Sensing and Control of an Interferometer Gravitational Wave Detector TAMA300

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National Astronomical Observatory of Japan

TAMA300: Interferometer GW detector

- TAMA300:

  A 300-m Power-recycled Fabry-Perot Michelson Interferometer
  Site: National Astronomical Observatory of Japan
  (Mitaka, Tokyo)

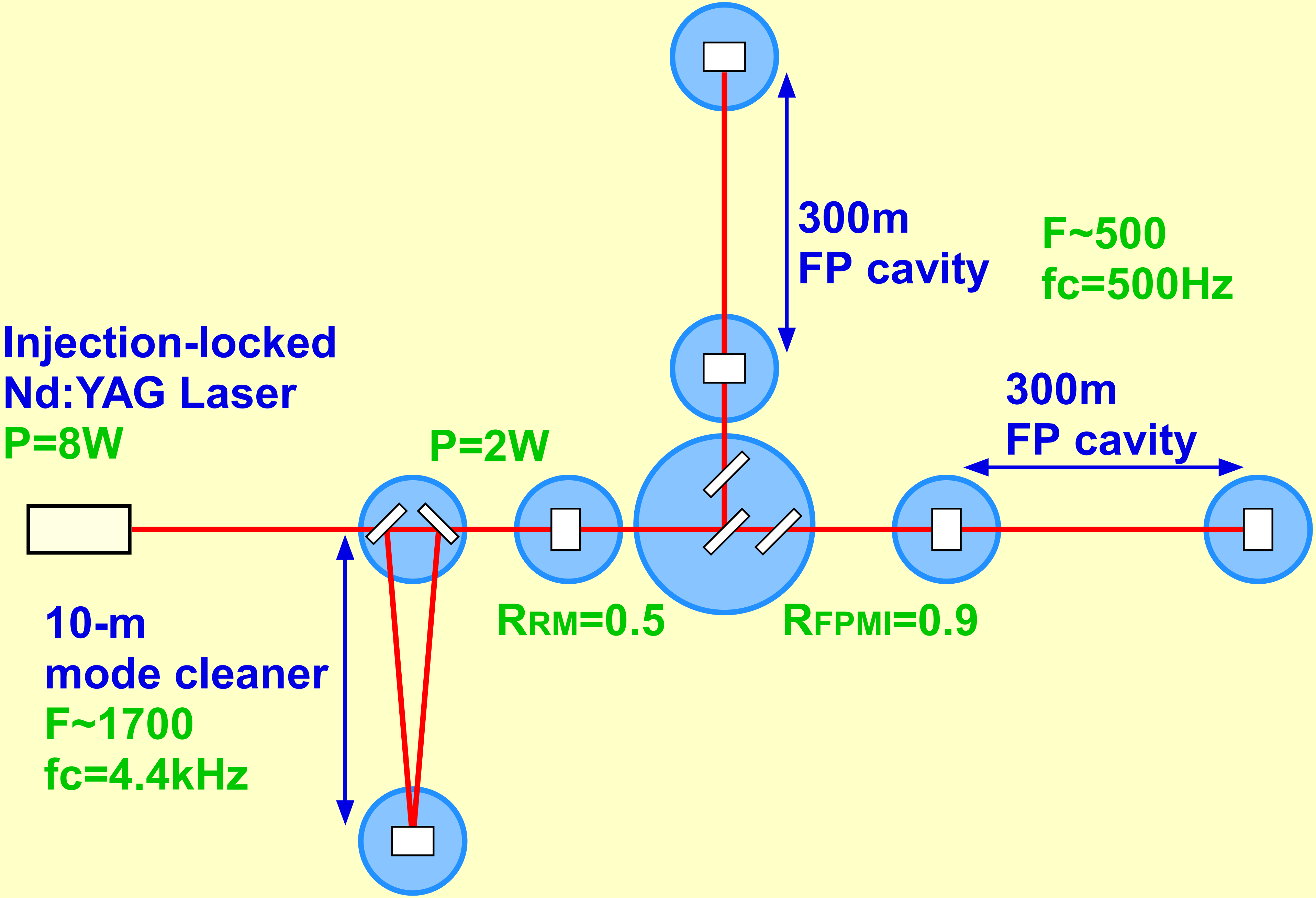
- Operation of TAMA300

  Fabry-Perot Michelson: 1999~2001
  Power Recycling: 2001~Present

- This talk

  Length sensing and control
  Lock acquisition
  Alignment control

Optical configuration of TAMA300



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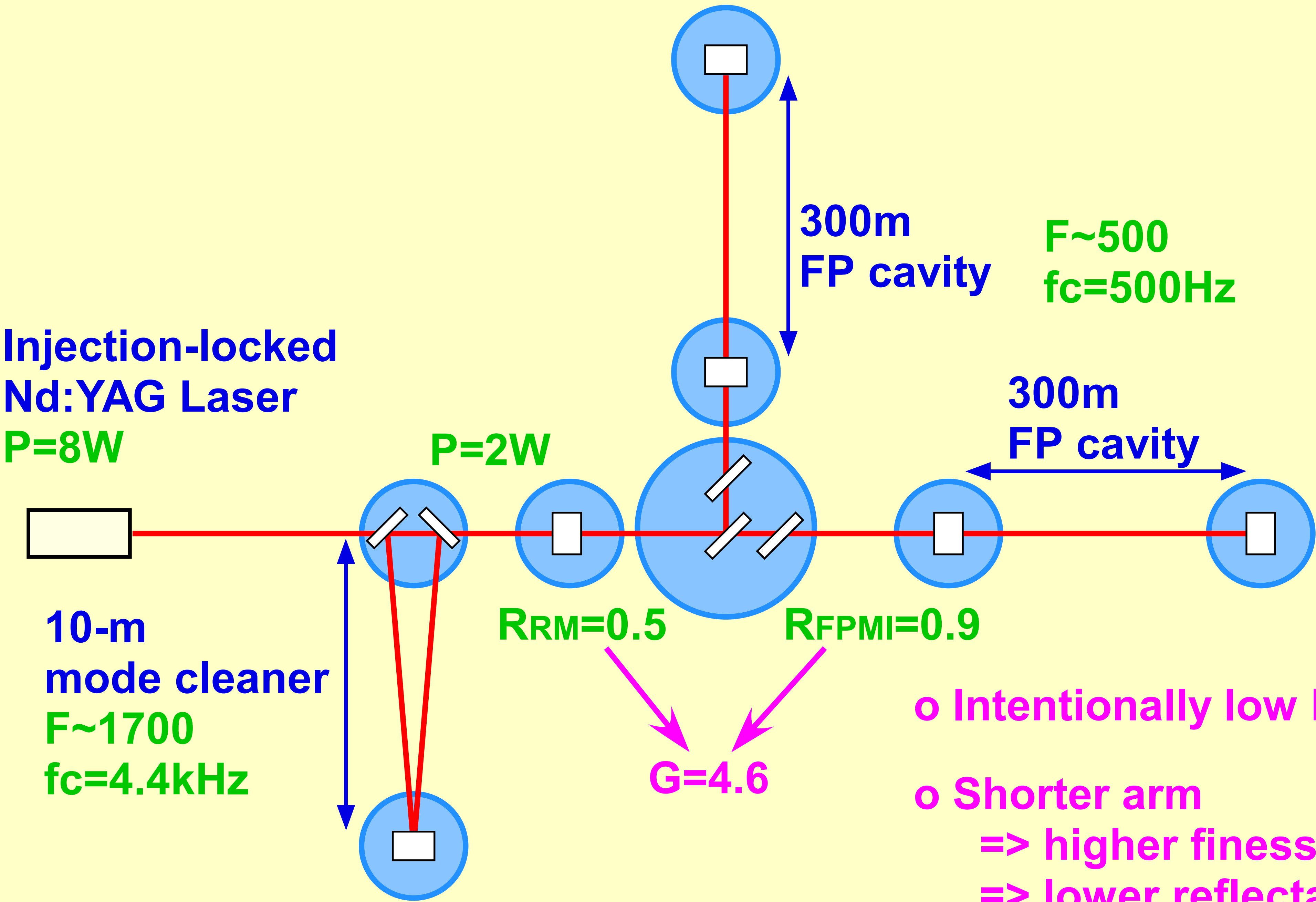


