Recent Progress of TAMA300

Koji Arai

(National Astronomical Observatory of Japan)

on behalf of the TAMA collaboration

TAMA300 interferometer

- **Laser interferometer GW detector**

- Arm length: 300m
- Location: National Astronomical Observatory of Japan (Mitaka, Tokyo)

- **Purposes**

- Development of the detector capable to catch GW events in nearby galaxies
- Establishment of interferometer technologies for LCGT

Progress of TAMA300

1995-1997 Facility/Vacuum System Construction

Recombined Interferometer

1999-2001 6 times of observation runs
(Total 1370 hours)

Recycled Interferometer

2001 Implement of power recycling

2003-2004 3 times of observation runs
(Total 1740 hours)

Seismic Attenuation System (SAS)

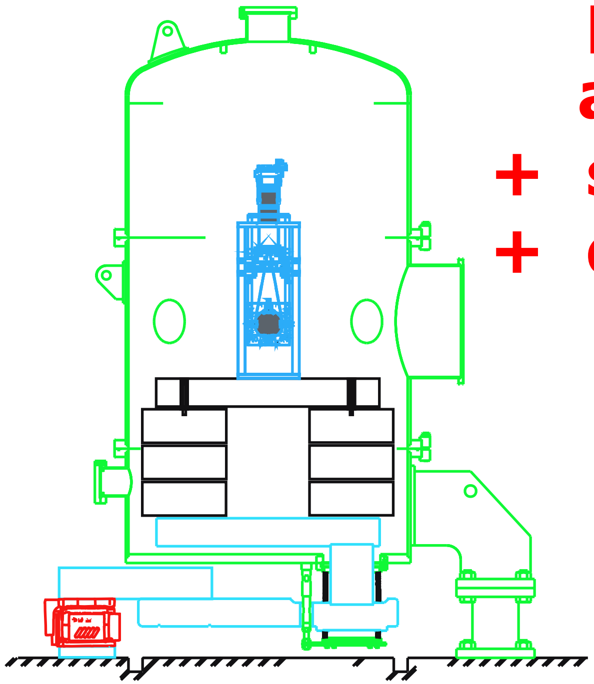
2005 Start installation of SAS

2007 Full interferometer lock with SAS

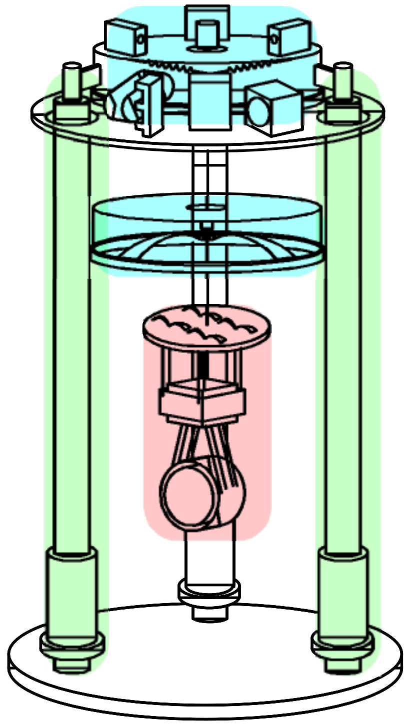
Current focus

- **Establishment of detector operation with SAS**

Replacement of the vibration isolation system



pneumatic
active isolator
+ stack
+ double pendulum



inverted pendulum
+ vertical filters
+ multiple pendulum

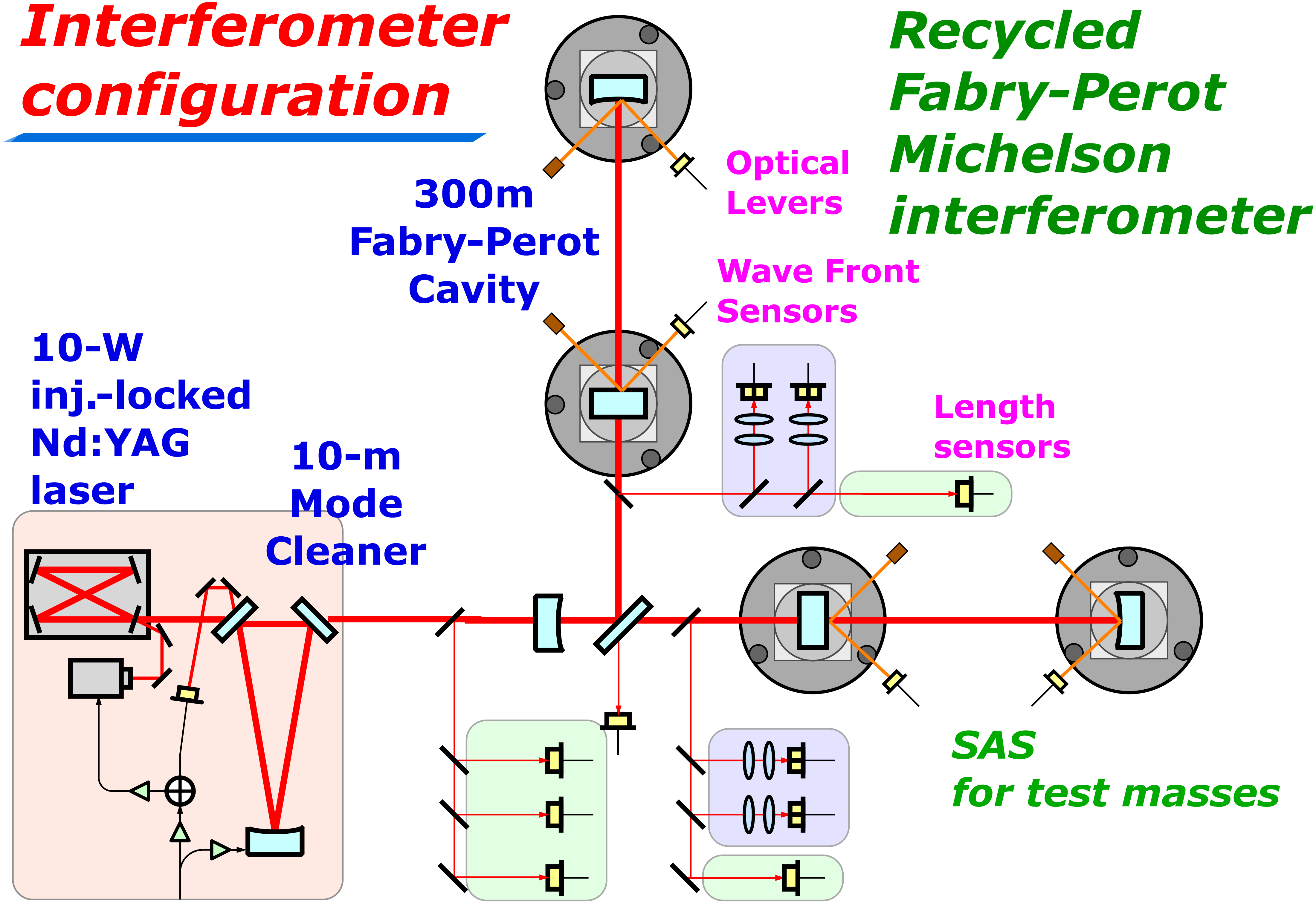
To realize the improvement

- Optimization of SAS control
- Optimization of interferometer control
- Application of digital control system

