New signal extraction scheme with harmonic demodulation for power-recycled Fabry-Perot Michelson interferometers

Koji Arai, Masaki Ando[A], Shigenori Moriwaki[B],
Keita Kawabe[A], and Kimio Tsubono[A]

National Astronomical Observatory

[A]Department of Physics, University of Tokyo

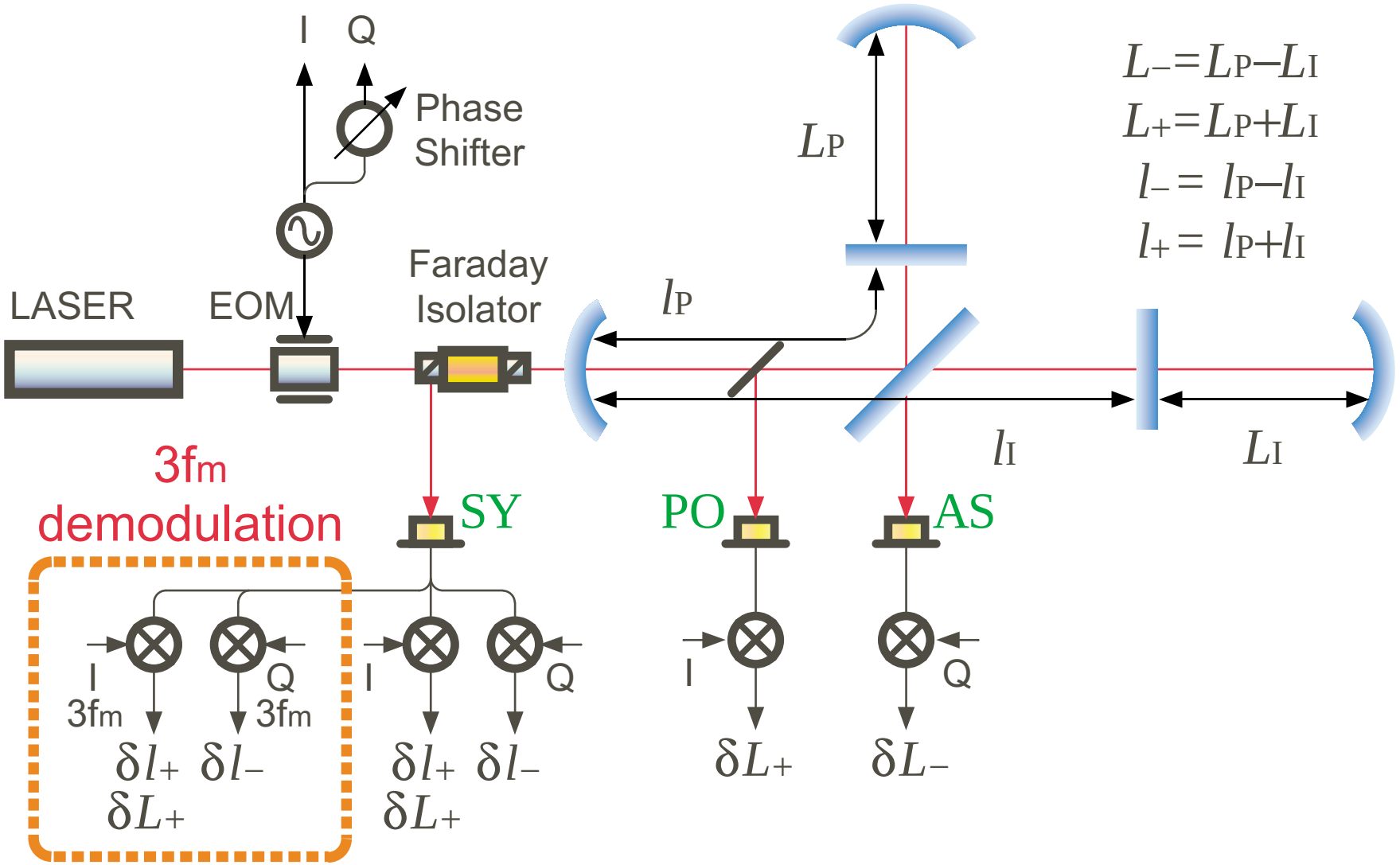
[B]Department of Advanced Materials Science, University of Tokyo

Introduction

- New scheme to extract control signals
  for power-recycled Fabry-Perot Michelson
  - **~ Based on frontal modulation**
  - **~ Demodulation at the 3rd harmonic frequency (3fm)**
  - **~ Control signals for RM and BS**
- Principle
  - **~ Beating of 1st and 2nd order modulation sidebands**
- Advantages
  - **~ Insensitivity to arm cavity motions**
  - **~ Robust extraction: amplitudes and signs of the signals**
    - **-- less dependent on the optical parameters**
- Experimental tests on the 3m suspended prototype

Harmonic Demodulation Scheme

Demodulating reflected light at the 3rd harmonic frequency



Problems of conventional scheme

- Difficulty in separating δl_+ from δL_+

  ~ because of the phase enhancement by the arm cavities

  ~ signal ports are ~100 times more sensitive to $\delta L+$ than to $\delta l+$

- The δl_+ and δl_- signals can disappear

  The $\delta l+$ signal vanishes when G0 = G1 .

  The $\delta l-$ signal vanishes when G0 is maximized.