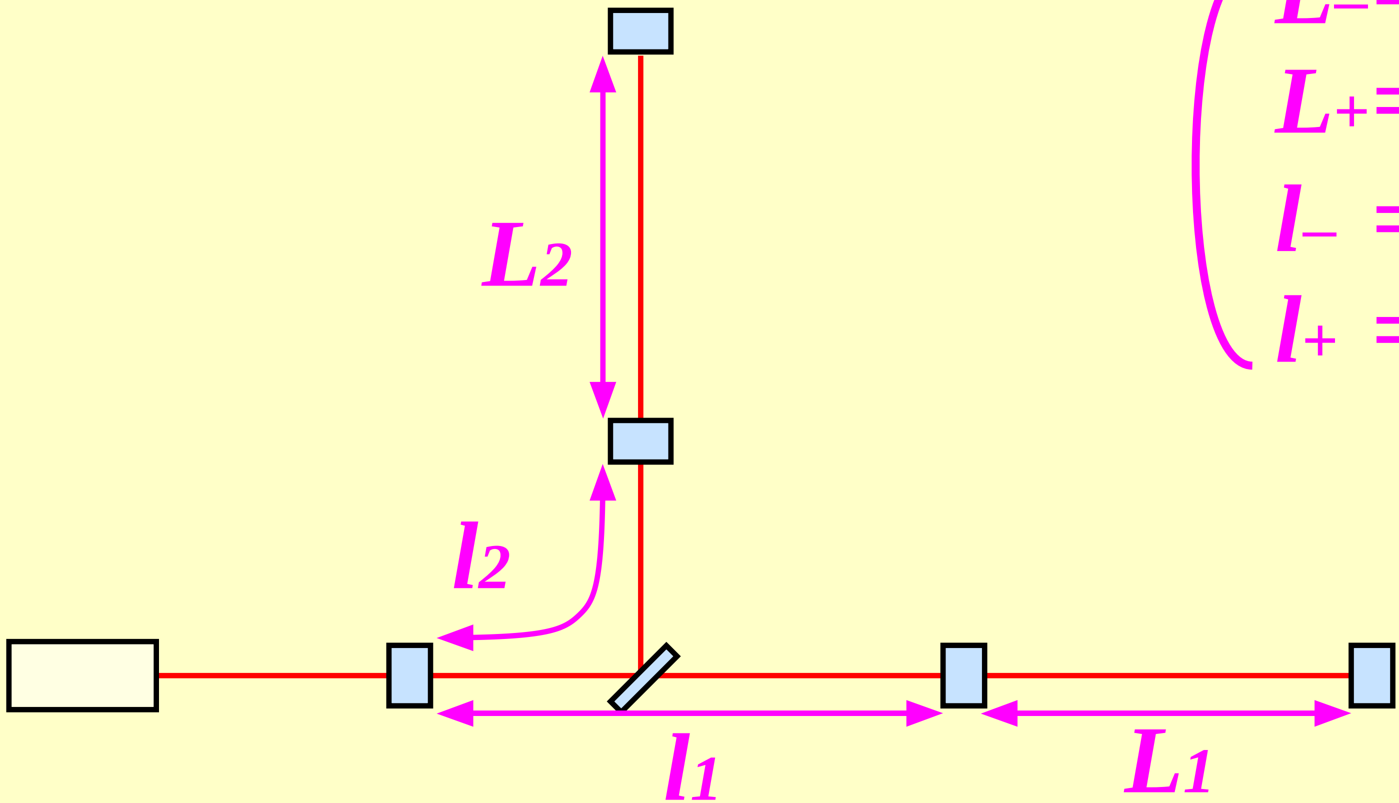
- Intentionally low R_{RM}
- Shorter arm
  - => higher finesse
  - => lower reflectance

Length sensing and control

- Recycled Fabry-Perot Michelson Interferometer

  4 longitudinal d.o.f. to be controlled

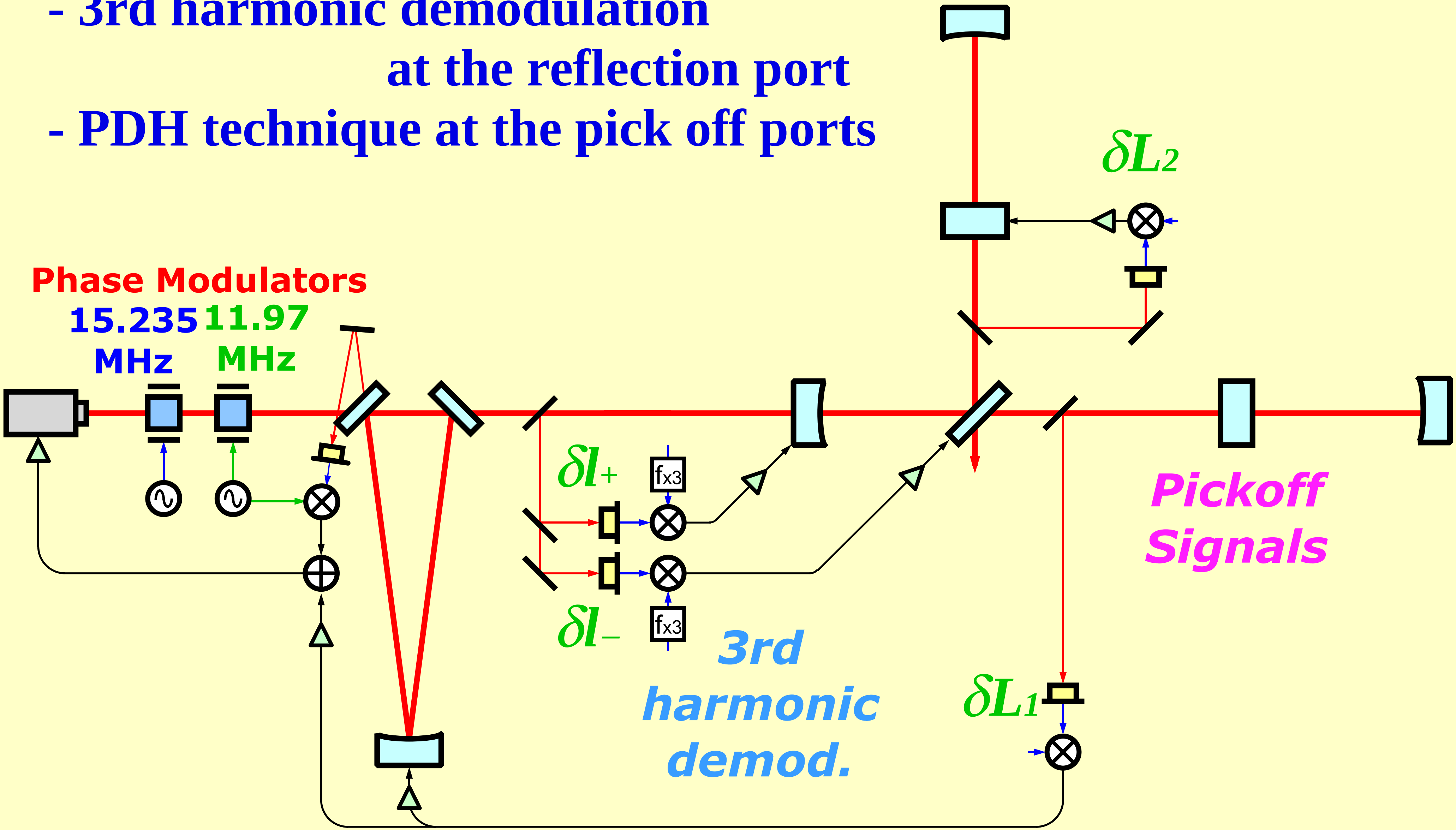
  ~ The optical cavities and the Michelson interferometer must be on the operating point



$$
\begin{cases}
L_- = L_2 - L_1 \\
L_+ = L_2 + L_1 \\
l_- = l_2 - l_1 \\
l_+ = l_2 + l_1
\end{cases}
$$