  =>Enables the complex servo system

  =>High level automatization of the operation

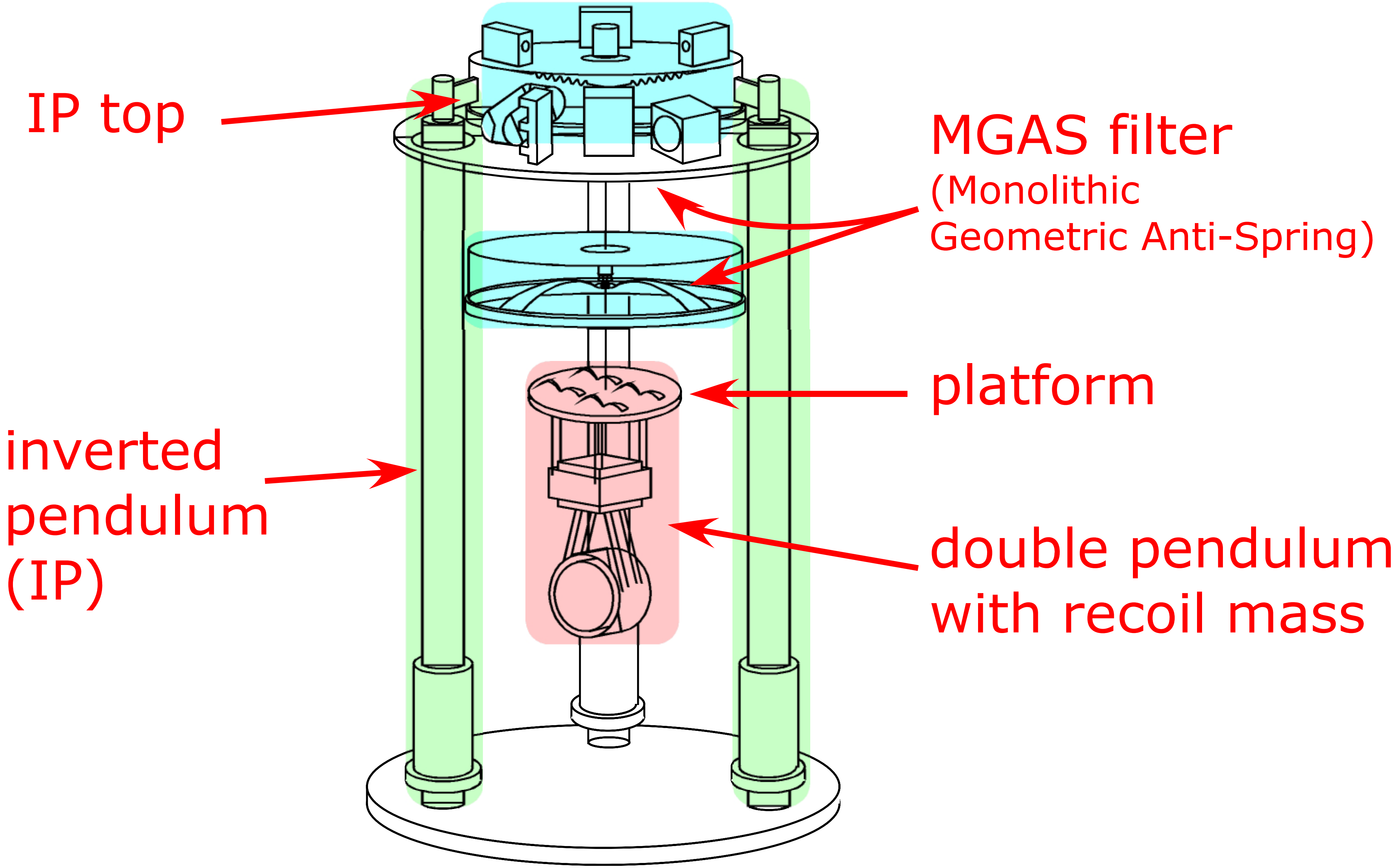
Interferometer configuration



Seismic Attenuation System

● Structure of SAS

Multiple pendulum suspended from IP



Seismic Attenuation System

● Vibration Isolation

Passive isolation with soft springs + active damping

Tortional

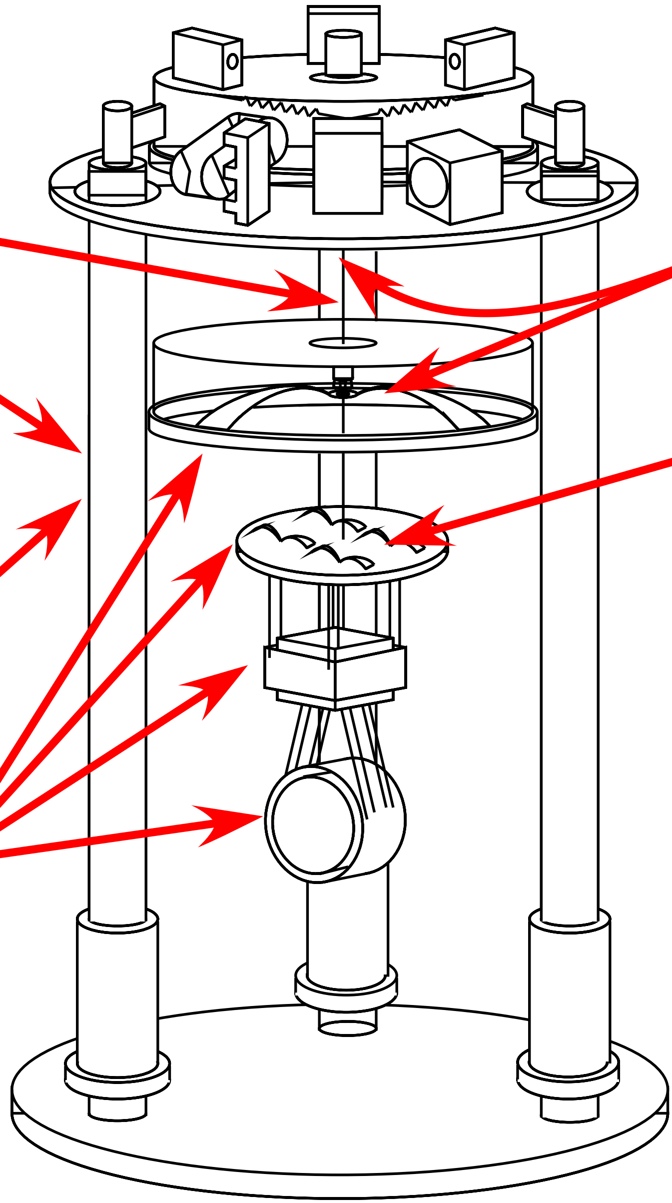
Tortion Pendulum
f~40mHz

Inverted Pendulum
f~500mHz

Horizontal

Inverted Pendulum
f~30mHz

Multiple Pendulum
f~650mHz



Vertical

MGAS Filter
f~500mHz

MiniGAS Filter
f~1.5Hz

Seismic Attenuation System

Active Control of SAS

Local control stabilize the mirror motion
=> to enable lock of the interferometer

