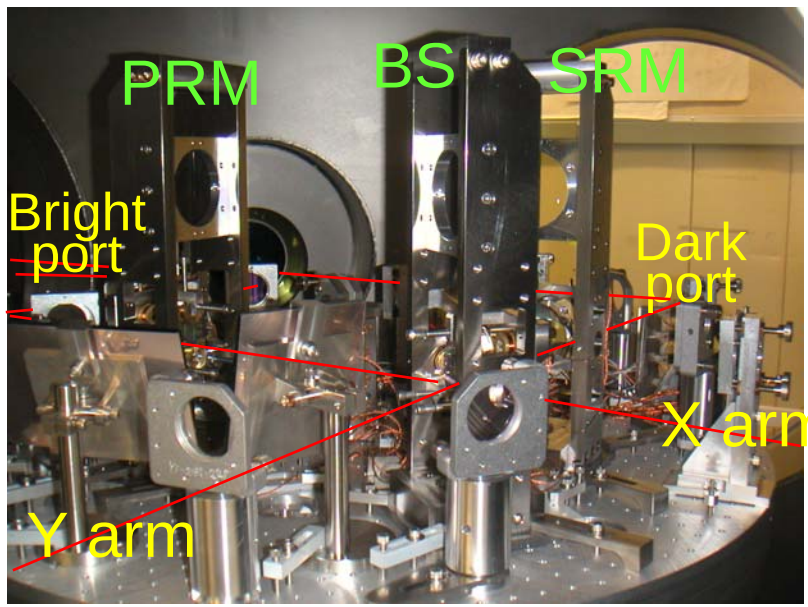


Caltech 40 meter prototype interferometer

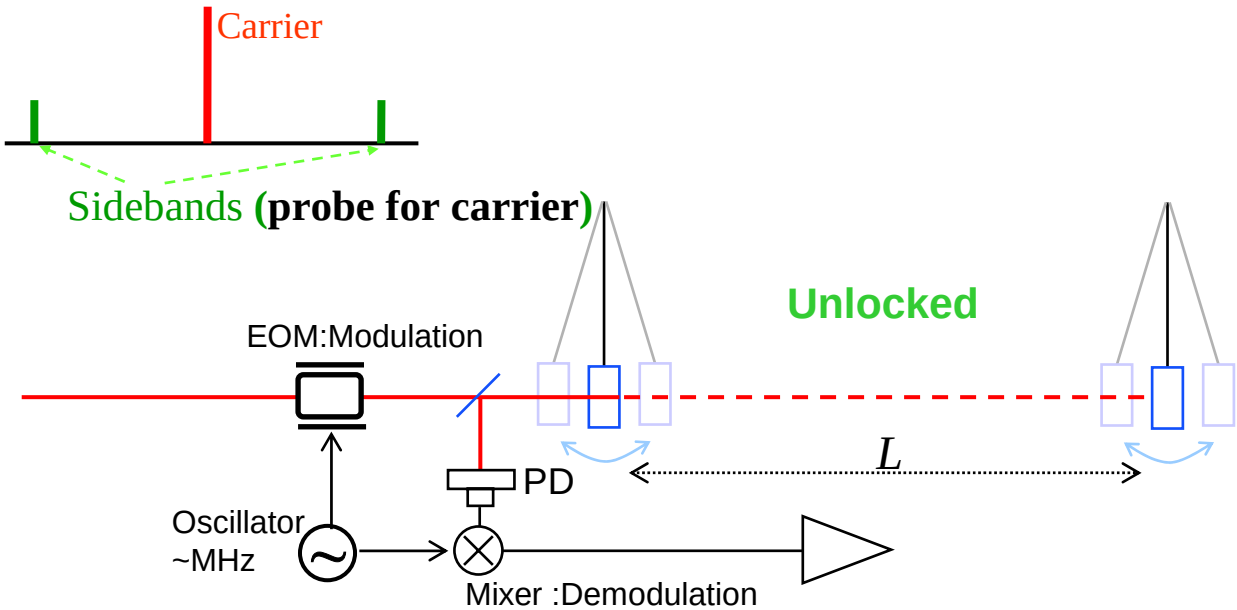
Objectives

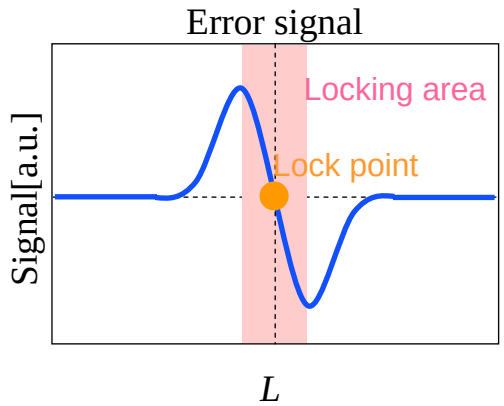
- Develop **lock acquisition procedure** of suspended-mass detuned Resonant Sideband Extraction (RSE)
- Characterize noise mechanism
- Verify optical spring effect
- Develop readout scheme