Length sensing and control ~ for lock acquisition

- Based on the PDH technique and Schunupp modulation
  - single phase modulation at 15MHz
  - 3rd harmonic demodulation at the reflection port
  - PDH technique at the pick off ports



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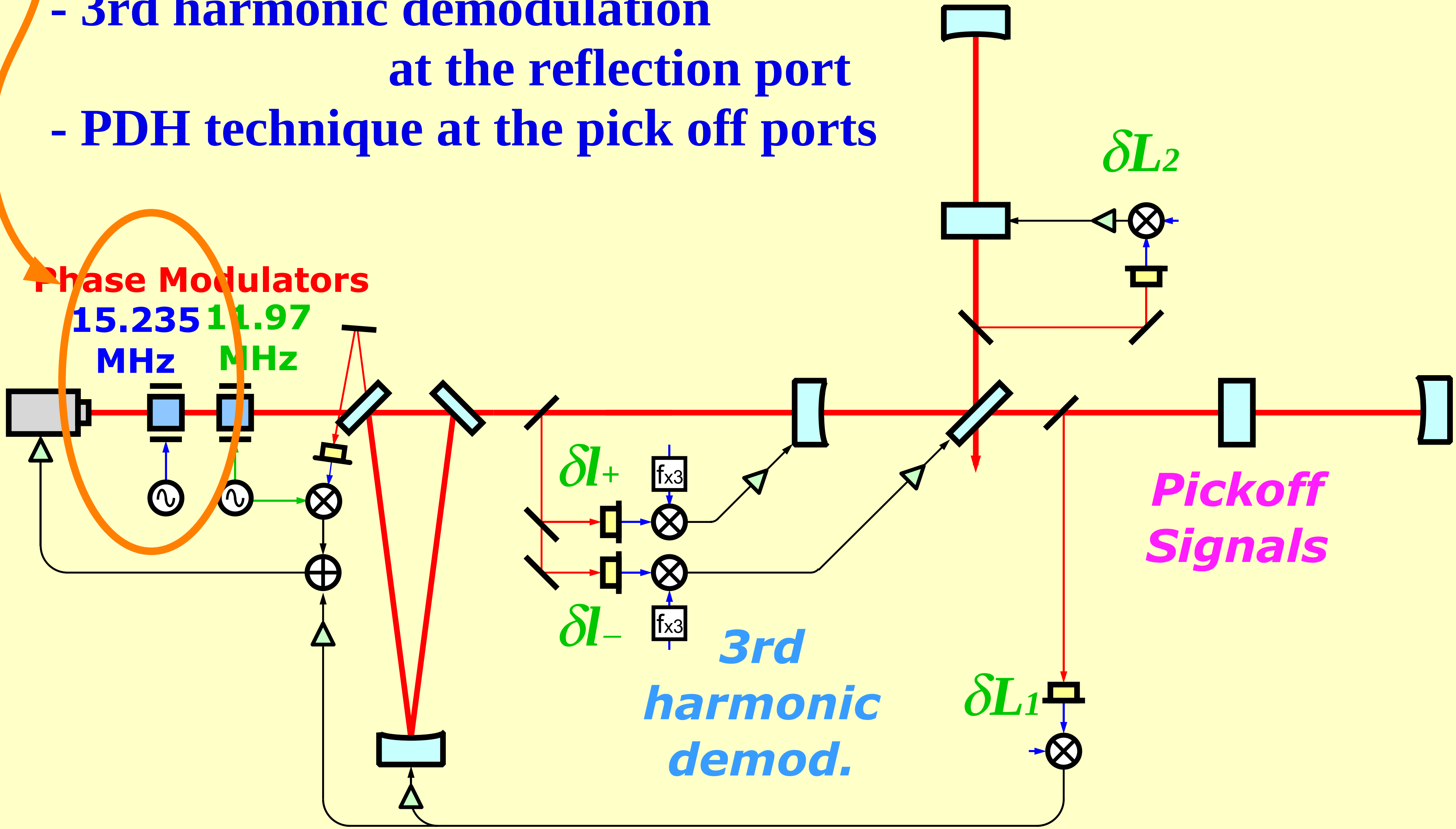

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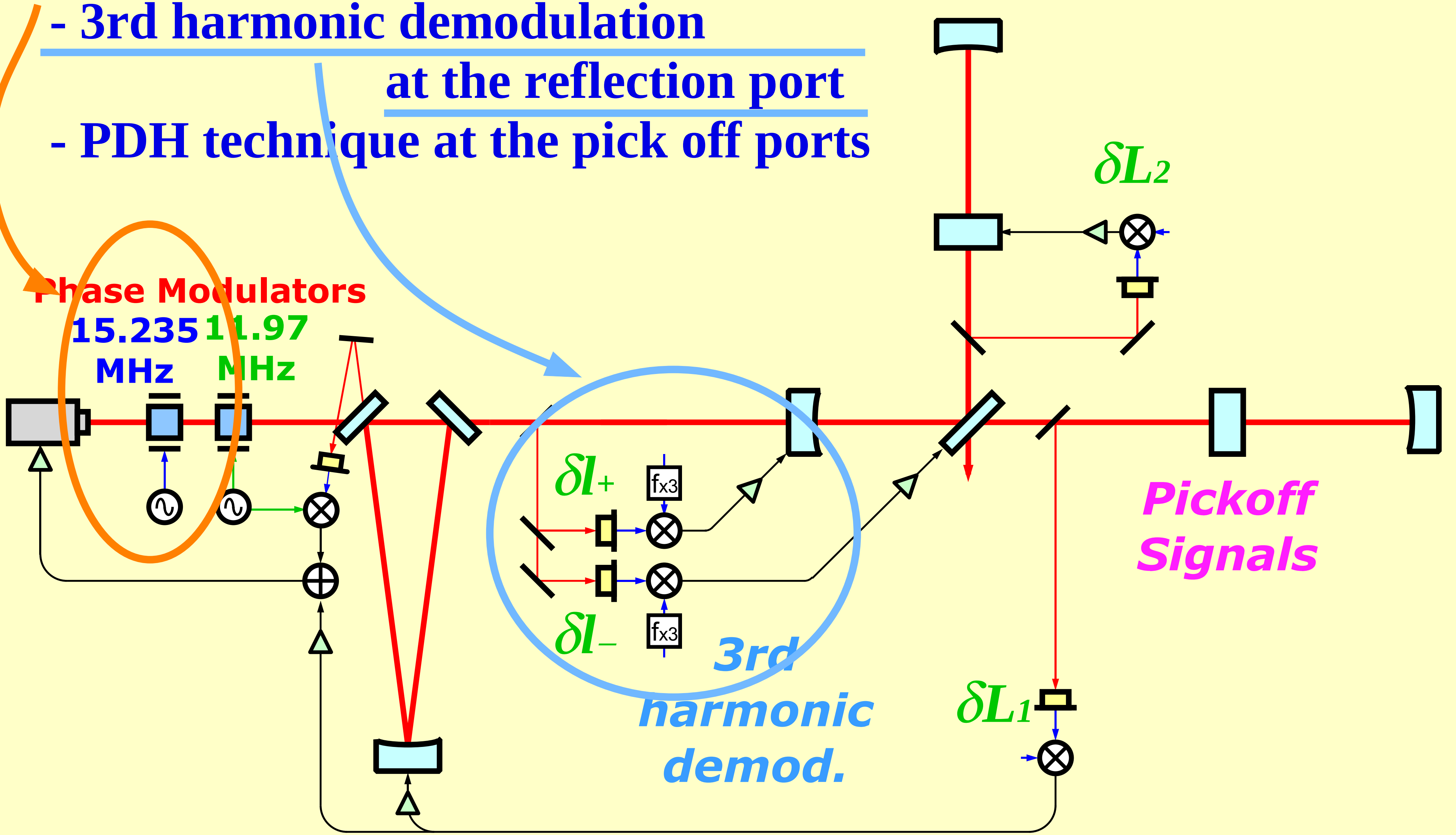