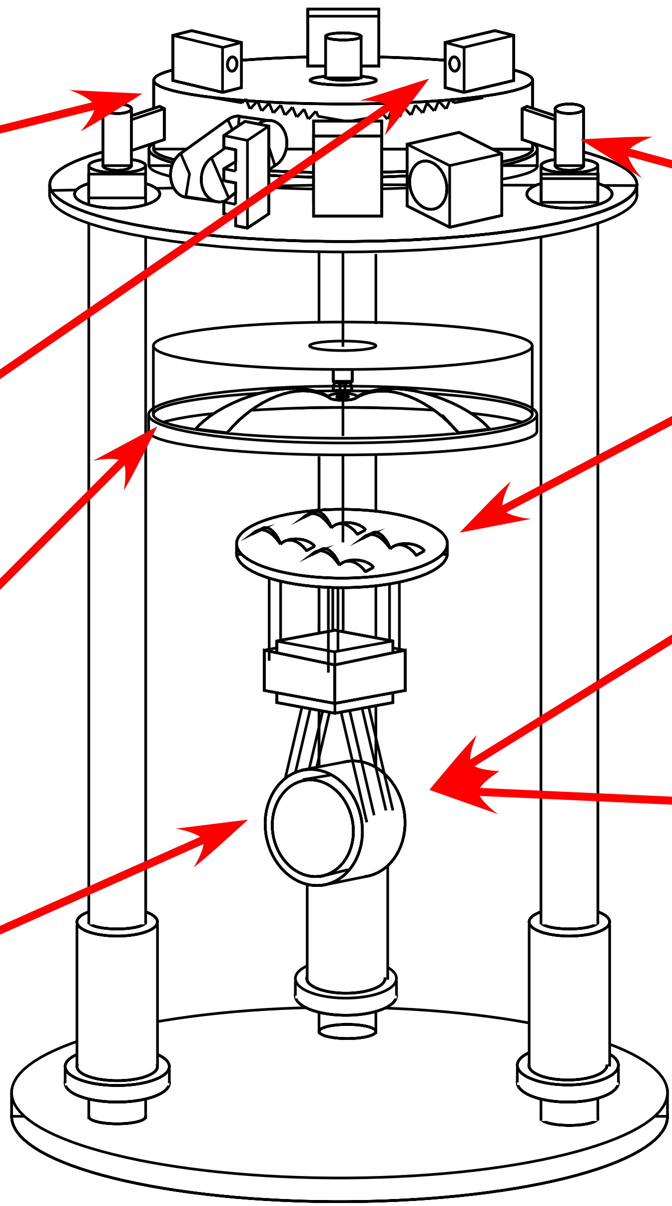
Local control

IP Position
Sensor: LVDT
Bandwidth: ~60mHz

IP Inertial damping
Sensor: Accelerometer
Bandwidth: 60m~2Hz

Tortion damping
Sensor: Photo Sensor
Bandwidth: 40mHz

Test mass servo
Sensor: Optical Lever
Bandwidth: ~2Hz



Global control

IP Position
Bandwidth: ~10mHz

Plat form
Bandwidth: ~10mHz

Test mass (angular)
Bandwidth: <3Hz

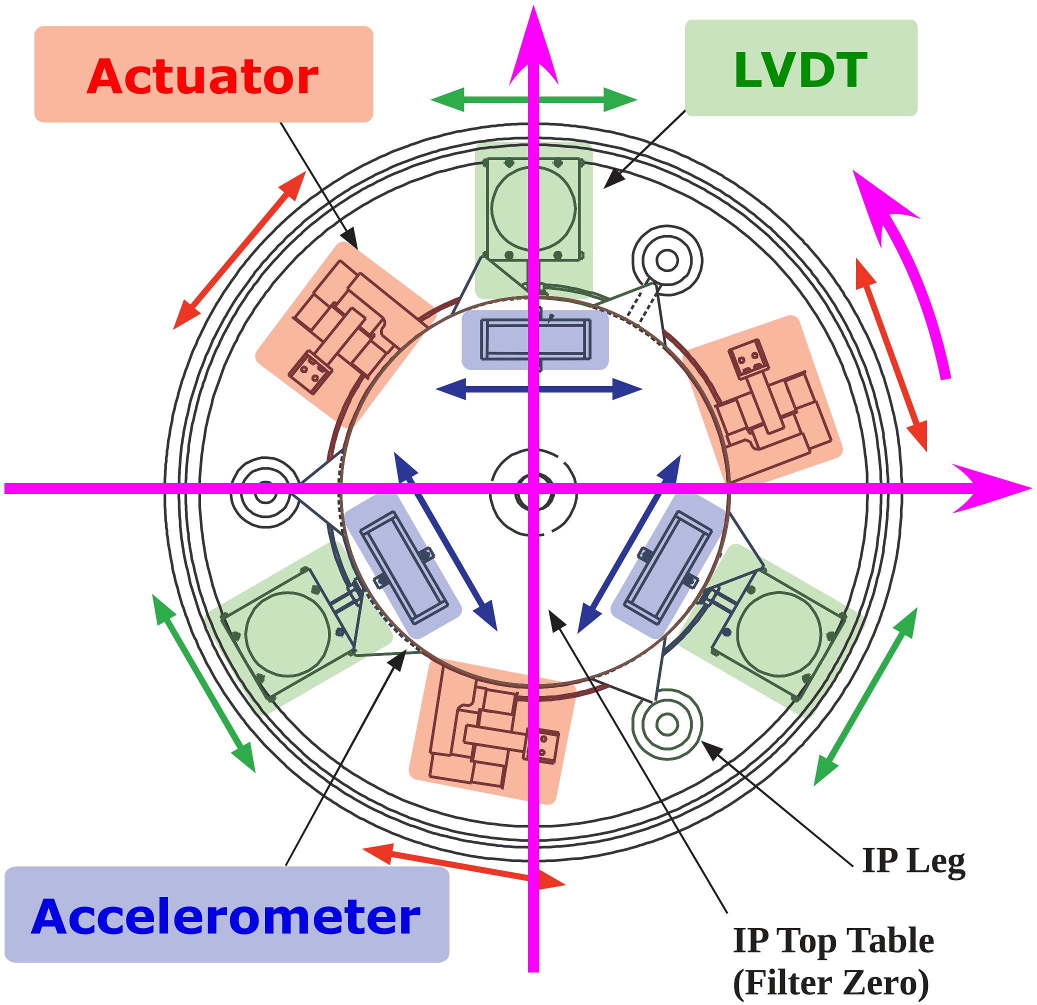
Test mass (Length)
Bandwidth: <1kHz

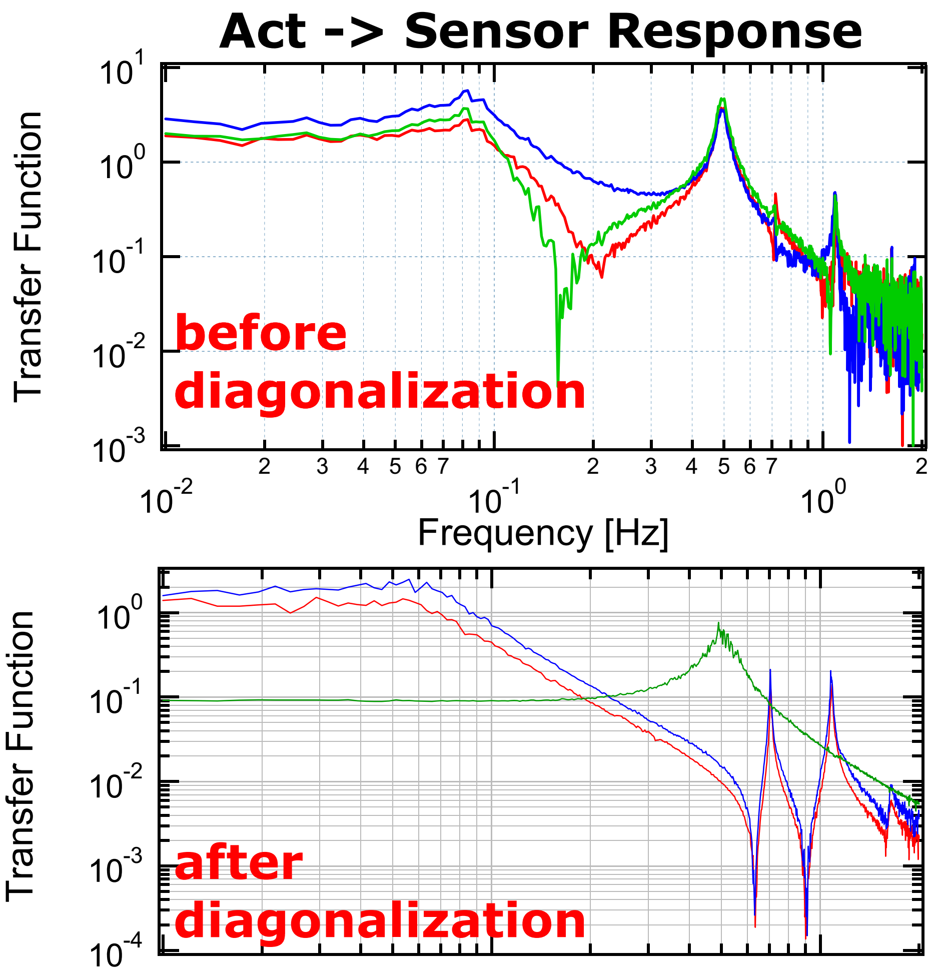
Inertial damping of IP

● Diagonalization of Sensors / Actuators