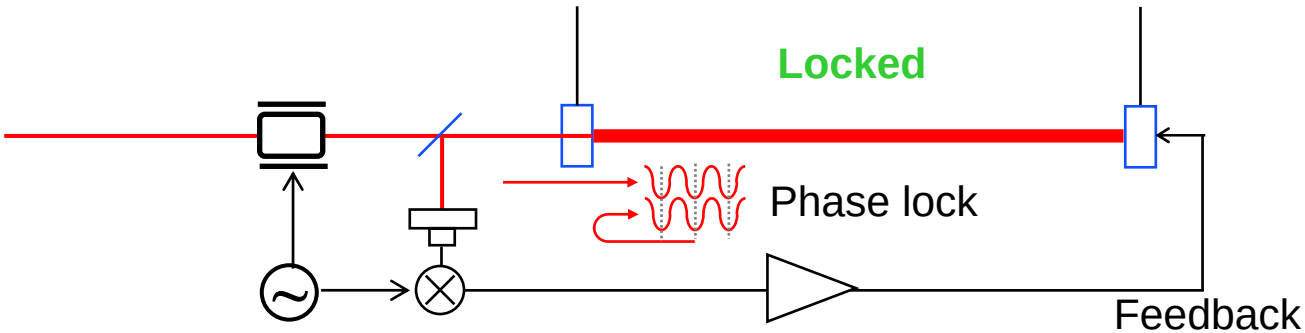
for Advanced LIGO and other future GW detectors



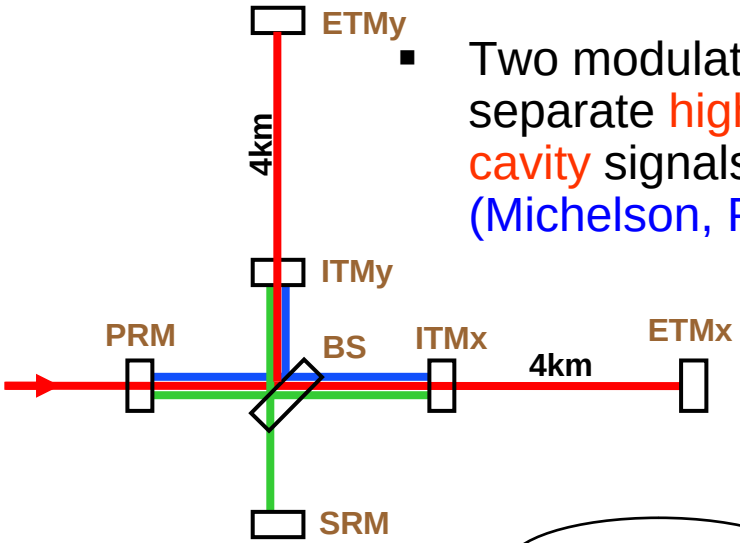
Length sensing and control



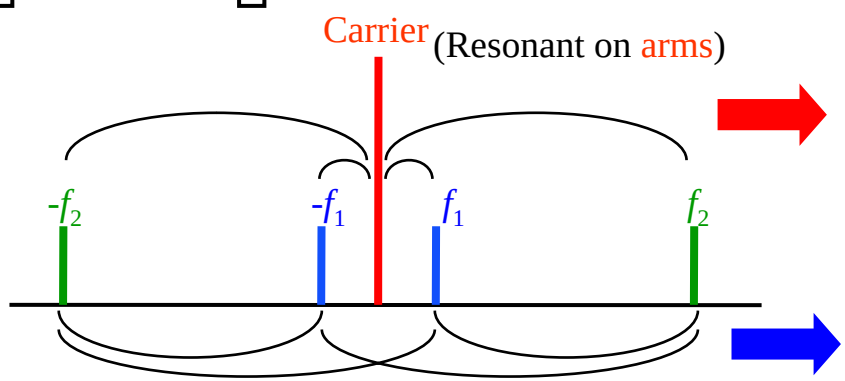




Signal extraction for AdvLIGO



- Two modulations are used to separate high finesse, 4km long arm cavity signals from Central part (Michelson, PR, SR) signals.