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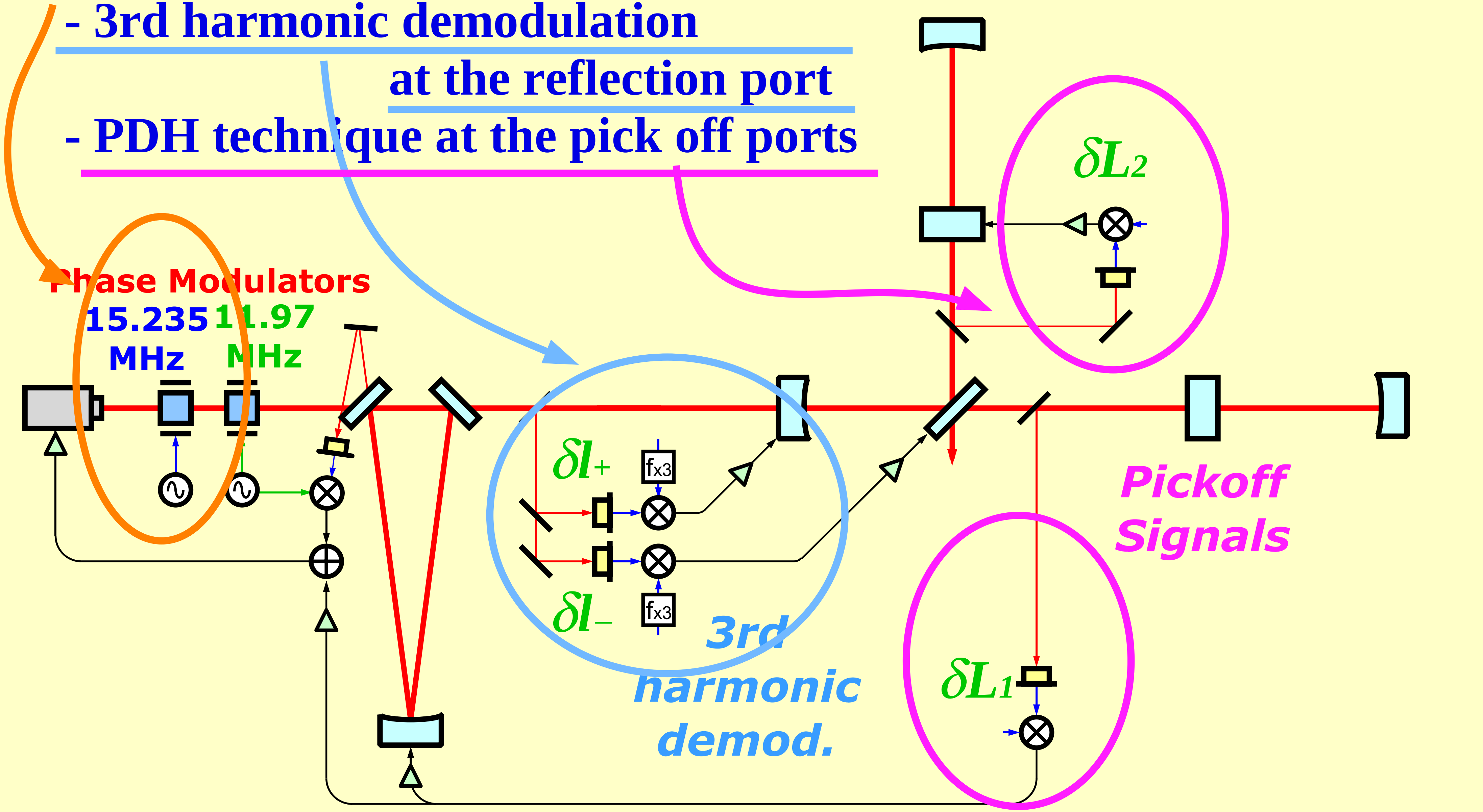
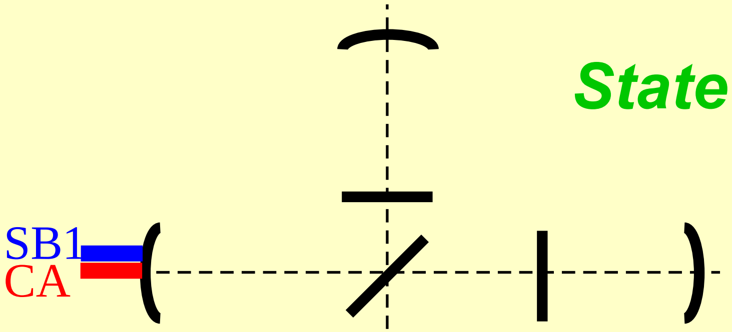


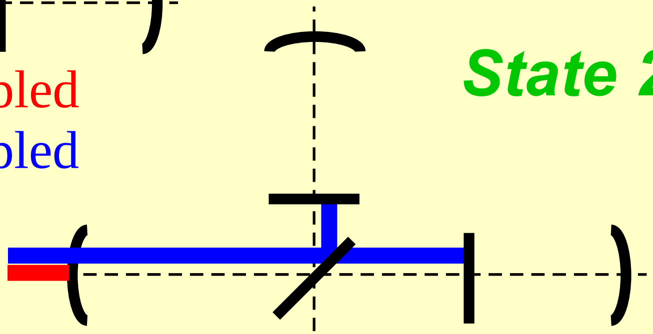
Lock acquisition

State 1



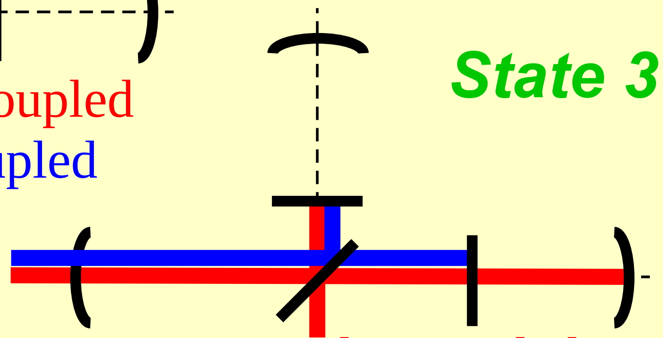
CA G0=0, under-coupled
SB1 G1=0, under-coupled