Decompose Actuator -> Sensor response
into mechanical eigenmodes of IP

=> servo design becomes simpler
allows the different strategy for each modes





Inertial damping of IP

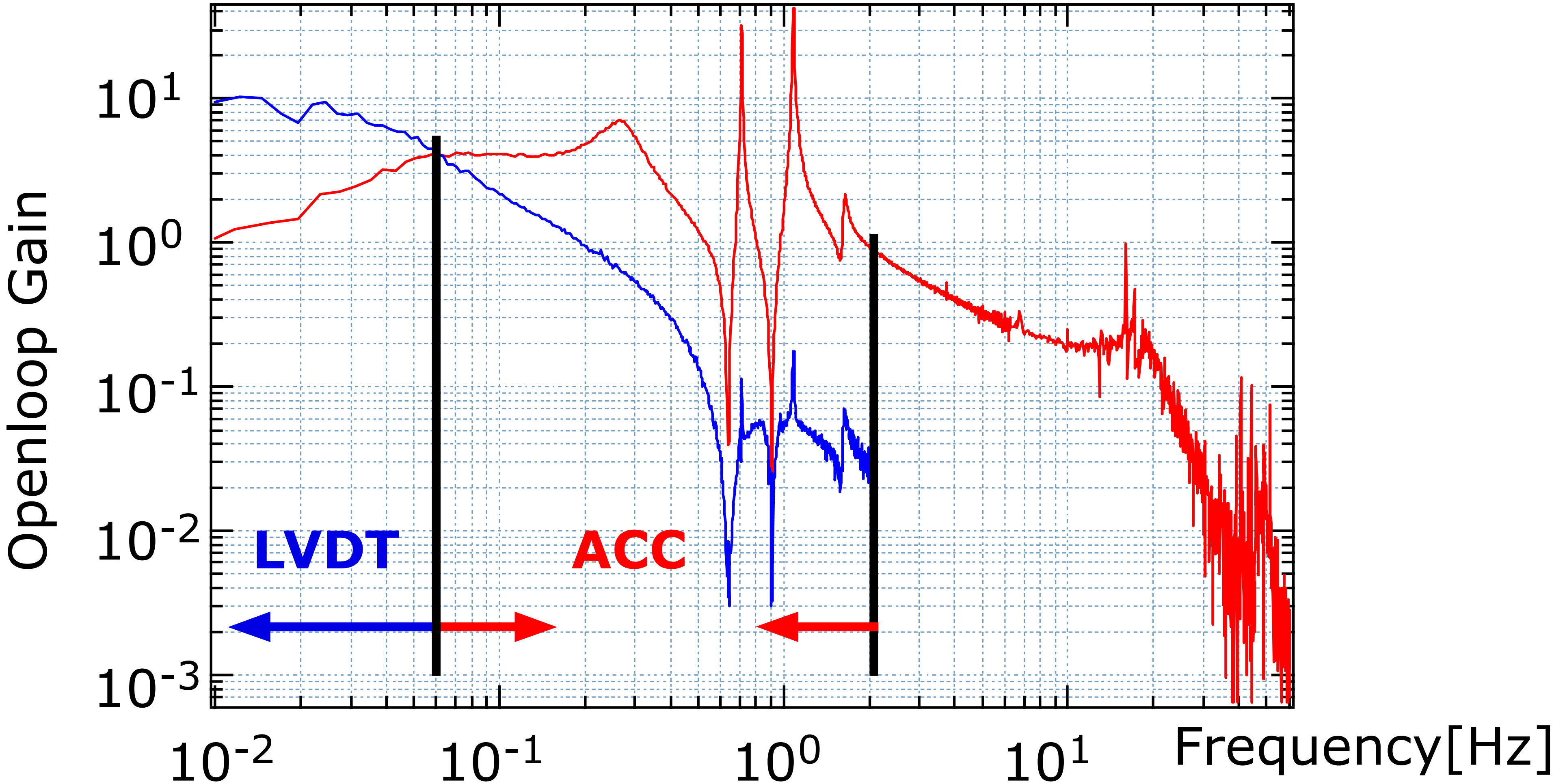
- **Two loop configuration**

LVDT loop (position sensing loop) f<60mHz

- drift control of the IP position

Accelerometer loop (inertial sensing loop) 60mHz<f<2Hz

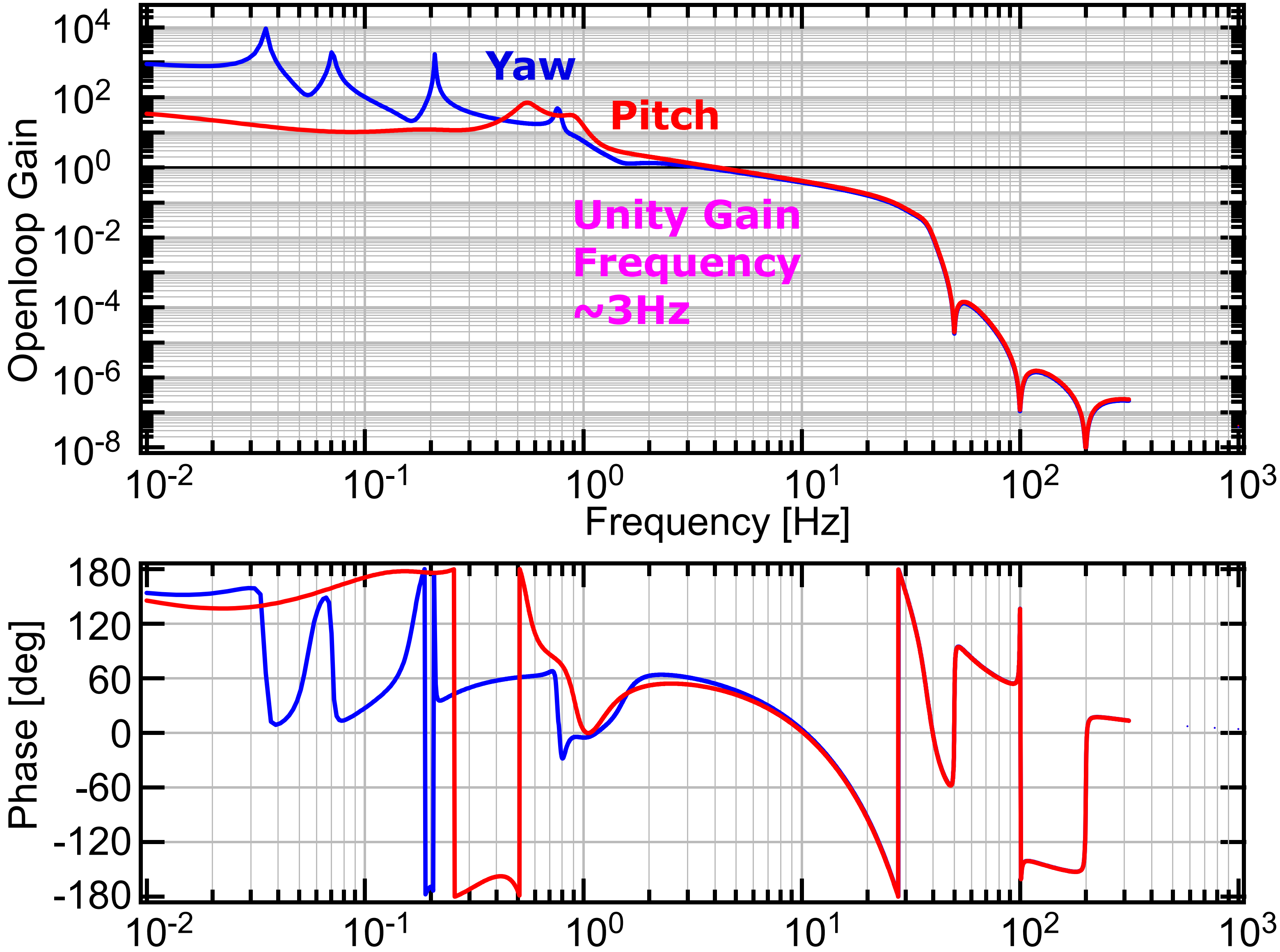
- stabilization of IP in terms of the inertial frame
- damping of the pendulum reactions at around 1Hz