- Single demodulation
- Arm information

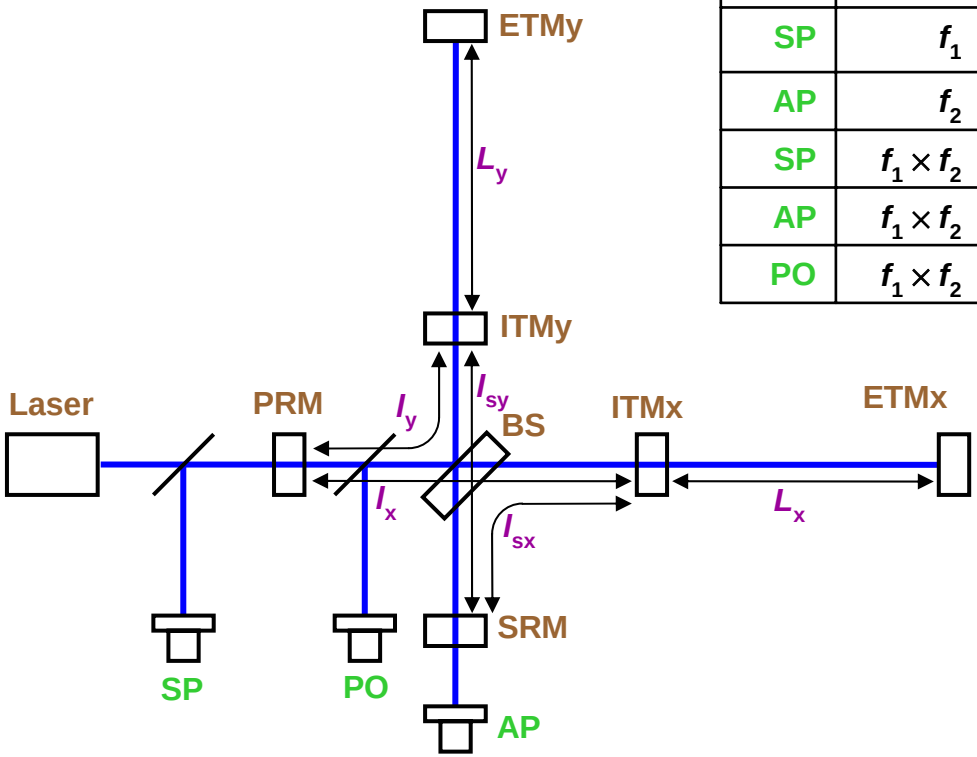
- Double demodulation
- Central part information

- Arm cavity signals are extracted from beat between carrier and f_1 or f_2.
- Central part (Michelson, PR, SR) signals are extracted from beat between f_1 and f_2, not including arm cavity information.

5 DOF for length control

Signal Extraction Matrix (in-lock)

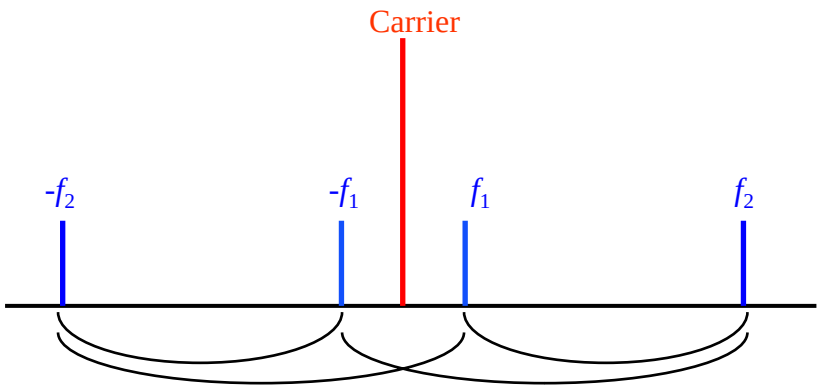
Port	Dem. Freq.	L_+	L_-	l_+	l_-	l_s
SP	f_1	1	-3.8E-9	-1.2E-3	-1.3E-6	-2.3E-6
AP	f_2	-4.8E-9	1	1.2E-8	1.3E-3	-1.7E-8
SP	$f_1 \times f_2$	-1.7E-3	-3.0E-4	1	-3.2E-2	-1.0E-1
AP	$f_1 \times f_2$	-6.2E-4	1.5E-3	7.5E-1	1	7.1E-2
PO	$f_1 \times f_2$	3.6E-3	2.7E-3	4.6E-1	-2.3E-2	1