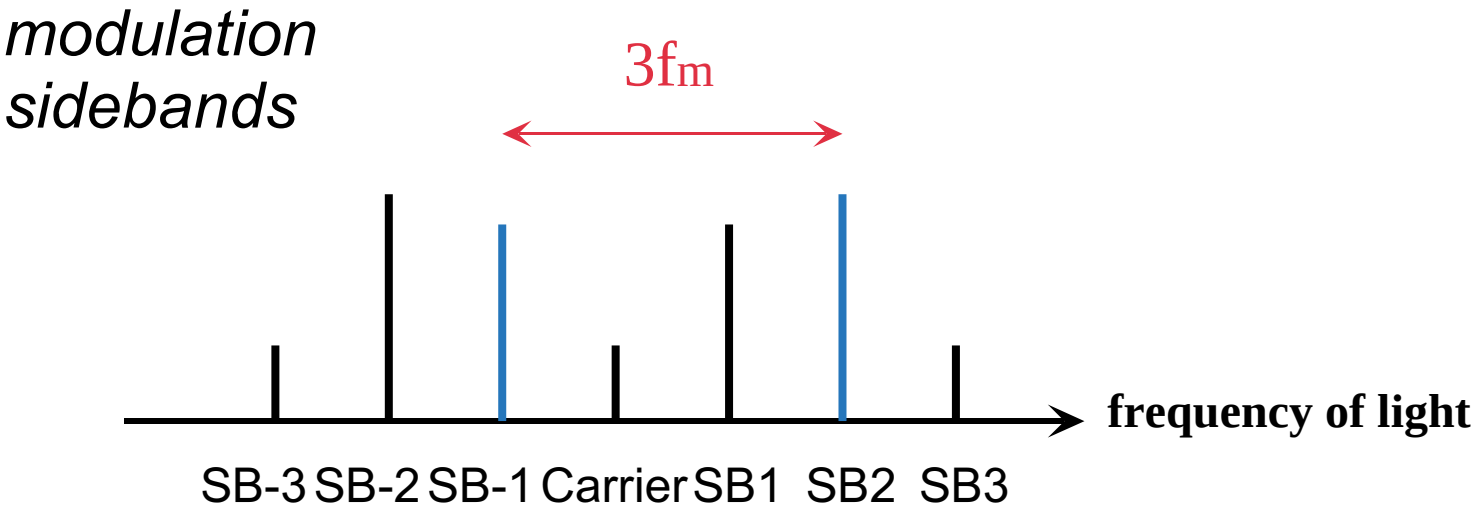
Recycling gain

G_0 : for the carrier

G_1 : for the 1st order sidebands

Principle

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



- SB2s are not resonant with the IFO

→ Effect of SB2

Emphasized at the reflection port

→ The amplitudes and the signs

Less dependent on the couplings of CA and SB1

Advantages

- Easy to implement

  ~ no addtional modulation

- Contribution of δL_+ is reduced

  ~ in comparison with the fm demodulation

- Robust extraction of δl_+ and δl-

  Amplitudes of the signals

  ~ less dependent on the optical parameters

  Signs of the signals

  ~ do not depend on the optical parameters

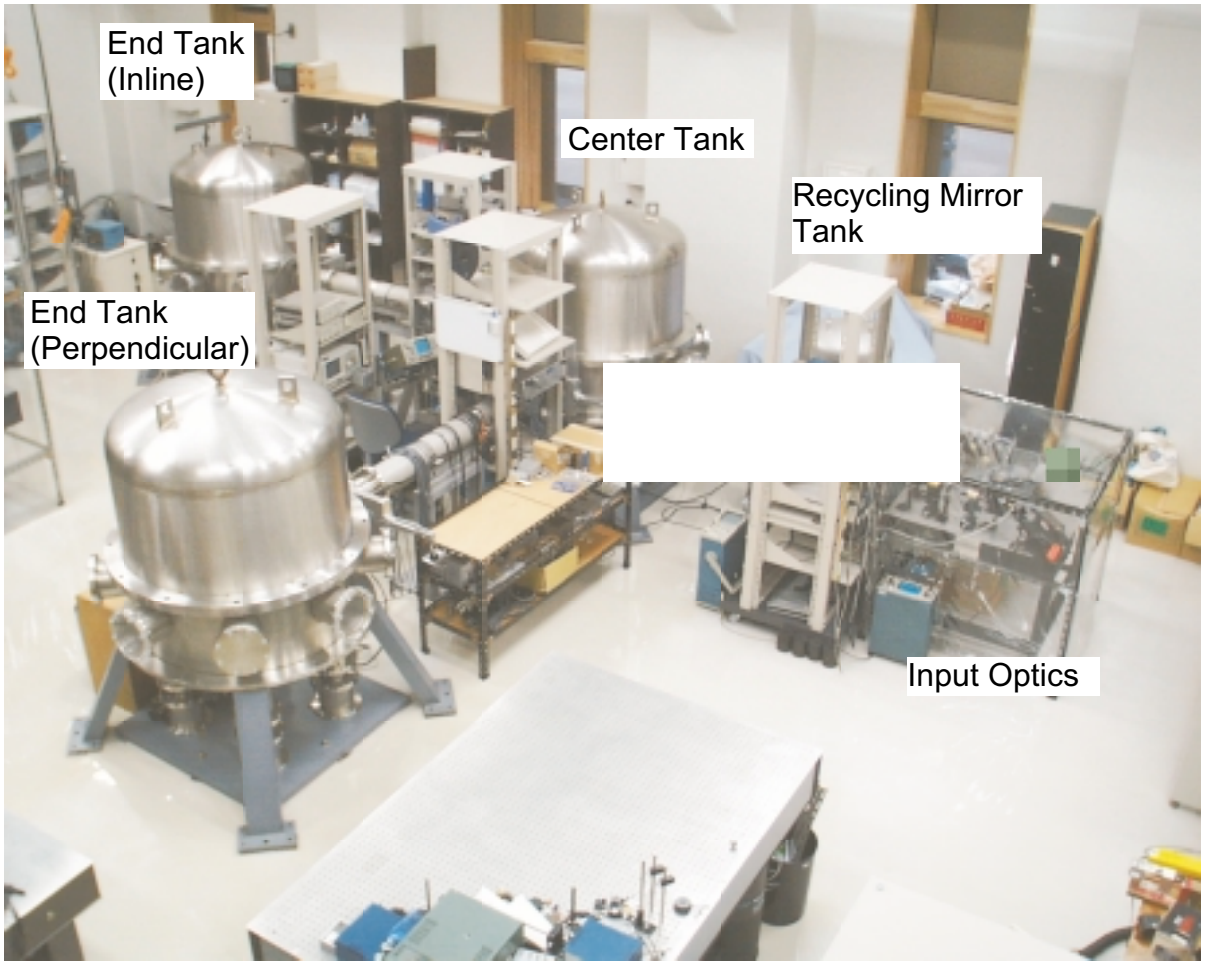
  ~ never change during lock acquisition

- Operating the IFO without the pick-off mirror

  ~ the δL_+ signal is extracted at the reflection port

Experimental tests on the 3m prototype

- 3m prototype power-recycled interferometer at University of Tokyo



Features

Suspended Mirrors

Double pendulums

Enclosed in chambers

Recycling Gain

~3.8 (R_R=0.63)

~5.4 (R_R=0.81)

Light source:

Nd:YAG

1064 nm, 42 mW

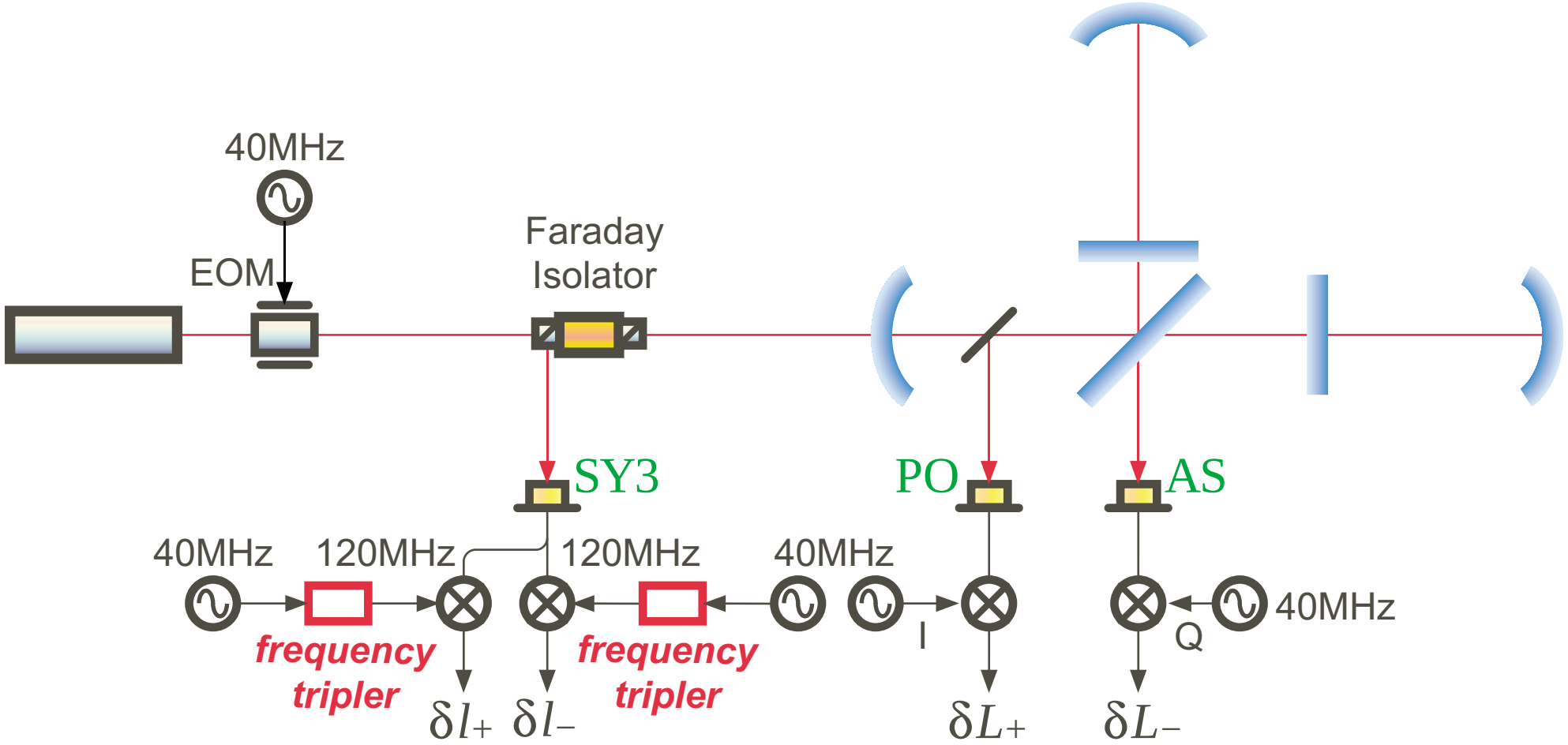
Arm length:

2.95 m

Arm finesse:

~240

Harmonic Demodulation for the 3m

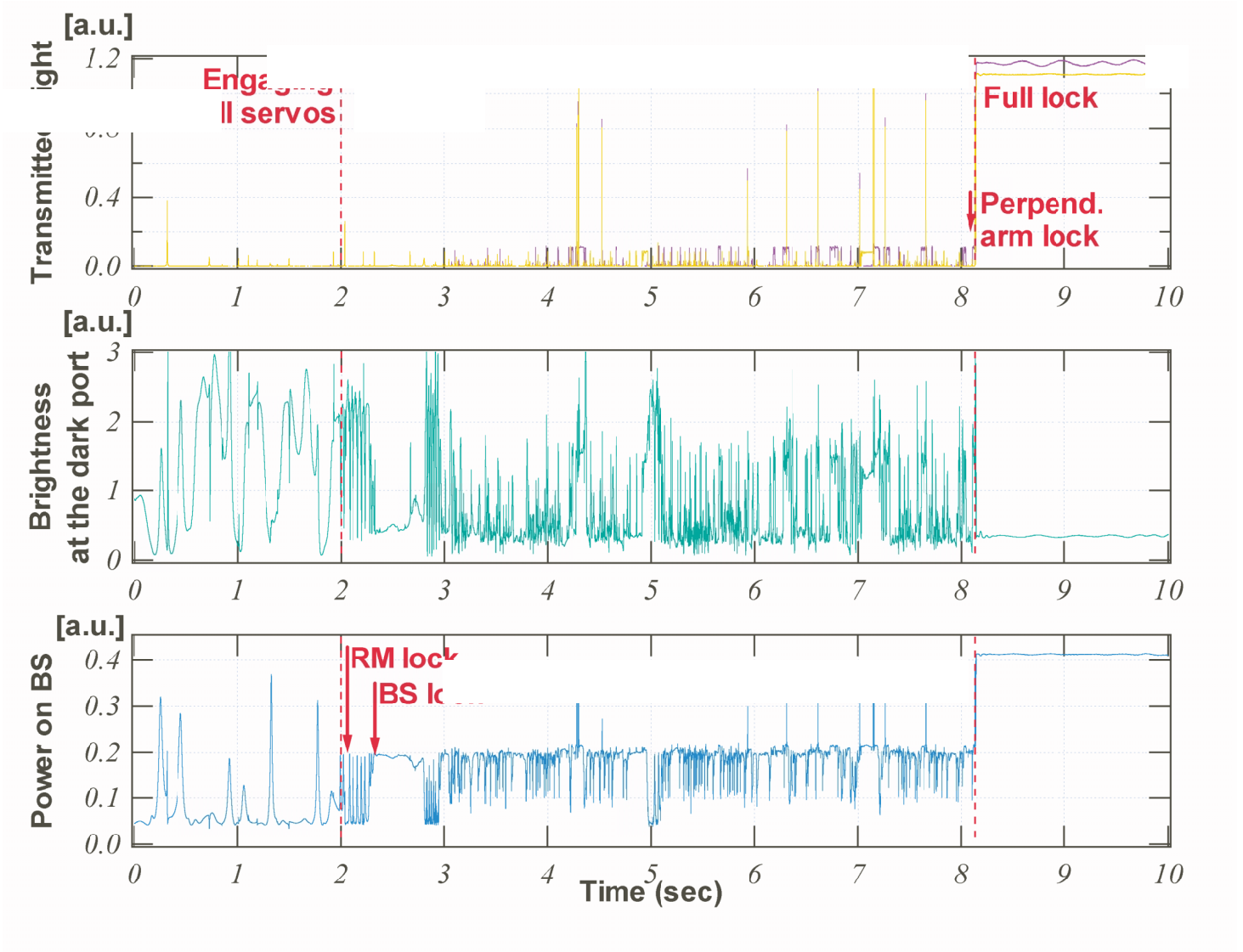


Frequency of the local oscs. is tripled by tuned amplifiers with nonlinearly driven transistors

Experimental achievements

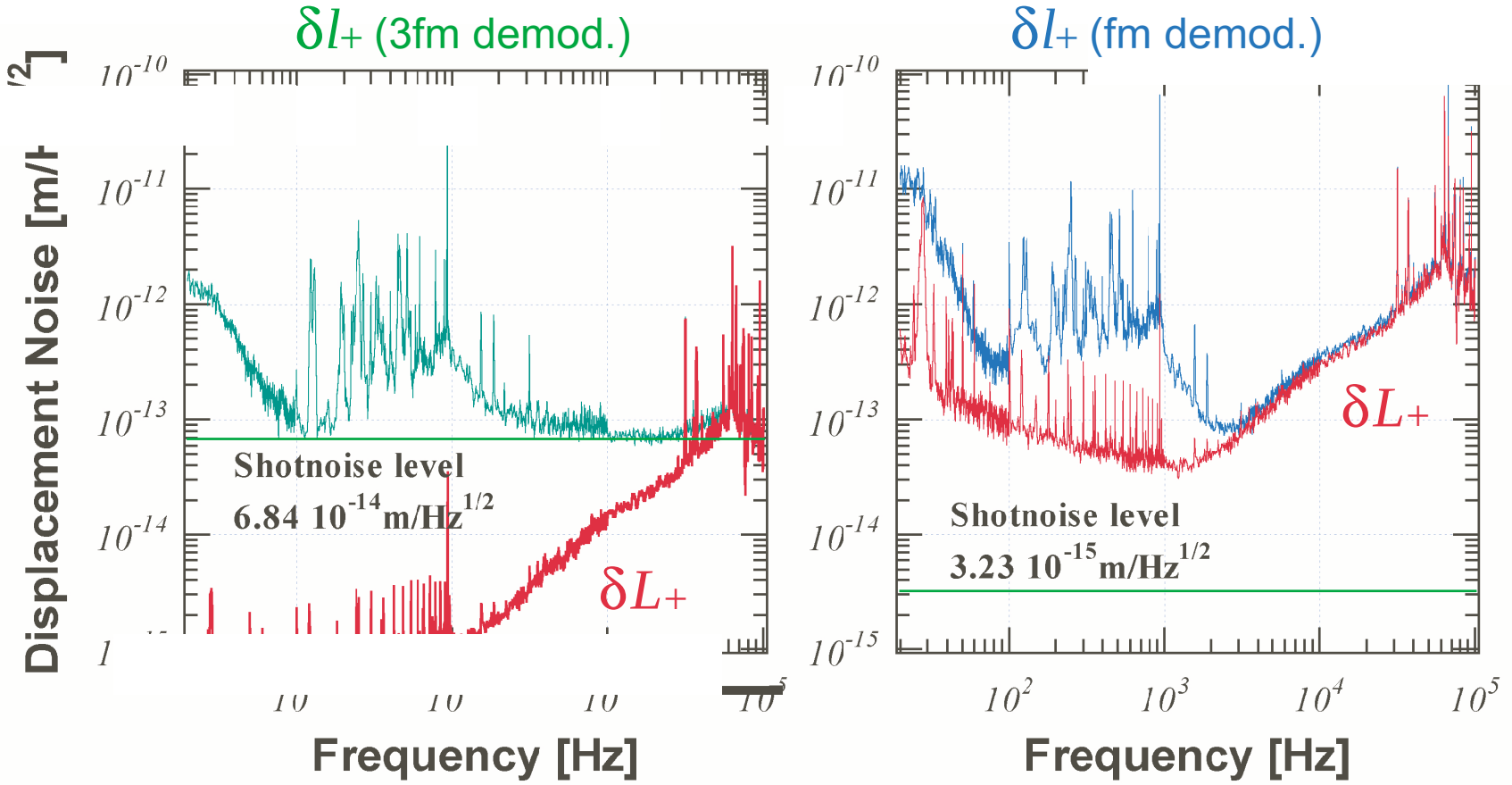
- Automatic lock / stable operation
- Reduction of dL+ contribution
  - ~ Sensitivity to dL+ --- 20 times reduced.
- Robust extraction of dl+ and dl-
  - ~ Modest optical gain variations during lock --- confirmed.
  - ~ Sign of the dl- signal --- never been flipped.
- Operation without pick-off inside the recycling caivty
  - ~ Stable operation with recycling gain of 5.4