Test mass control

● Optical lever servo

Rather complicated servo loops have been realized in virtue of digital control



Performance of SAS

● Test mass angular motion

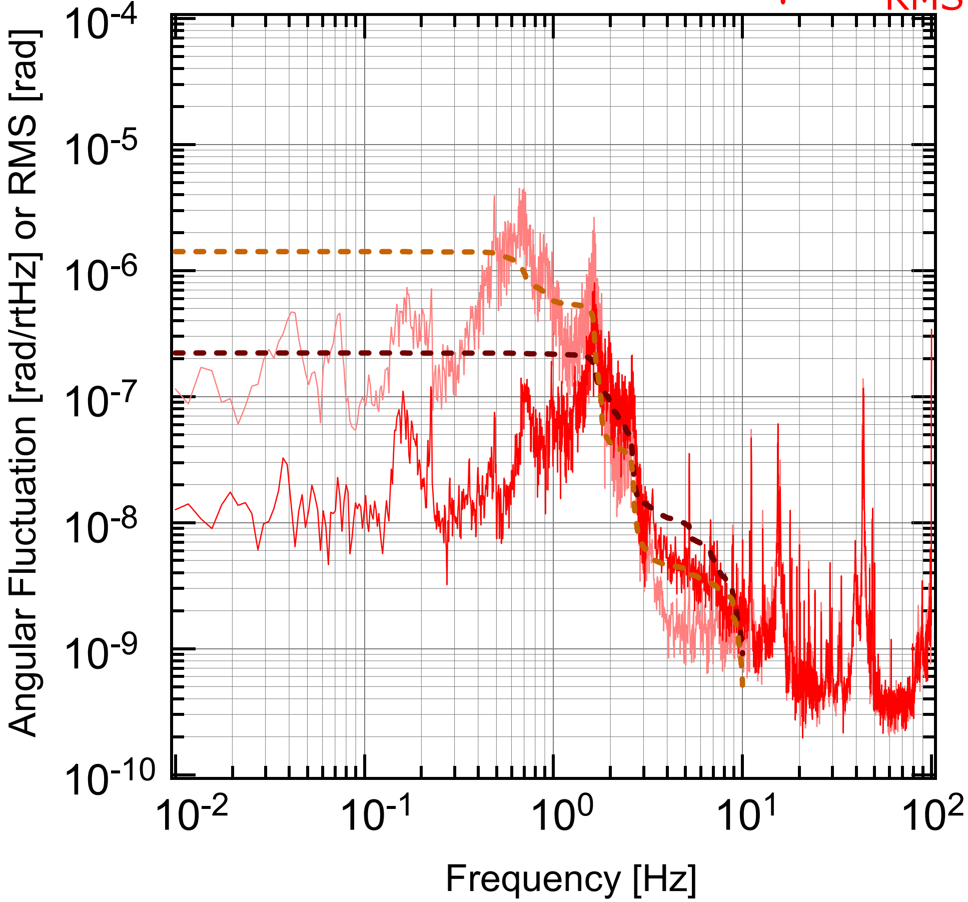
Mirror angular motion: sub-μrad$_{RMS}$

=> Sufficiently stable for interferometer operation

(with previous suspension system: 1.0 μrad$_{RMS}$)