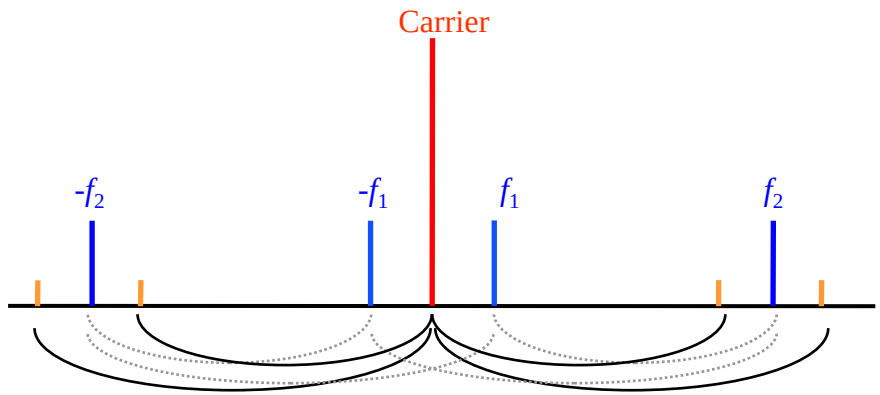
Common of arms : $L_+ = (L_x + L_y) / 2$
Differential of arms : $L_- = L_x - L_y$
Power recycling cavity : $l_+ = (l_x + l_y) / 2$
Michelson : $l_- = l_x - l_y$
Signal recycling cavity : $l_s = (l_{sx} + l_{sy}) / 2$

Disturbance by sidebands of sidebands

Original concept



Real world

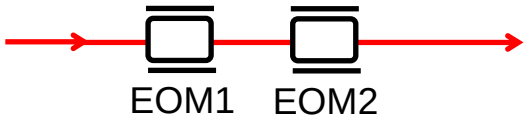


- Sidebands of sidebands are produced by two series EOMs.
- Beats between carrier and f_2 +/- f_1 disturb central part.

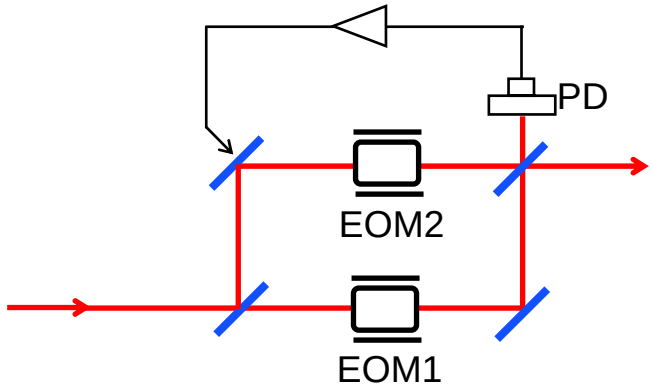
Port	Dem. Freq.	L_+	L_-	I_+	I_-	I_s
SP	f_1	1	-1.4E-8	-1.2E-3	-1.3E-6	-6.2E-6
AP	f_2	1.2E-7	1	1.4E-5	1.3E-3	6.5E-6
SP	$f_1 \times f_2$	7.4	-3.4E-4	1	-3.3E-2	-1.1E-1
AP	$f_1 \times f_2$	-5.7E-4	32	7.1E-1	1	7.1E-2
PO	$f_1 \times f_2$	3.3	1.7	1.9E-1	-3.5E-2	1