Locking acquisition



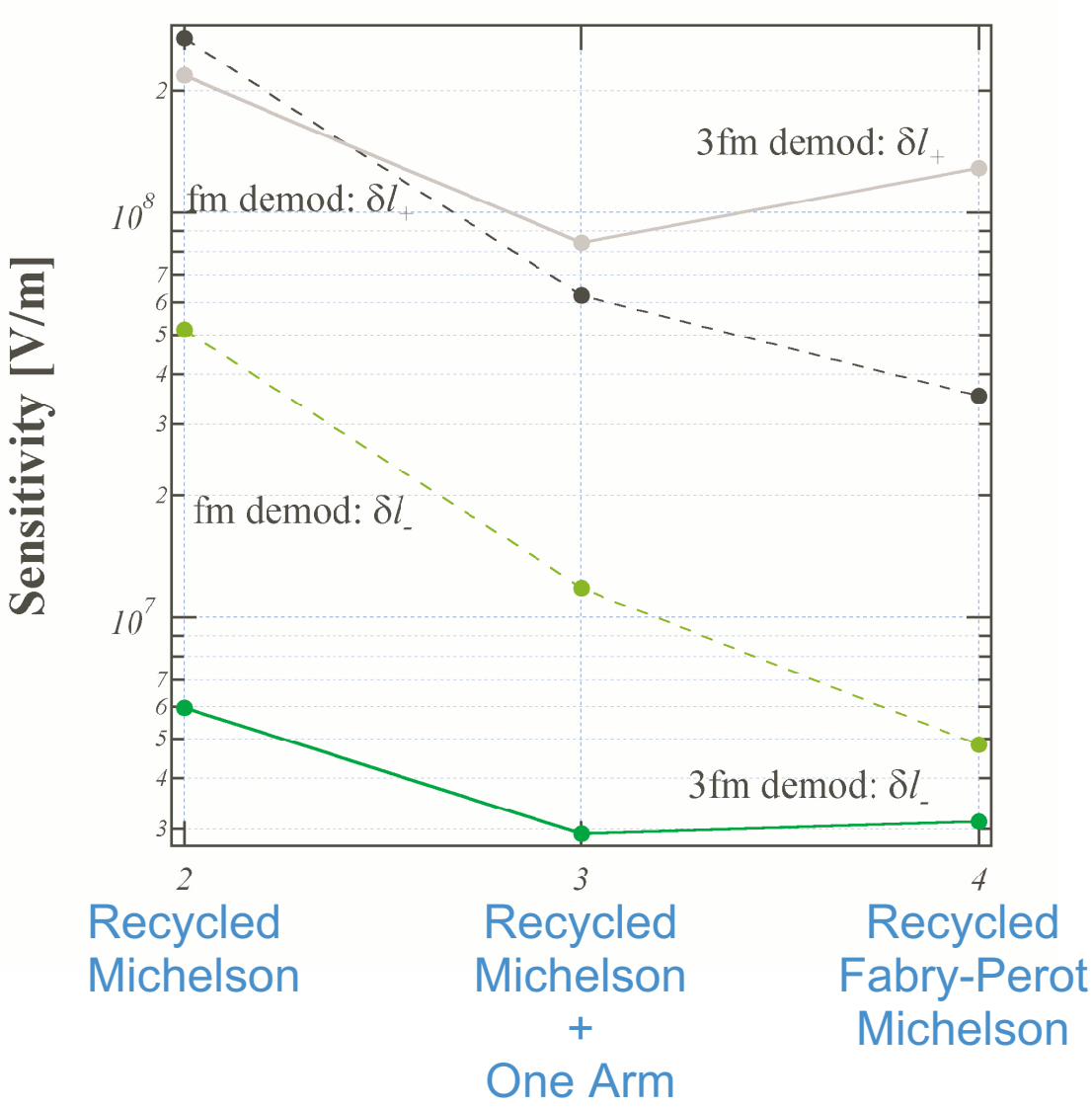
Reduction of dL+ contribution

- Sensitivity to dL+ has been 20 times improved by the 3fm scheme



Robust extraction of dl+ and dl-

- Sensitivity variation during lock acquisition

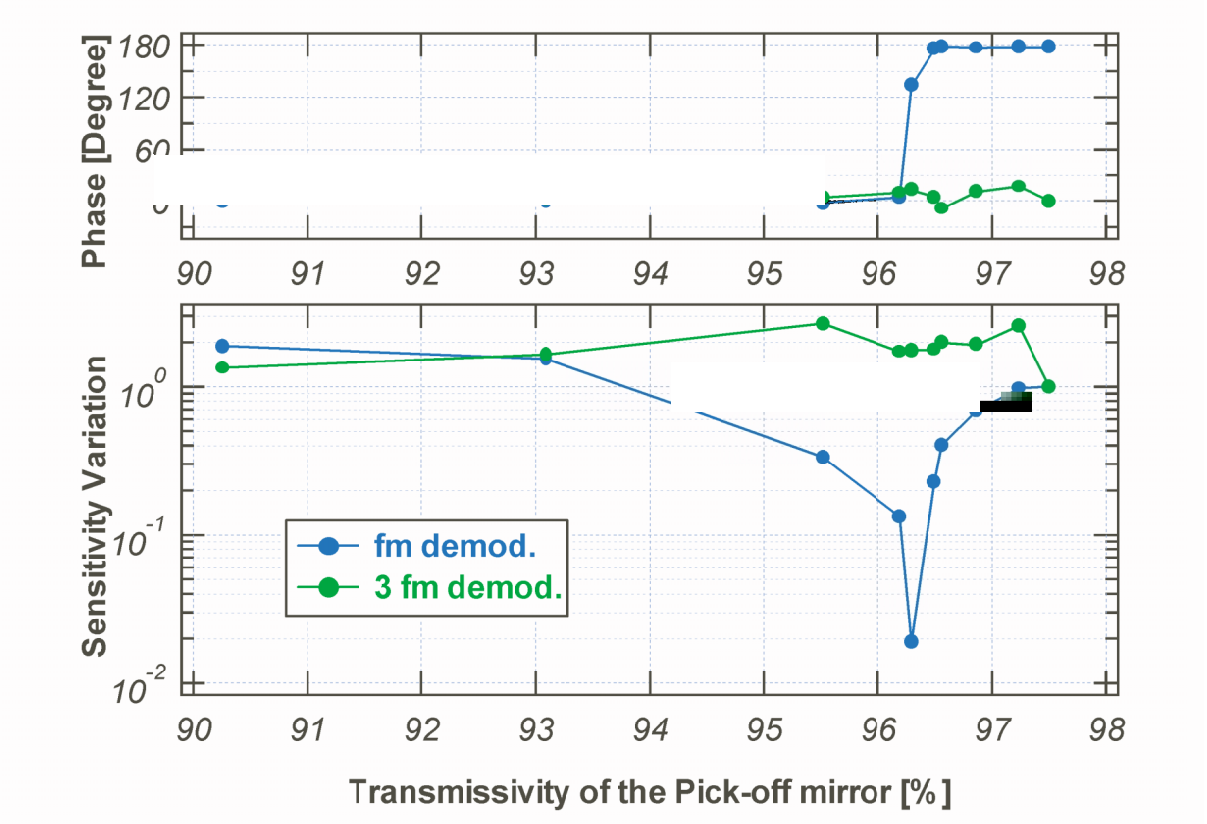


	RMI –> RFPMI
fm $\delta l+$	1 / 7.6
fm $\delta l-$	1 / 10.7
3fm $\delta l+$	1 / 1.7
3fm $\delta l-$	1 / 1.9

Robust extraction of dl+ and dl-

- Sign flipping of δl- during lock / by change in optical param.