State 2



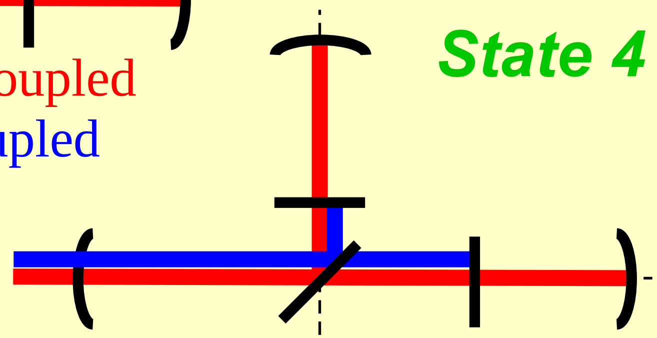
CA G0=0.18, under-coupled
SB1 G1=4.4, over-coupled

State 3



CA G0=0.51, under-coupled
SB1 G1=4.4, over-coupled

State 4



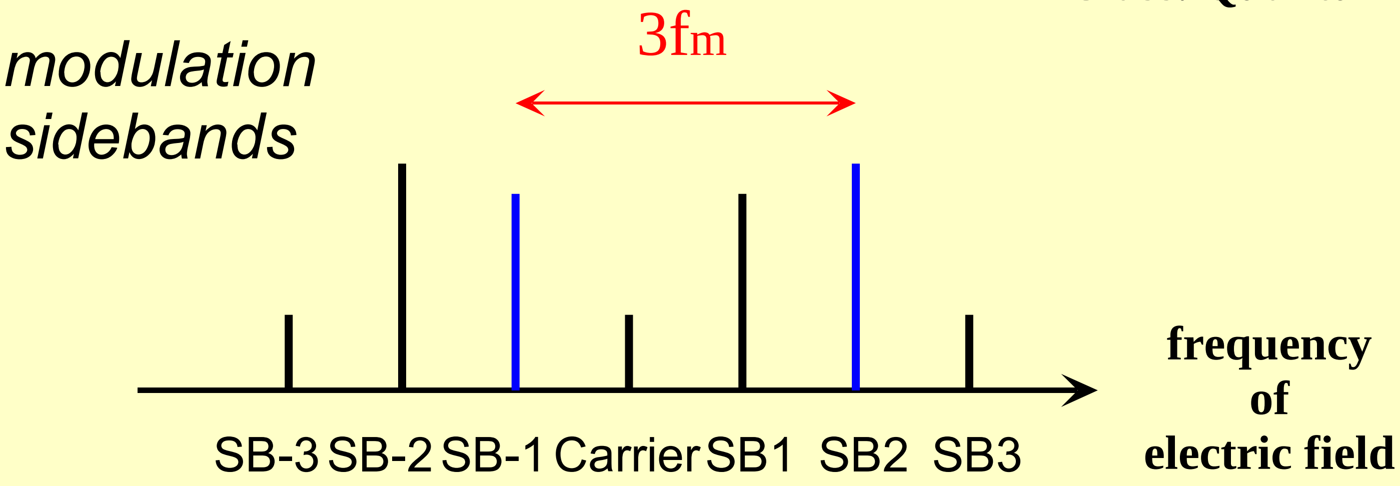
CA G0=4.6, over-coupled
SB1 G1=4.4, over-coupled

Drastic increase of the internal power
Change of the couplings to the IFO
=> change in optical gains and signal sign

3rd harmonic demodulation

- Photocurrent at the $3f_m$
  ~ beating of SB2 and SB-1

K. Arai, et al,
Phys. Lett. A 273 (2000) 15
K. Arai, et al,
Class. Quantum Grav. 19 (2002) 1843



- Effect of SB2s are emphasized at the reflection port

Signal with fm demod. and 3fm demod. ~ order of m and m^3

SB2s are not resonant => reflectance is ~1

CA, SB1s, and SB3s are resonant => reflectance can be low

3rd harmonic demodulation

- Merit of 3fm demod

  ~ robust extraction of δl_+ and δl_-

Contribution of carrier audio-sidebands (~ δL_+)

=> Reduced

Amplitudes of the δl_+ and δl_- signals

=> Less dependent on the couplings of CA and SB1

=> Less variation during lock acquisition

Signs of the signals

=> Independent from the optical parameters

=> Invariant during lock acquisition

Extracted signal (calculation)

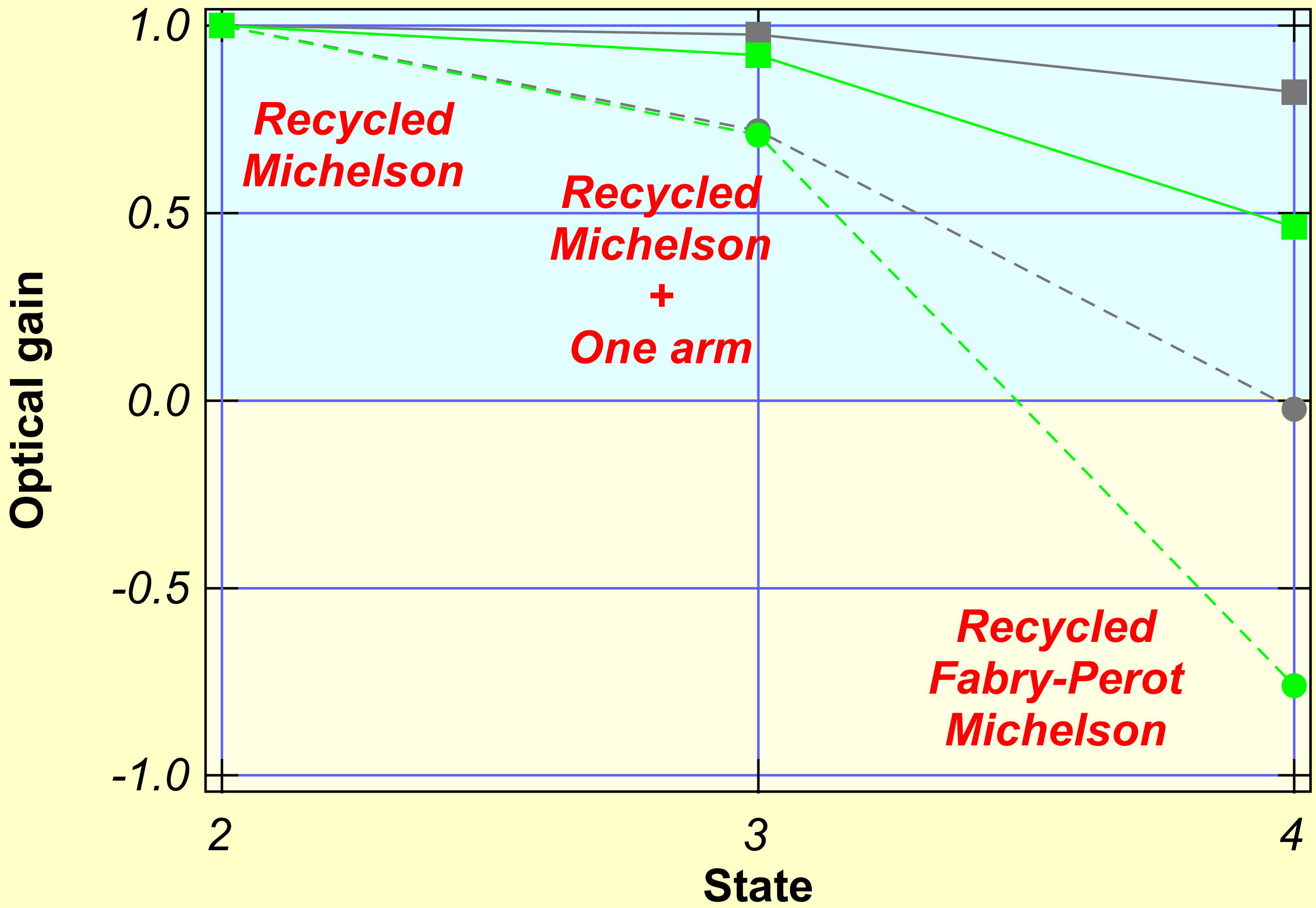
●Well-diagnalized signals

Port	Demod	Phase	L-	L+	l-	l+
Dark	fm	Q	1	3.0e-4	3.0e-3	1.0e-6
Bright	fm	I	1.5e-4	1	6.1e-6	8.4e-5
Bright	3fm	Q	1.0e-2	2.3e-2	1	3.6e-2
Bright	fm	Q	1.5e-2	6.2e-1	1	1.6e-3
Bright	3fm	I	1.5e-4	6.5e-2	1.2e-3	1