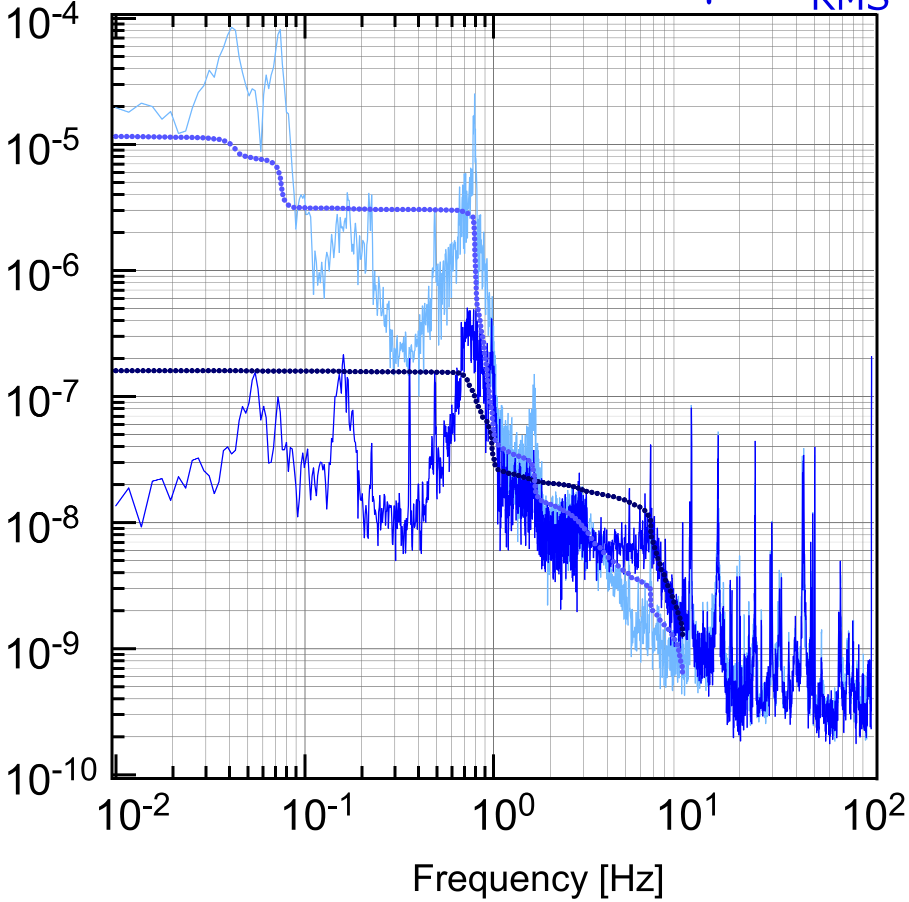
Pitch Free Run: 1.4 μrad$_{RMS}$

Controlled: 0.23 μrad$_{RMS}$



Yaw Free Run: 12 μrad$_{RMS}$

Controlled: 0.16 μrad$_{RMS}$

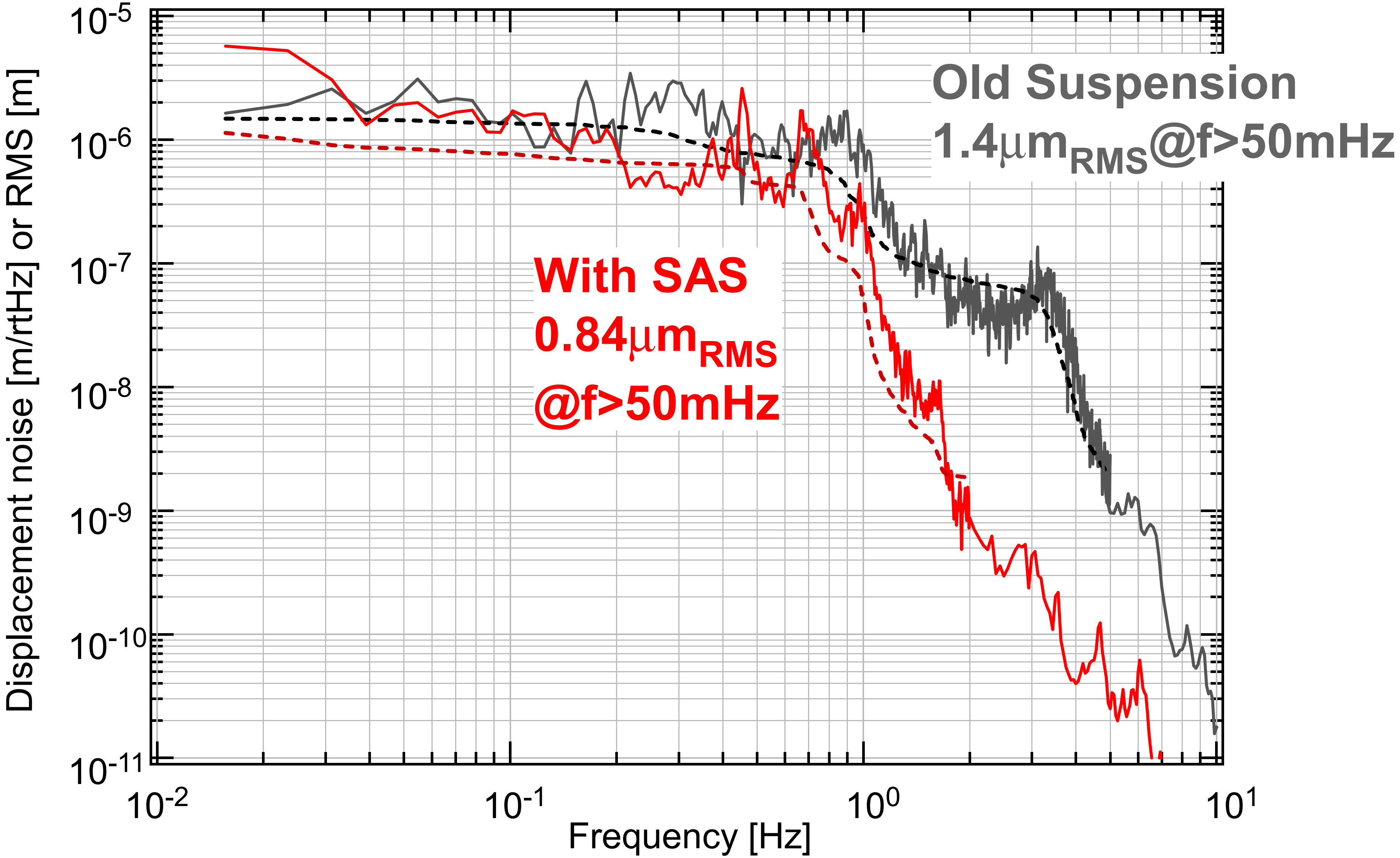


Performance of SAS

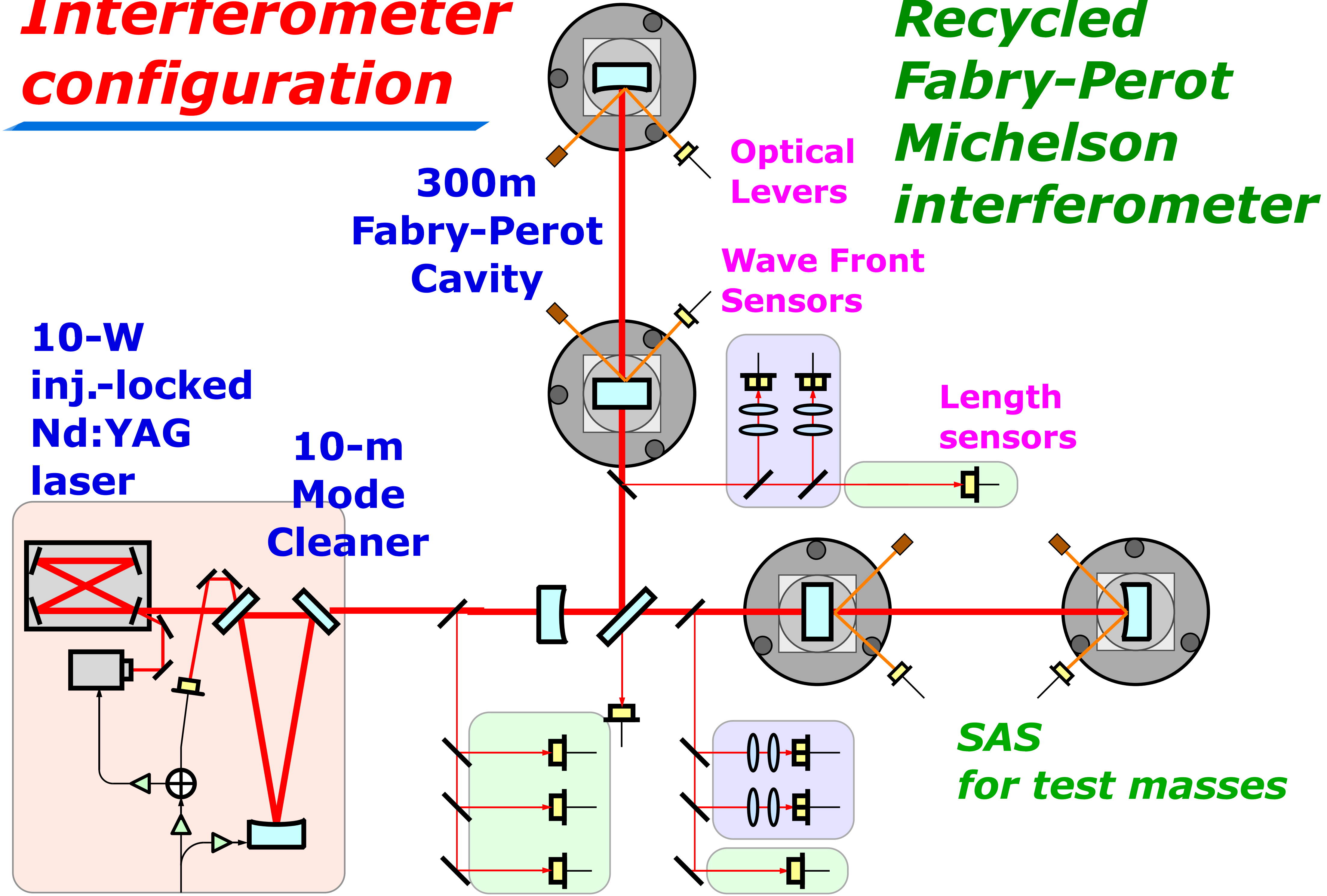
● Legth Fluctuation of 300-m arm

Comparison with the previous suspension system

=> improvement above 0.1Hz was confirmed



Interferometer configuration



Interferometer Operation

- **Recycling operation with SAS was achieved in July**

- **Control configuration**

Test mass length control:

Analog based servo

DSP based digital filter
=> only for lock acquisition
=> switched to analog based system after the lock

Test mass alignment control:

LabView based digital control

Optical lever control for fast control

Wave Front Sensing for drift control

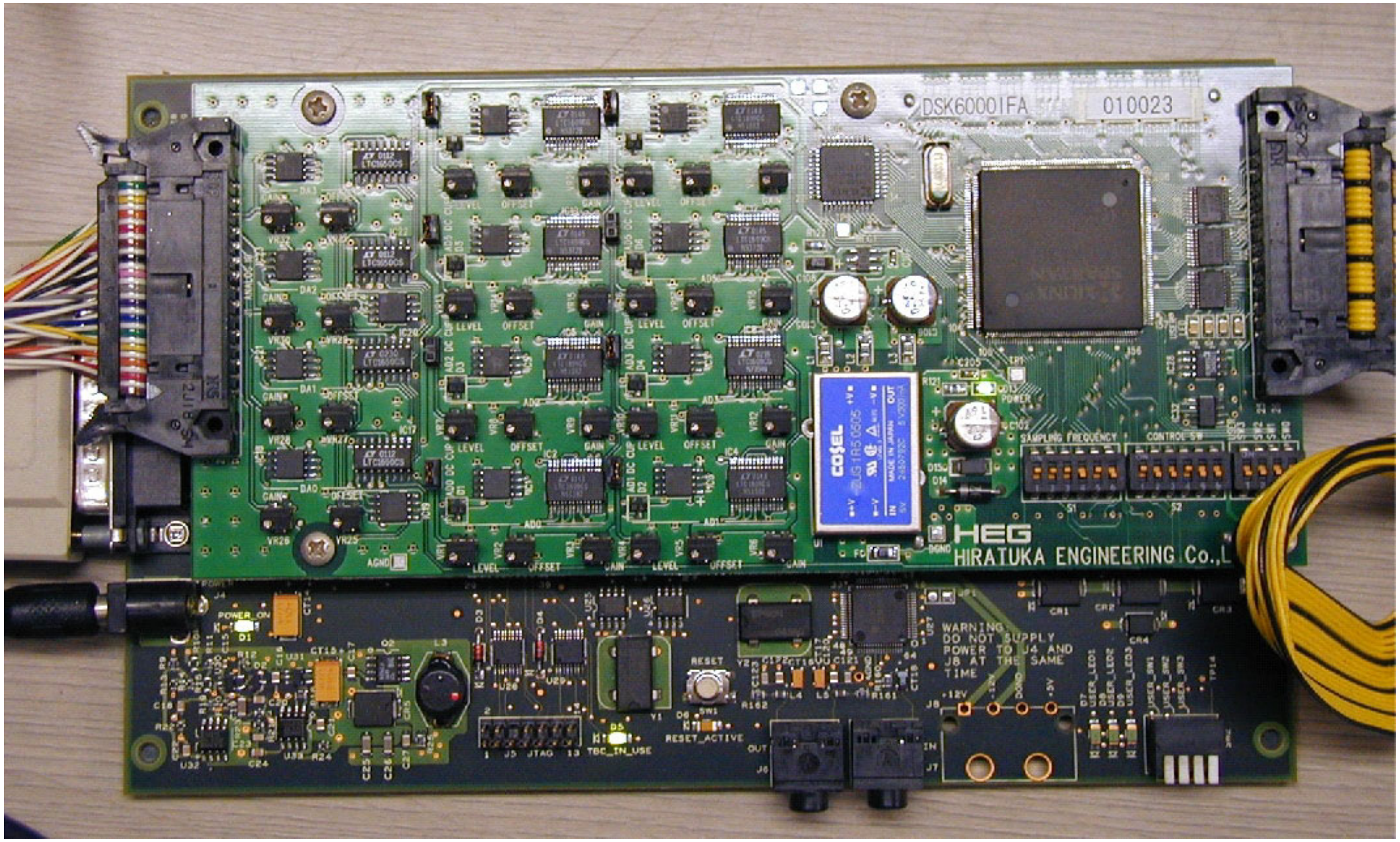
Digital mass lock filter

- **DSP based digital filter** (TI TMS32C6713 225MHz)

  Sampling freq: 200kHz

  Control BW: ~800Hz

Realized comperable bandwidth to analog filters



Digital mass lock filter

- **Some simple operations to the error signal**

  - Trigger at the resonance

    Eliminates glitches by sidebands/ higher order modes

  - Normalizaton of the error signal by cavity transmitted light

    Expands linear range (about x3)

  - Adaptive change of the digital filter coefficient

    Low frequency gain boost at the lock

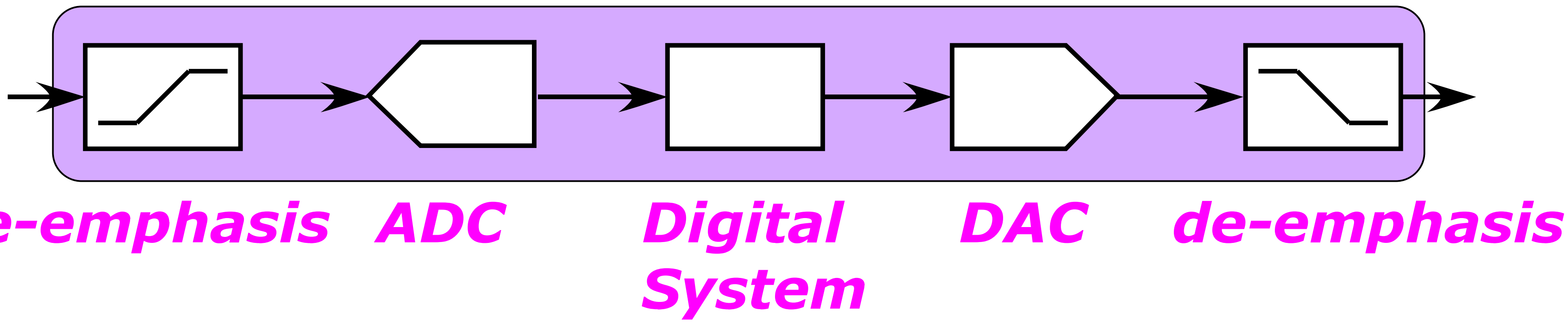
=> In combination with SAS, lock of RFPMI was realized even with 3 times weaker actuator

Pre-emphasis / De-emphasis

- **One of the demerits of the digital system**

  about 100-1000 times larger noise than analog circuits

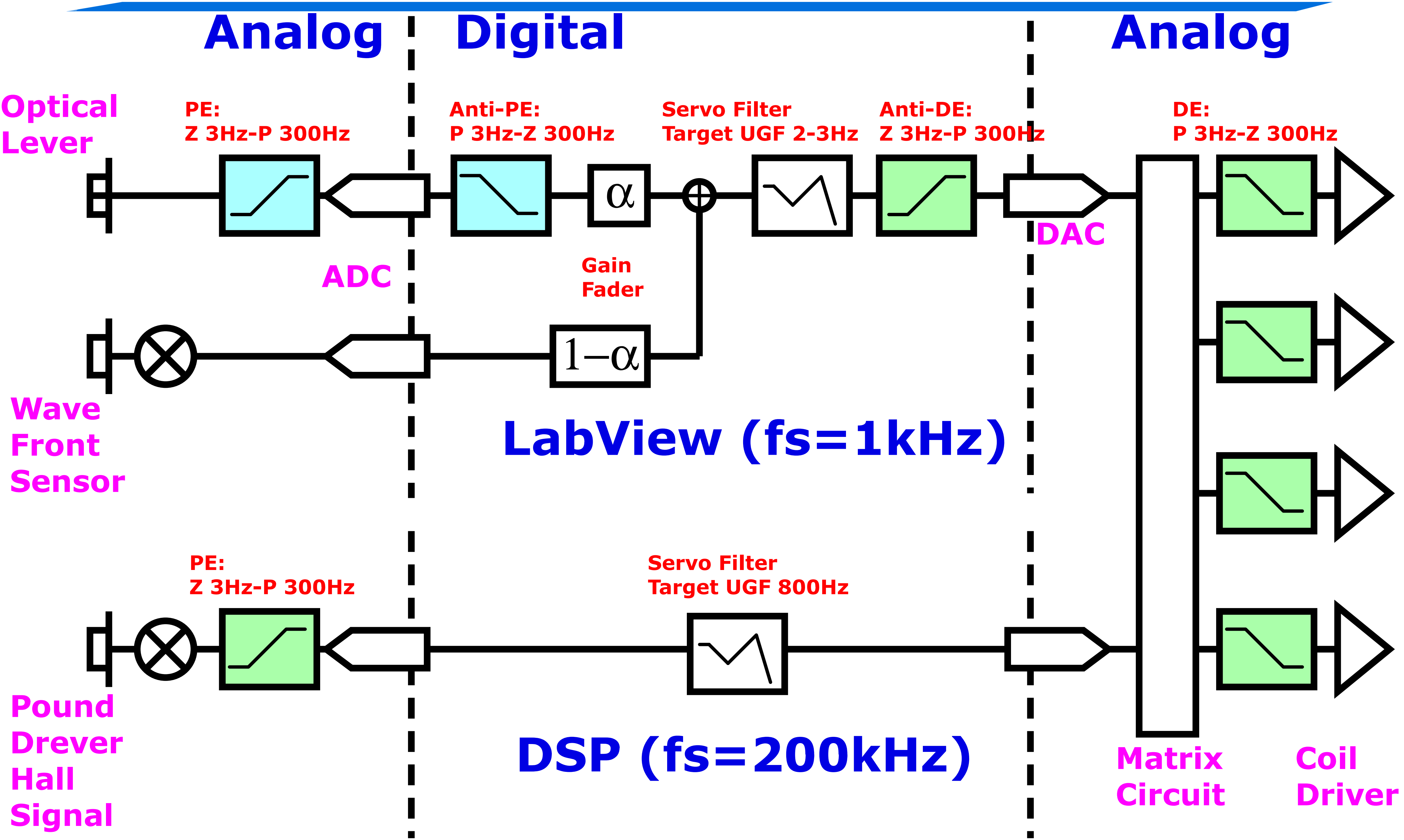
- **Pre-emphasis/De-emphasis filter**



Signal level is enhanced
while the range at low frequency is preserved

pre-emphasis: effect of ADC noise is reduced
de-emphasis: effect of DAC noise is reduced