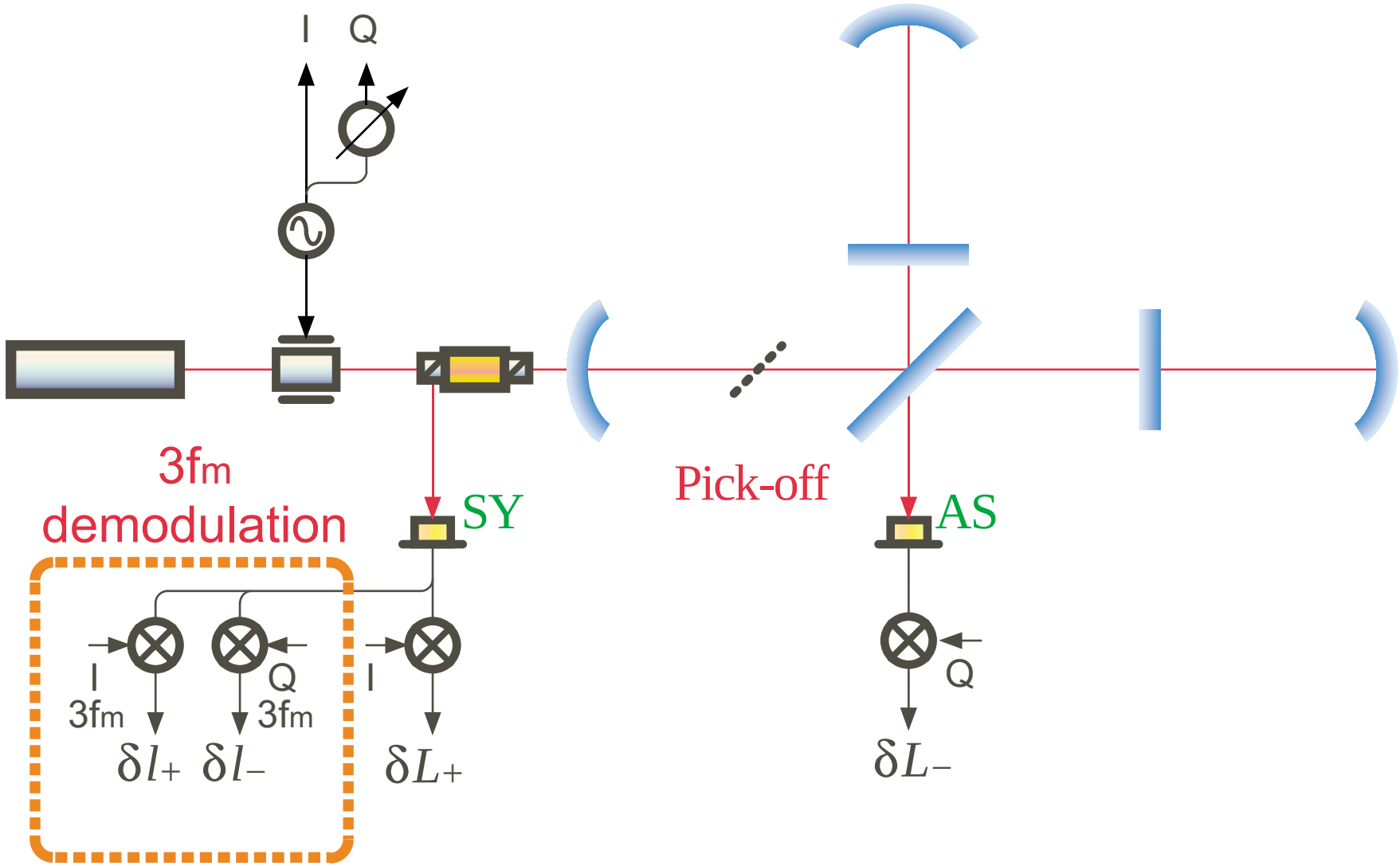
Tests by changing the transmissivity of pick-off mirror inside of the recycling caivty.