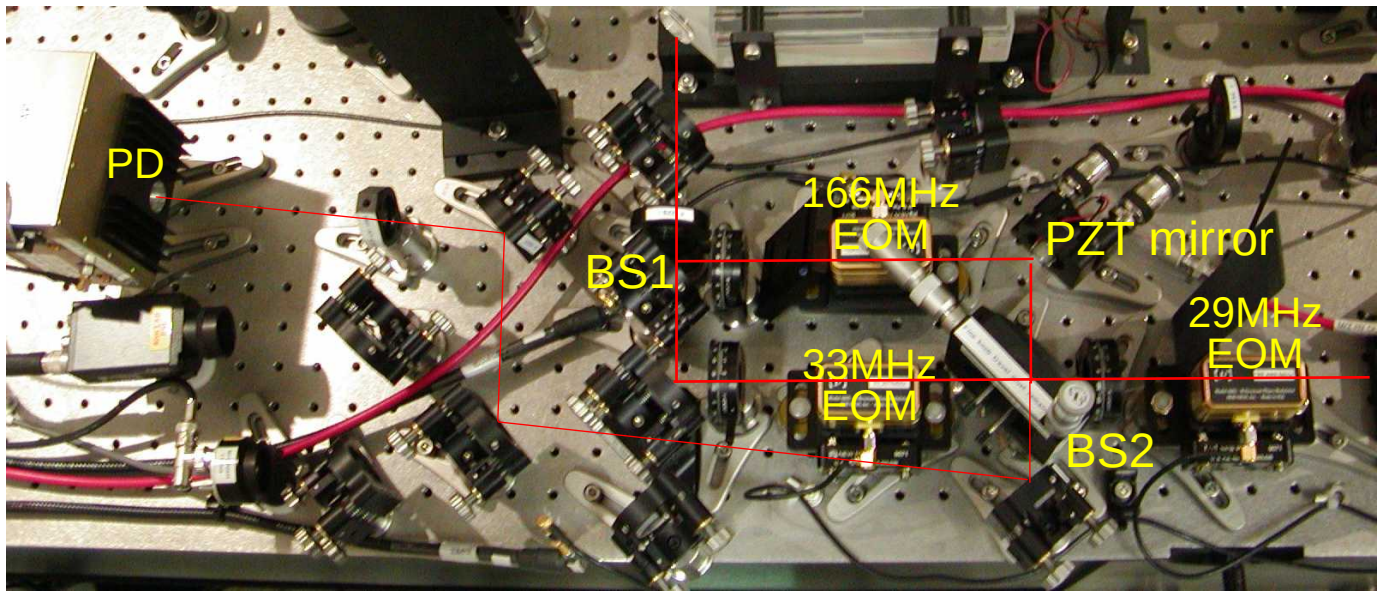
Mach-Zehnder on 40m PSL to eliminate sidebands of sidebands

Series EOMs
with sidebands of sidebands



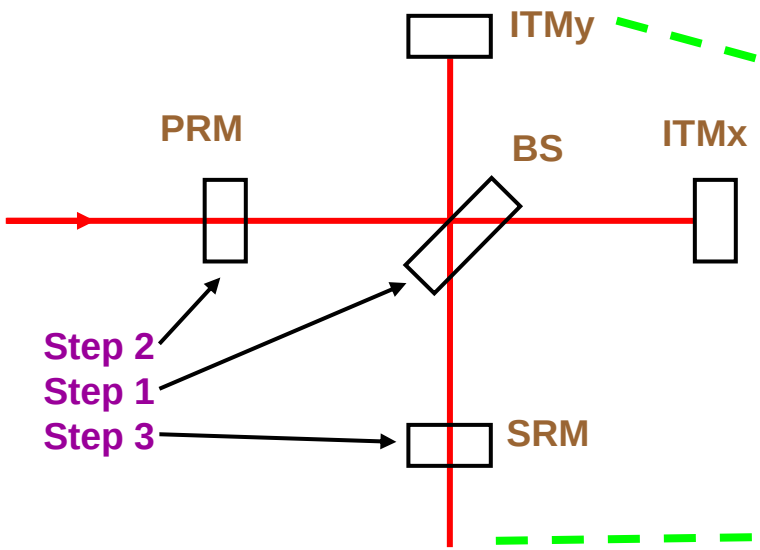
Mach-Zehnder interferometer
no sidebands of sidebands from beginning