●Shot noise limit

Port	Demod	Phase		Shotnoise level (m/Hz$^{1/2}$)	
Dark	fm	Q	L-	1.2×10^{-19}	$=4.0 \times 10^{-22}$ 1/Hz$^{-1/2}$
Pick-off	fm	I	L+	1.6×10^{-19}	$=1.5 \times 10^{-7}$ Hz/Hz$^{-1/2}$
Bright	3fm	Q	l-	1.4×10^{-14}	for lock
Bright	fm	Q	l-	2.0×10^{-16}	for operation
Bright	3fm	I	l+	2.8×10^{-15}	

Gain variation / Sign flip (Recycling1)



3fm signals

dl+ x 0.82

dl- x 0.46

fm signals

dl+ x –0.023

dl- x –0.76

No sign flip and less gain changes with 3fm signals

~ no need of adaptive servo system (variable gain adj., dynamic sign change)

Length sensing and control ~ for lock acquisition

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  - **- single phase modulation at 15MHz**
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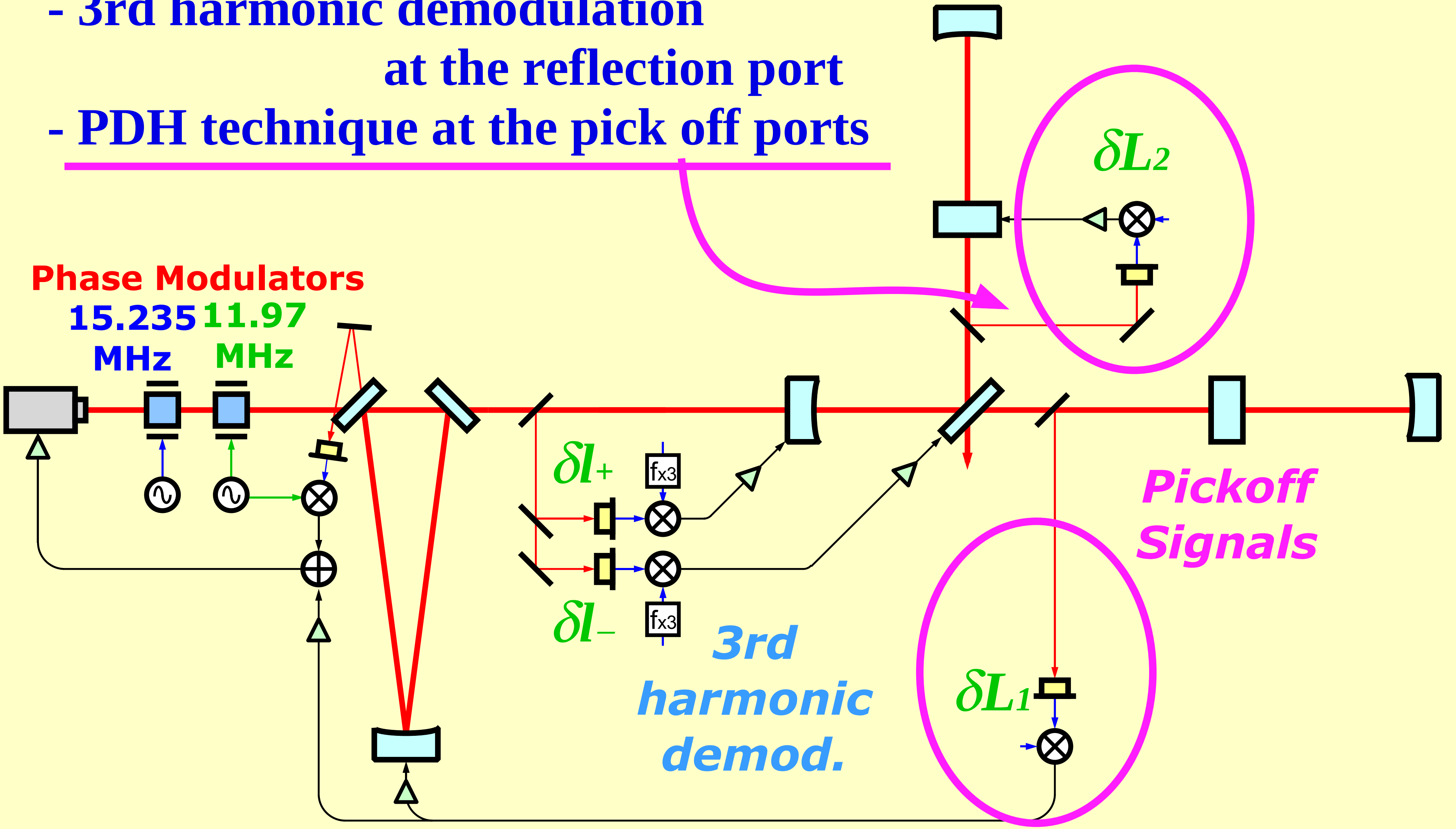


Mixing of arm Pound-Drever-Hall signals

- Power Recycling

~ Arm length signals are mixed

Power recycling gain of 4.5

$$\begin{pmatrix} \mathbf{Vpo1} \\ \mathbf{Vpo2} \end{pmatrix} = \begin{pmatrix} \mathbf{1} & \mathbf{0.5} \\ \mathbf{0.5} & \mathbf{1} \end{pmatrix} \begin{pmatrix} \mathbf{dL1} \\ \mathbf{dL2} \end{pmatrix}$$