The sign of δl- by the 3fm demod. never changes

IFO operation without pick-off

- Stable operation of the 3m without pick-off mirror



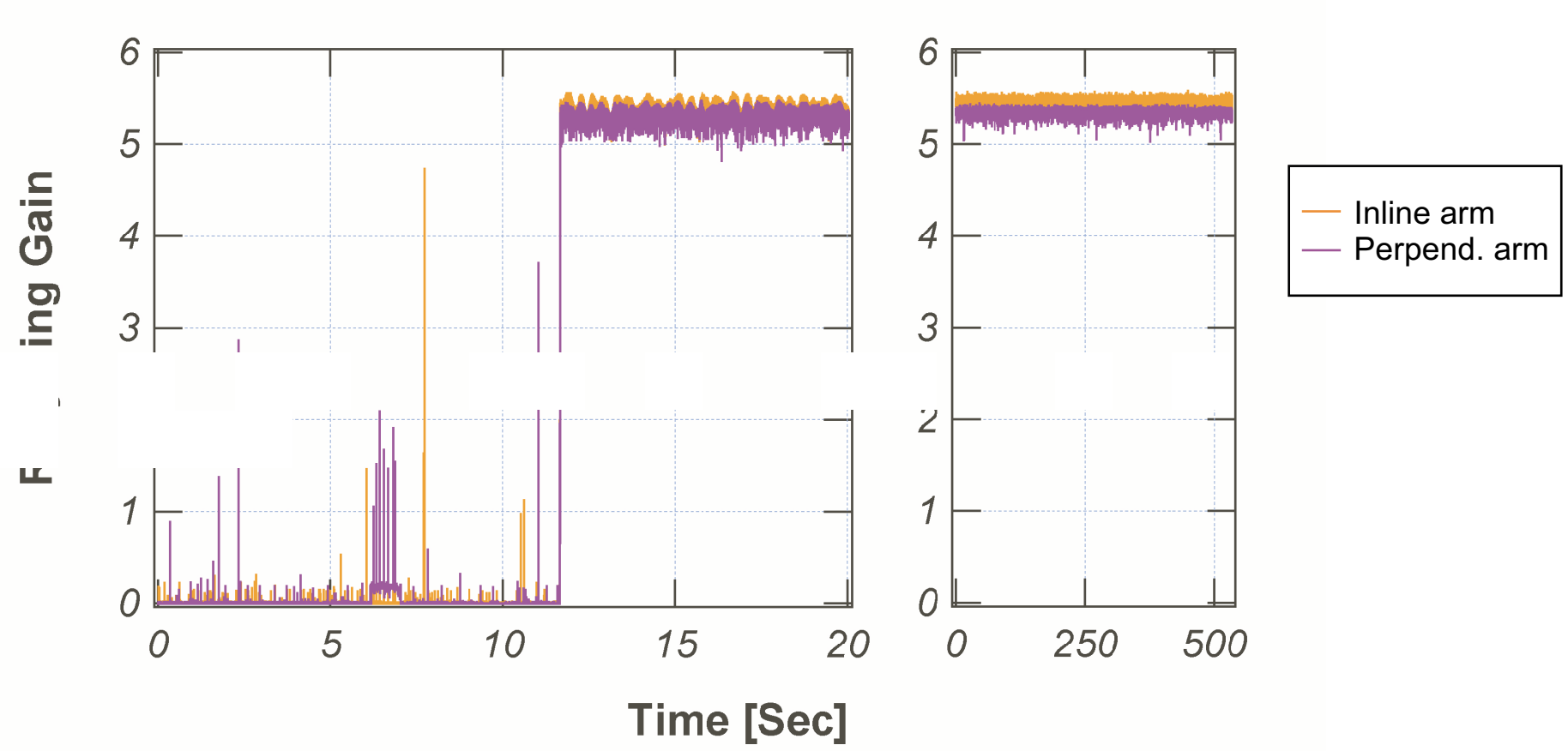
IFO operation without pick-off

- Stable operation of the 3m without pick-off mirror

Recycling Gain for the carrier

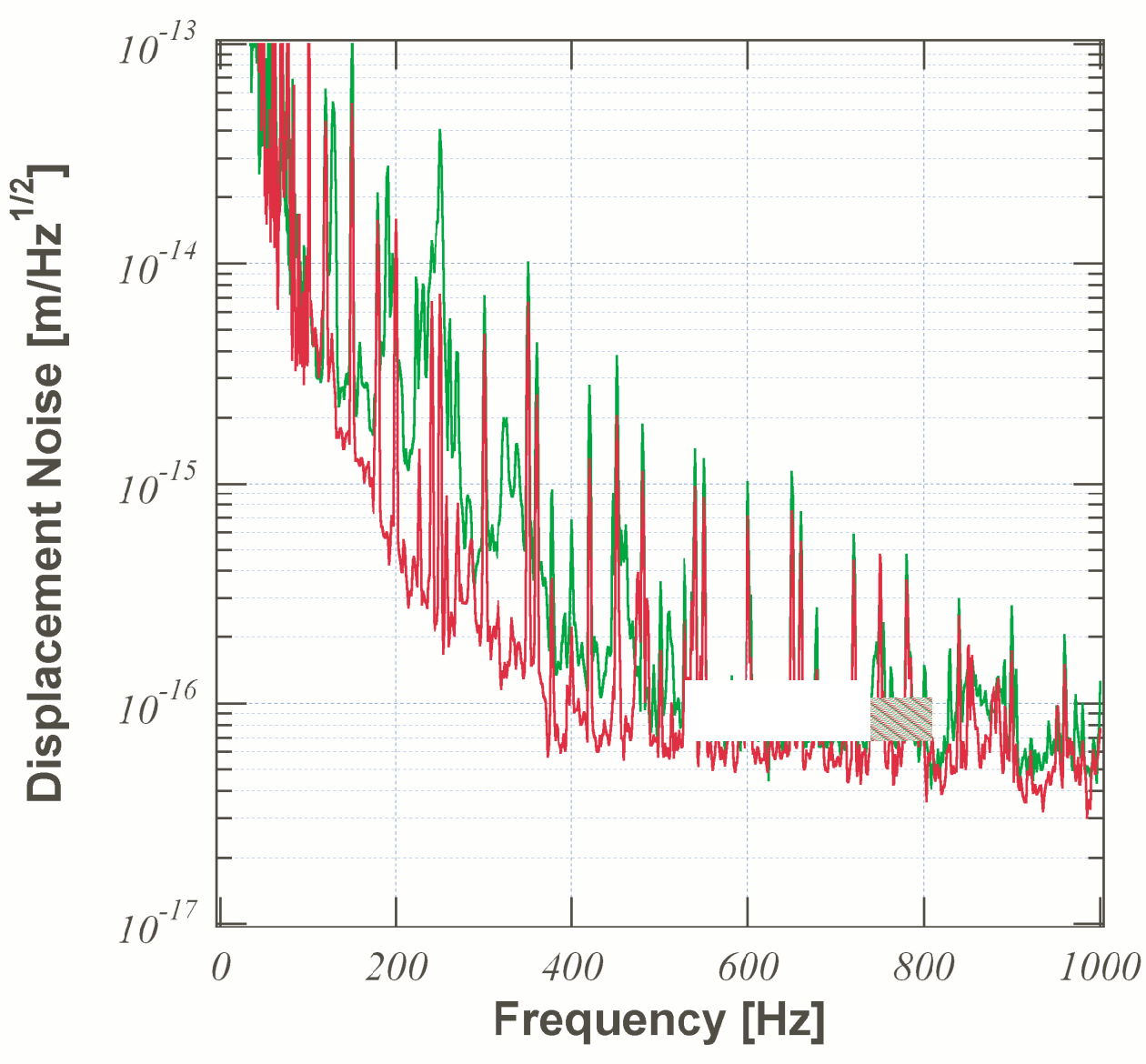
$G_0 = 5.4 \pm 0.05$ ($R_R = 0.81$)

(almost critical coupled)