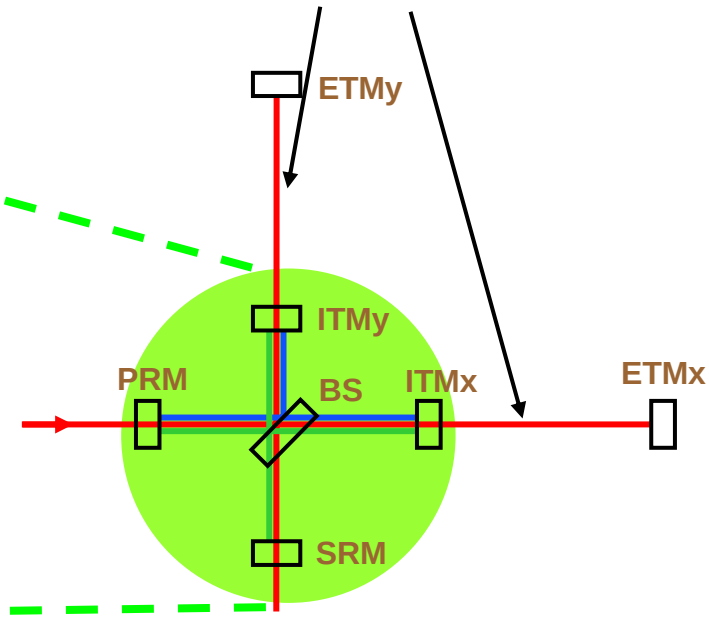


Lock Acquisition of Detuned RSE

1. lock central part using beat signal between f_1 and f_2



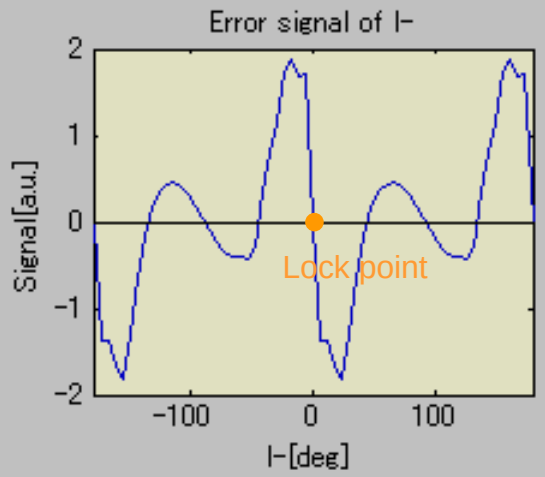
2. lock arm cavities

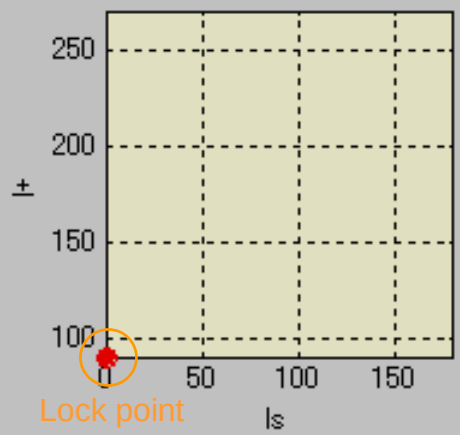


- Central part: not disturbed by lock status change of arm cavity
- Find primary signal not disturbed by the other two DOFs
- Find secondary signal not disturbed by the residual DOF

- Arm cavities: not disturbed by locked central part
- Lock each arm cavity independently
- Switch control servo to common/differential control

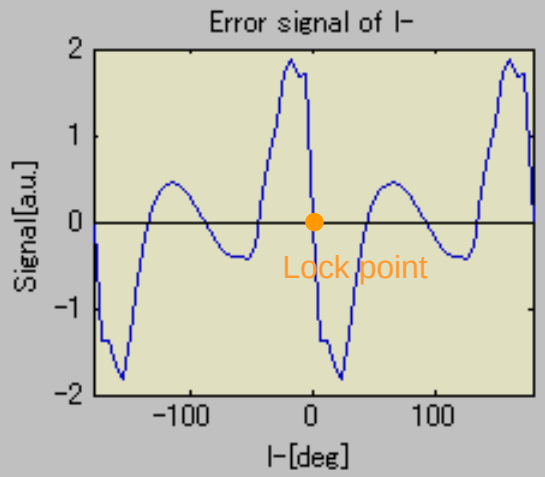
I_- signal with double demodulation

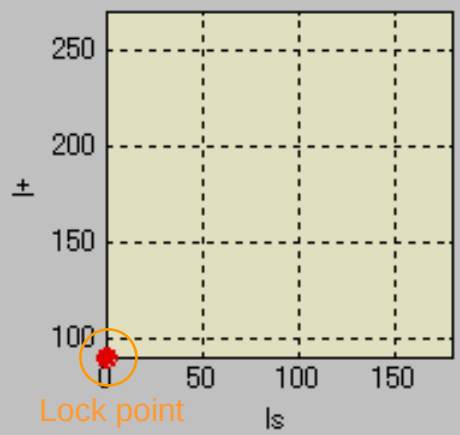




- Good I_- signal when I_+ and I_s is locked
- No good I_- signal once I_+ and I_s start moving