~ still enough independent for lock acquisition

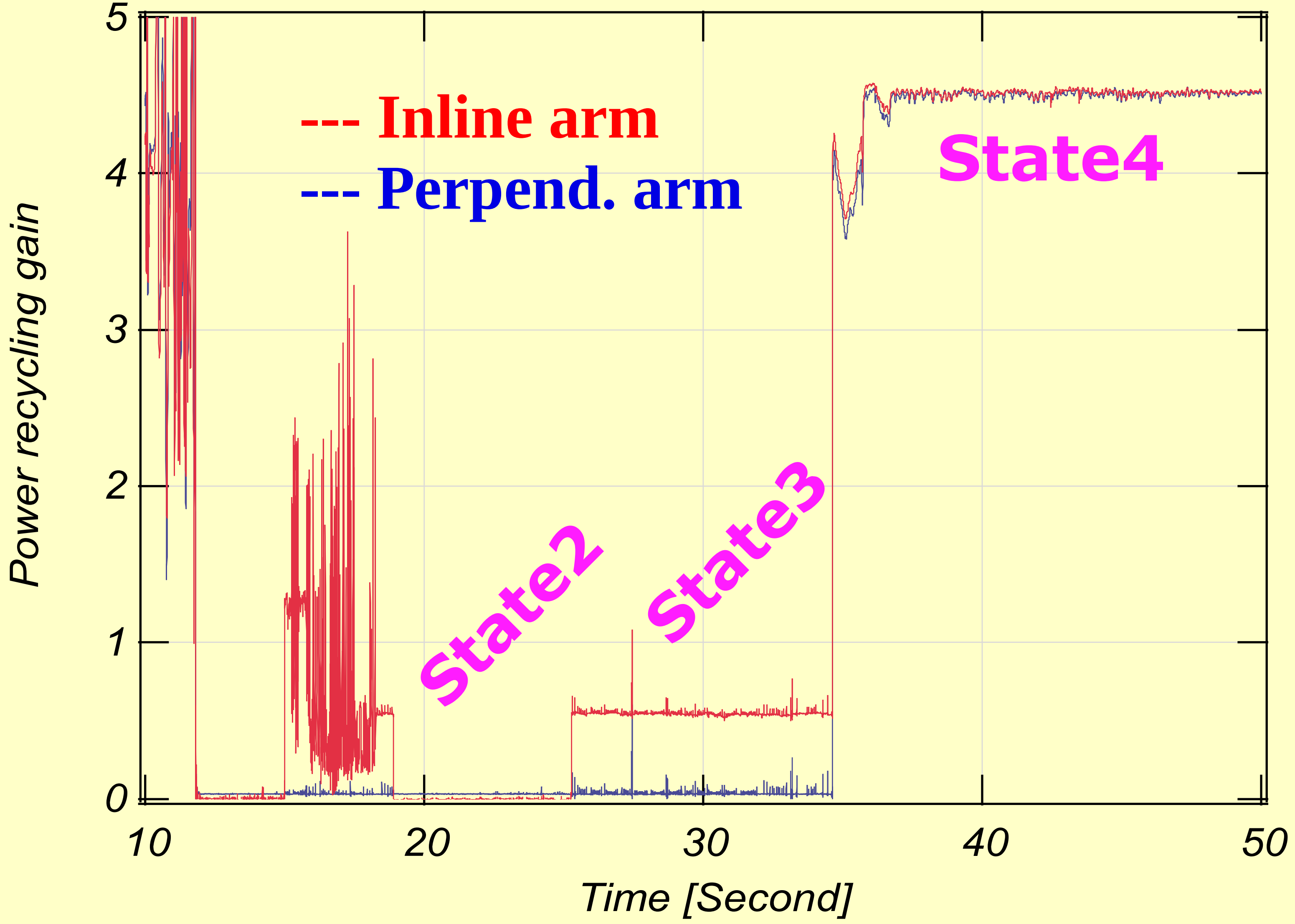
~ would be a problem with more recycling gain

G=10 => mixing of 0.85

Lock acquisition

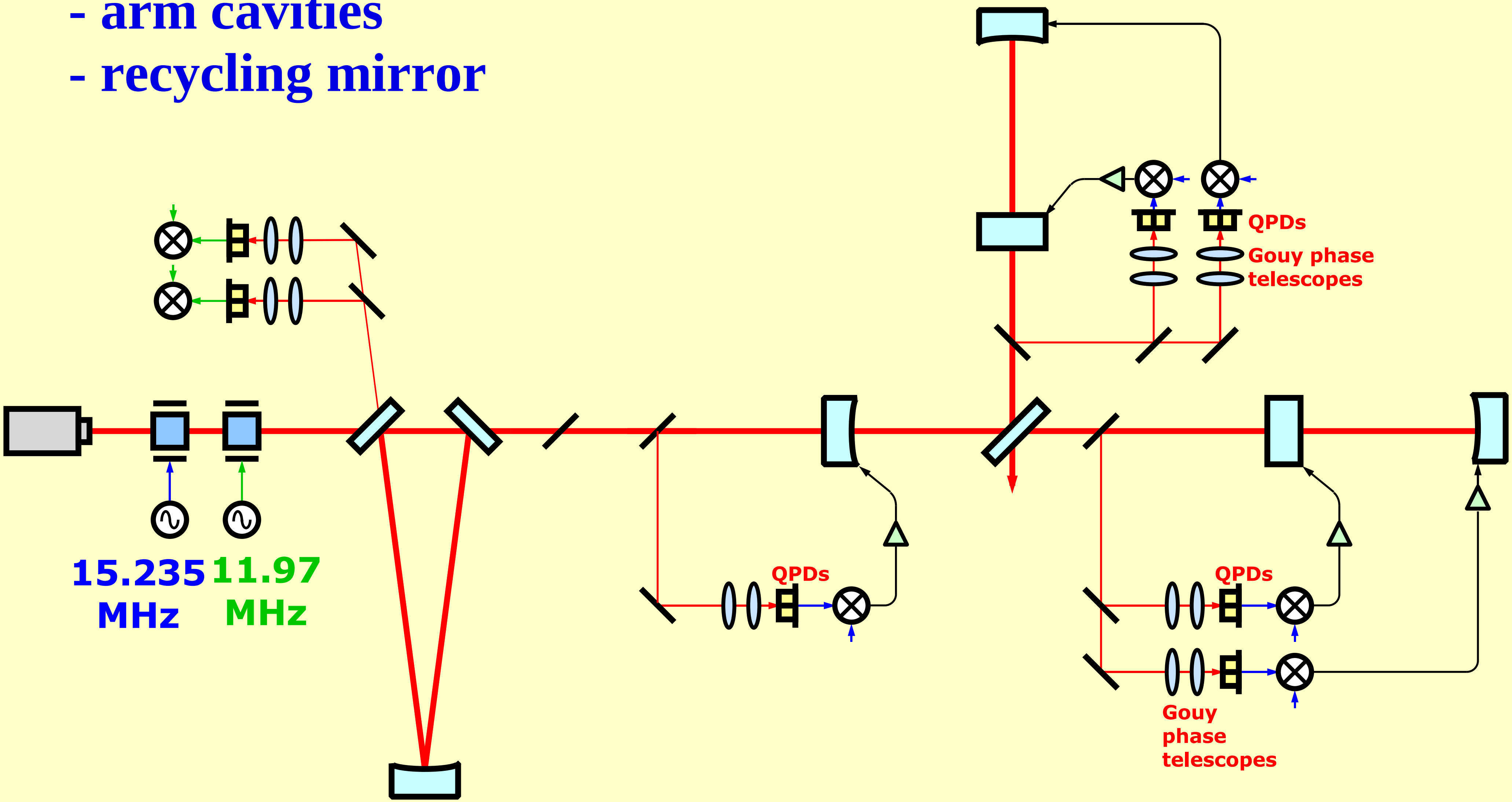
- Typically the lock is acquired within minutes