IFO operation without pick-off

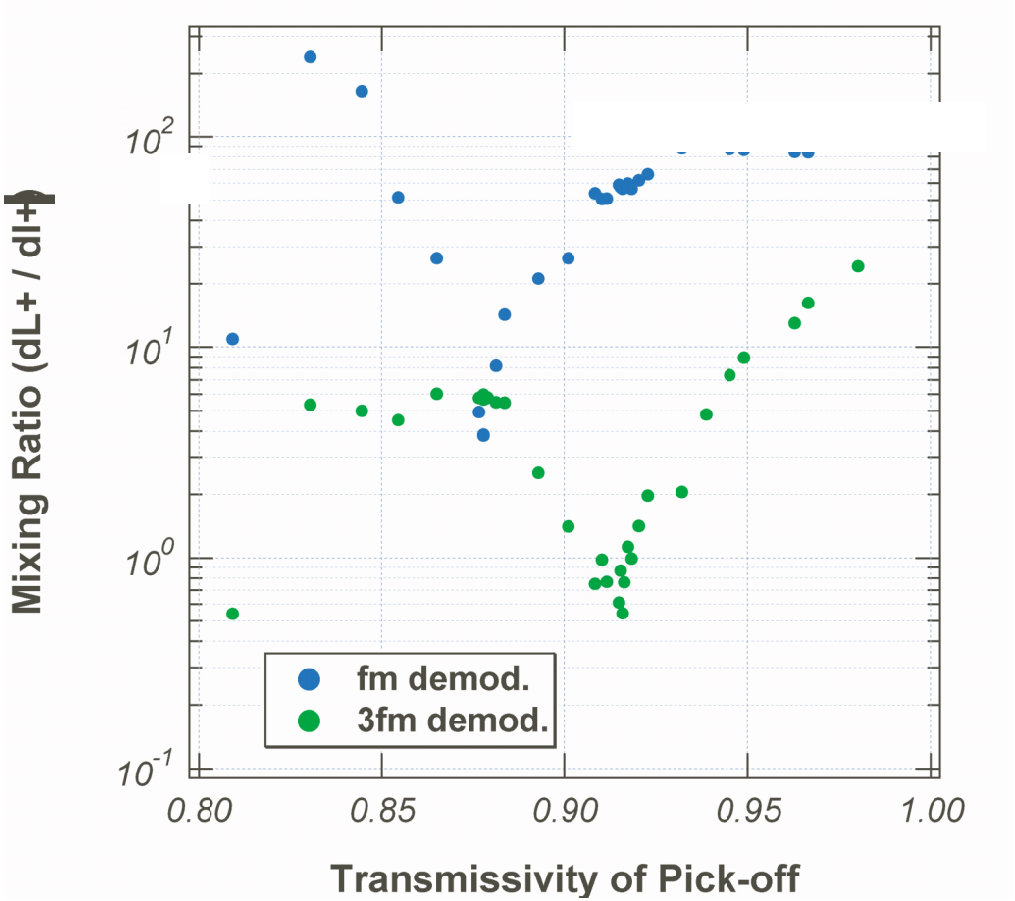
- Noise caused by the pick-off was eliminated



Further reduction of dL+

Erase the 3rd order sidebands at the reflection port!!!

- by adjusting the opt. param.
  ~ The best separation ratio (dL+ / dl+) of about 0.5

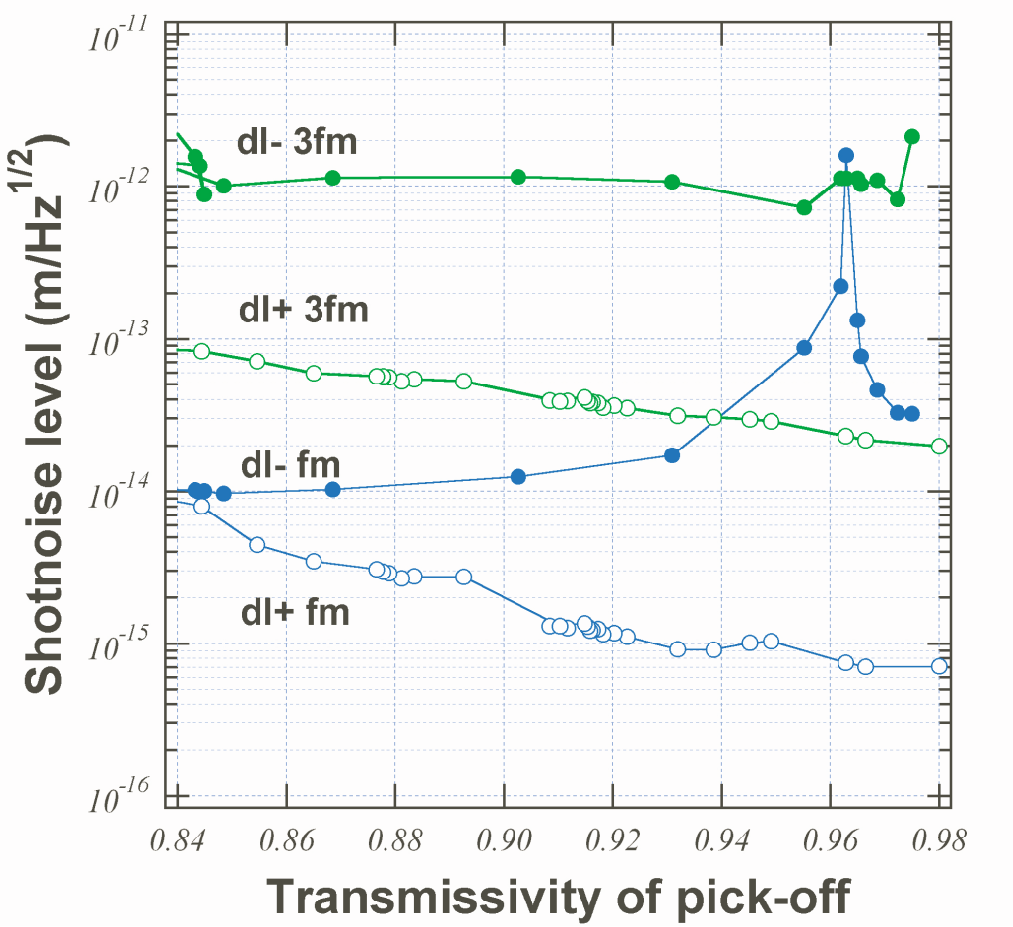


- by applying weak 3fm modulation

Discussion

- Shot-noise level of the 3fm signals are usually worse than those of the signals with the conventional scheme.

(measured with modulation depth *m* of 0.7)



Summary

- Harmonic demod. for extraction of δl_{-}^{+} signals

  ~ Demodulation at the 3rd harmonic frequency

- Experimental tests on the 3m prototype

  ~ Stable lock has been achived

  ~ Inherent insensitivity to $\delta L+$ (20 times improved)

  ~ Robustness of the signal amplitudes during lock

  ~ Sign of $\delta l-$ does not depend on the optical parameters.

  ~ Stable operation without pick-off mirror (rec. gain of 5.4)