I_- signal with double demodulation



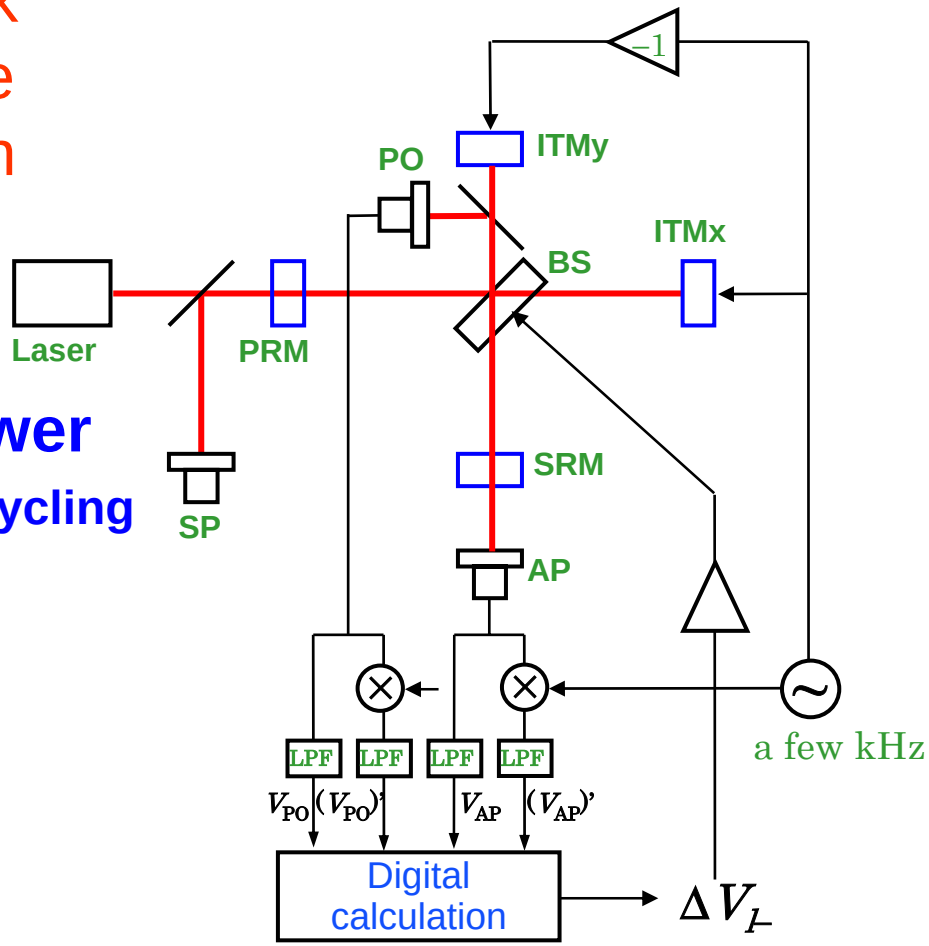


- Good I_- signal when I_+ and I_s is locked
- No good I_- signal once I_+ and I_s start moving

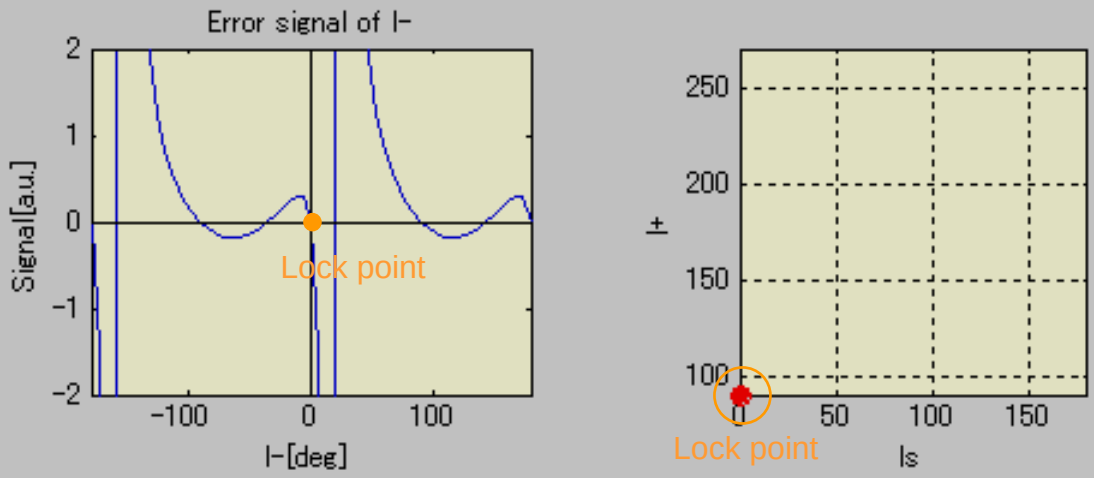
Looking for good signal for lock acquisition