  ~ with good alignment



Alignment sensing and control

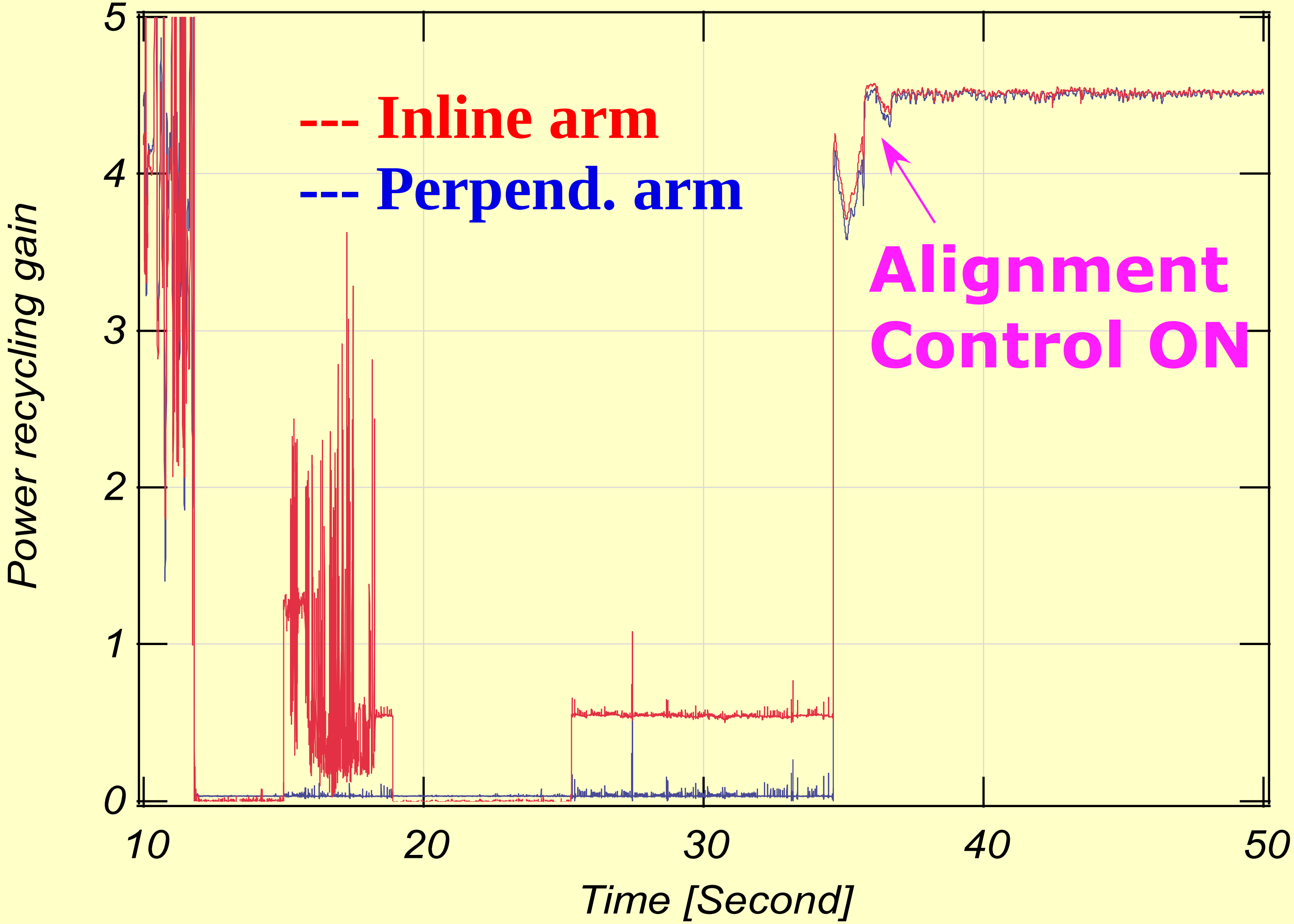
- Wave front sensing technique
  - mode cleaner cavity
  - arm cavities
  - recycling mirror



Lock acquisition

- Alignment control

for the arm, UGF: 5~10Hz, for the RM, UGF: ~10mHz



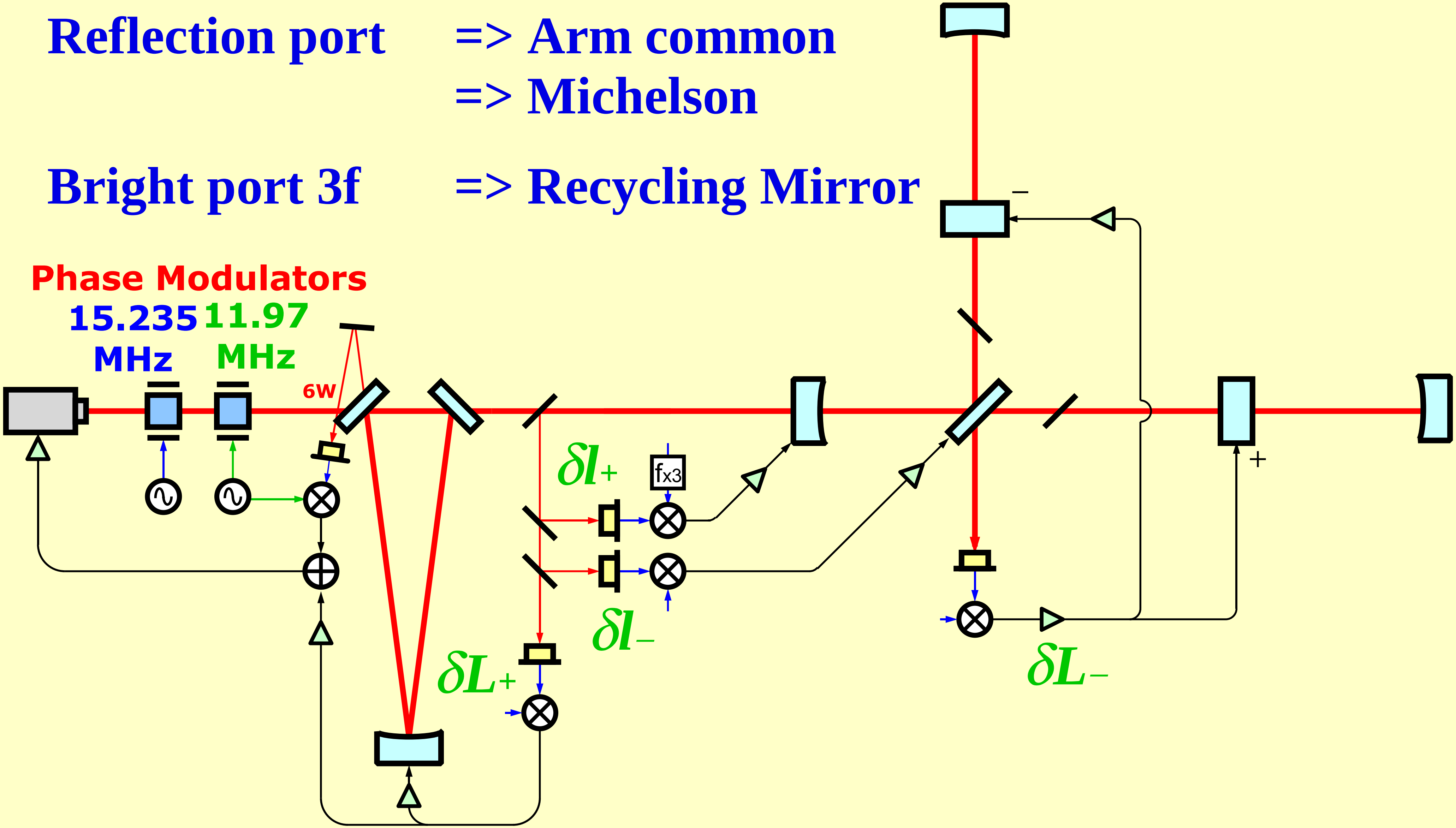
Length sensing and control ~ for low noise mode

- Common/differential separated control

Dark port => **Arm differential**

Reflection port => **Arm common**
=> **Michelson**

Bright port 3f => **Recycling Mirror**



Summary

- Length/Alignment sensing for TAMA300

- Based on the PDH technique and the Schnupp modulation

- Key features for lock acquisition:

3fm demodulation for dl+ and dl-

PO signals for the arms

- Alignment control

for the MC, the arms and the recycling mirror

- Switching to low noise control signals