- Unfortunately, no way to lock central part directly using the original double demodulation
- **Dither locking for l_- signal**
- **Divide signal by inside power**
  - » **Good cancellation of power recycling**

$$\Delta V_{l-} = \frac{d}{d\, l_-}\left(\frac{V_{\mathrm{AP}}}{V_{\mathrm{PO}}}\right) = \frac{V'_{\mathrm{AP}}\, V_{\mathrm{PO}} - V_{\mathrm{AP}}\, V'_{\mathrm{PO}}}{V_{\mathrm{PO}}{}^2}$$



l_- signal with dither

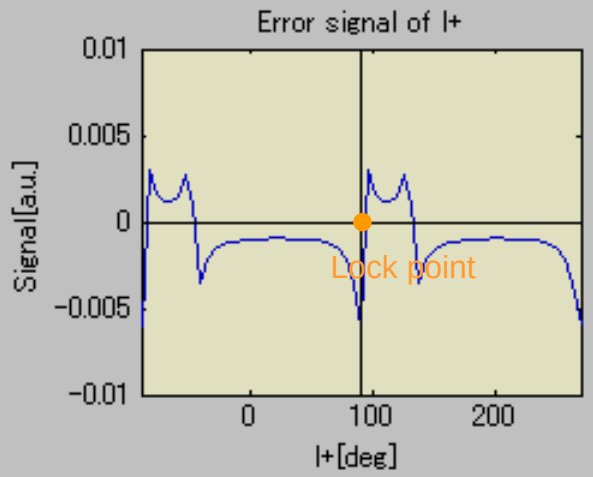


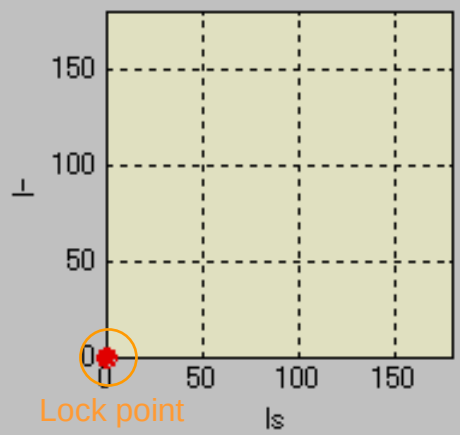
- Dither on ITMx, ITMy with 1kHz
- Error signal is calculated digitally as follows;

$$\Delta V_{l-} = \frac{d}{d\, l_-}\left(\frac{V_{\mathrm{AP}}}{V_{\mathrm{PO}}}\right) = \frac{V'_{\mathrm{AP}}\, V_{\mathrm{PO}} - V_{\mathrm{AP}}\, V'_{\mathrm{PO}}}{V_{\mathrm{PO}}{}^2}$$

- l_- signal does not depend on l_+ at all
- Good l_- signal obtained with all l_s movement

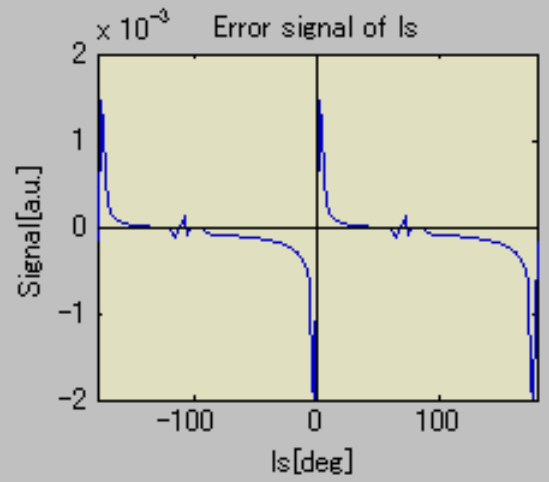
I_+ signal with I_- lock

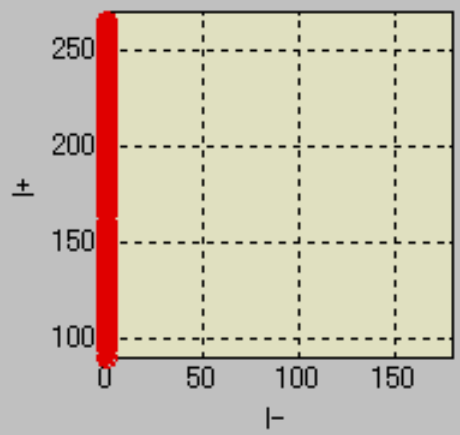




- Zero crossing point of I_+ corresponds with movement of I_s
- Distance between PRM and SRM is kept
- Good I_+ signal obtained with all I_s movement

l_s signal with l_- and l_+ lock





- Good l_s signal can be extracted

Summary

- Optical configuration for AdvLIGO being developed at 40m prototype interferometer
- Sidebands of sidebands: eliminated by M-Z interferometer
- Ready to try lock acquisition
- Lock acquisition: promising with dither lock

Hope we succeed in locking detuned RSE very soon!