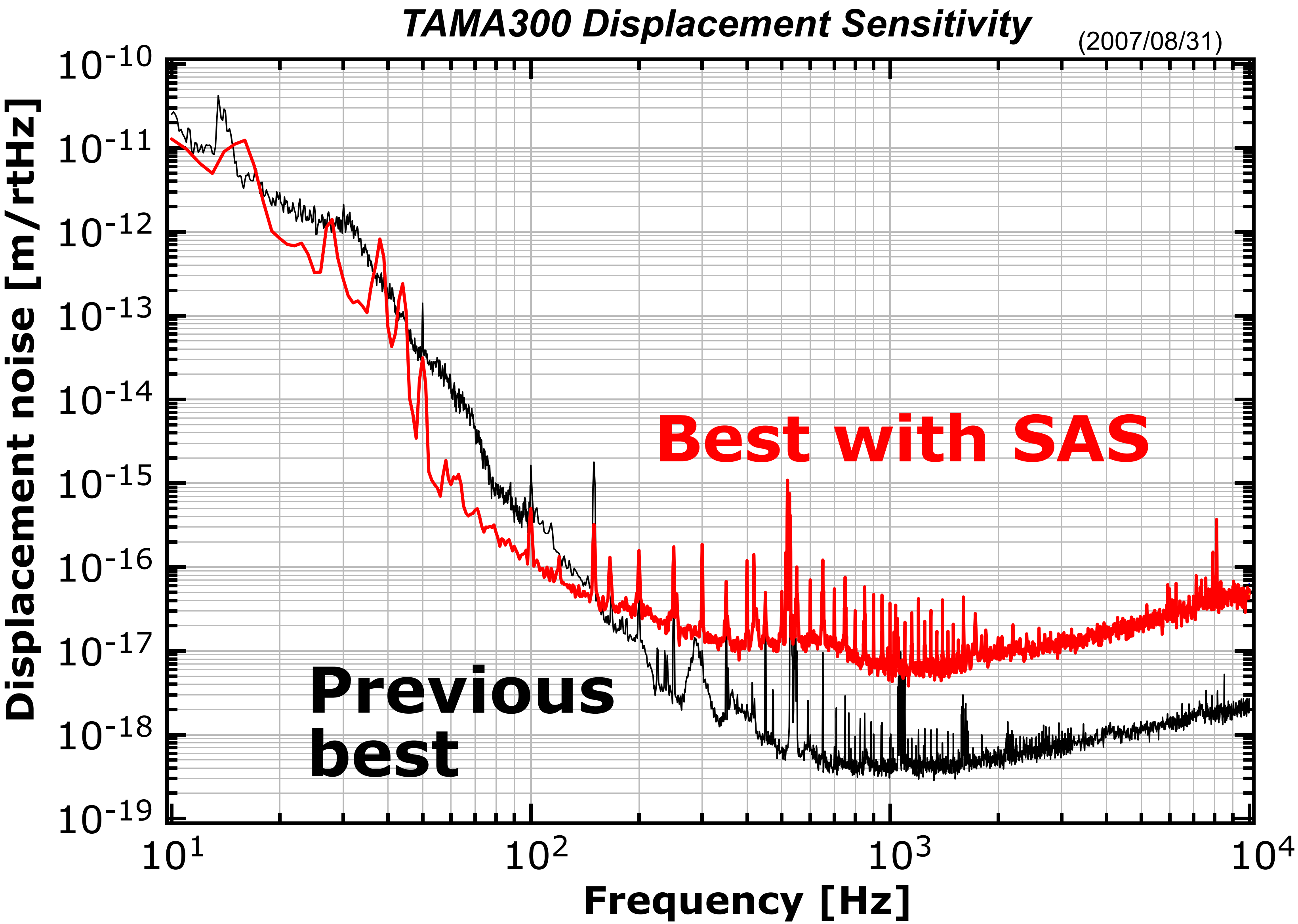
Pre-emphasis /De-emphasis



Sensitivity

- **Tuning of the system still underway**

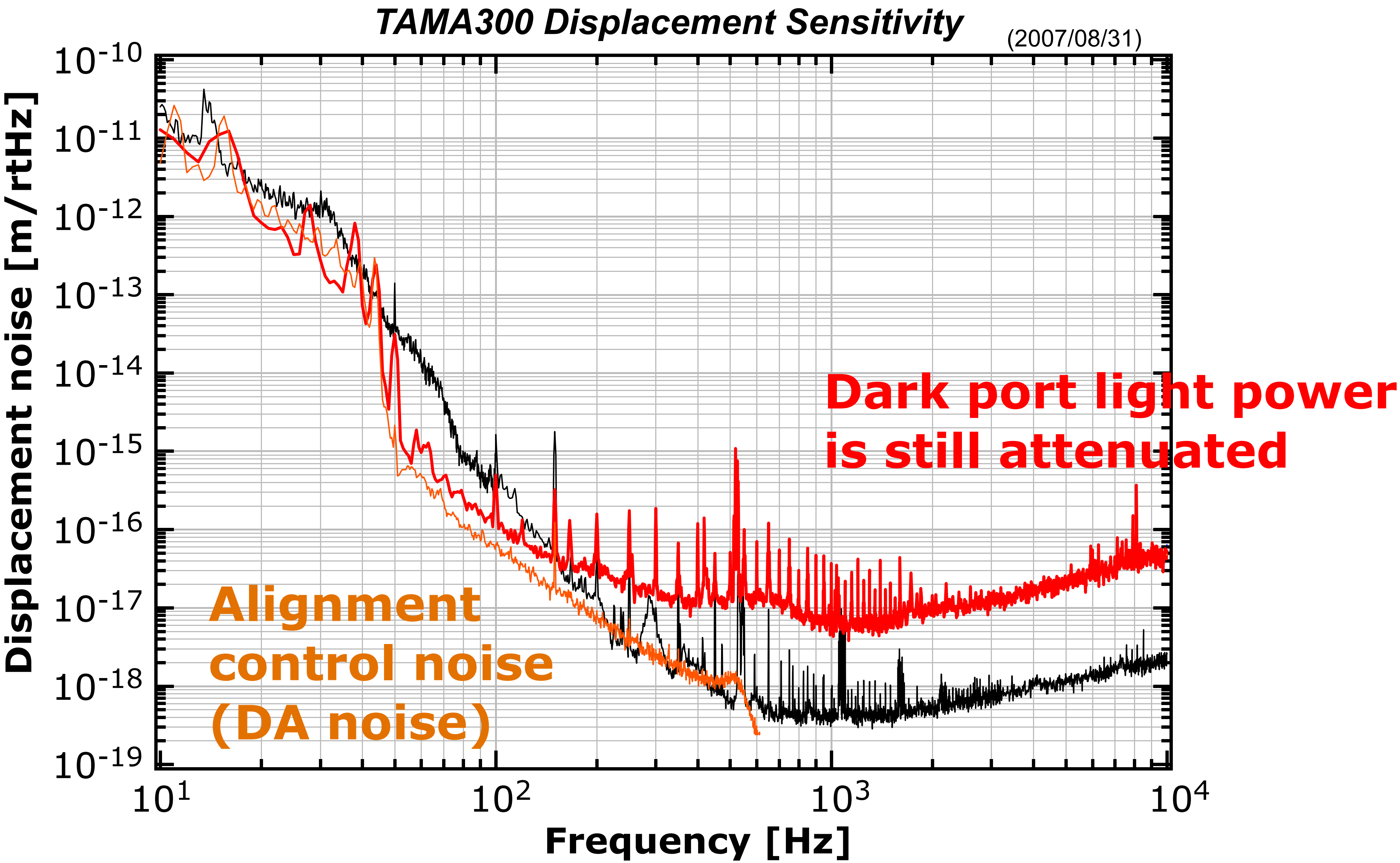
  So far, improvement below 150Hz was confirmed



Sensitivity

- **Tuning of the system still underway**

  So far, improvement below 150Hz was confirmed



Plan

- **How to achieve further improvement**

For alignment noise

Additional DA noise reduction is in progress

Activation of fast WFS servo (~x100 better sensing noise)

For high frequency

more power at the dark port

For further investigation

noise budgetting => needs more stability

For further improvement of SAS

performance of SAS is limted by the accelerometers

=> accelerometer study

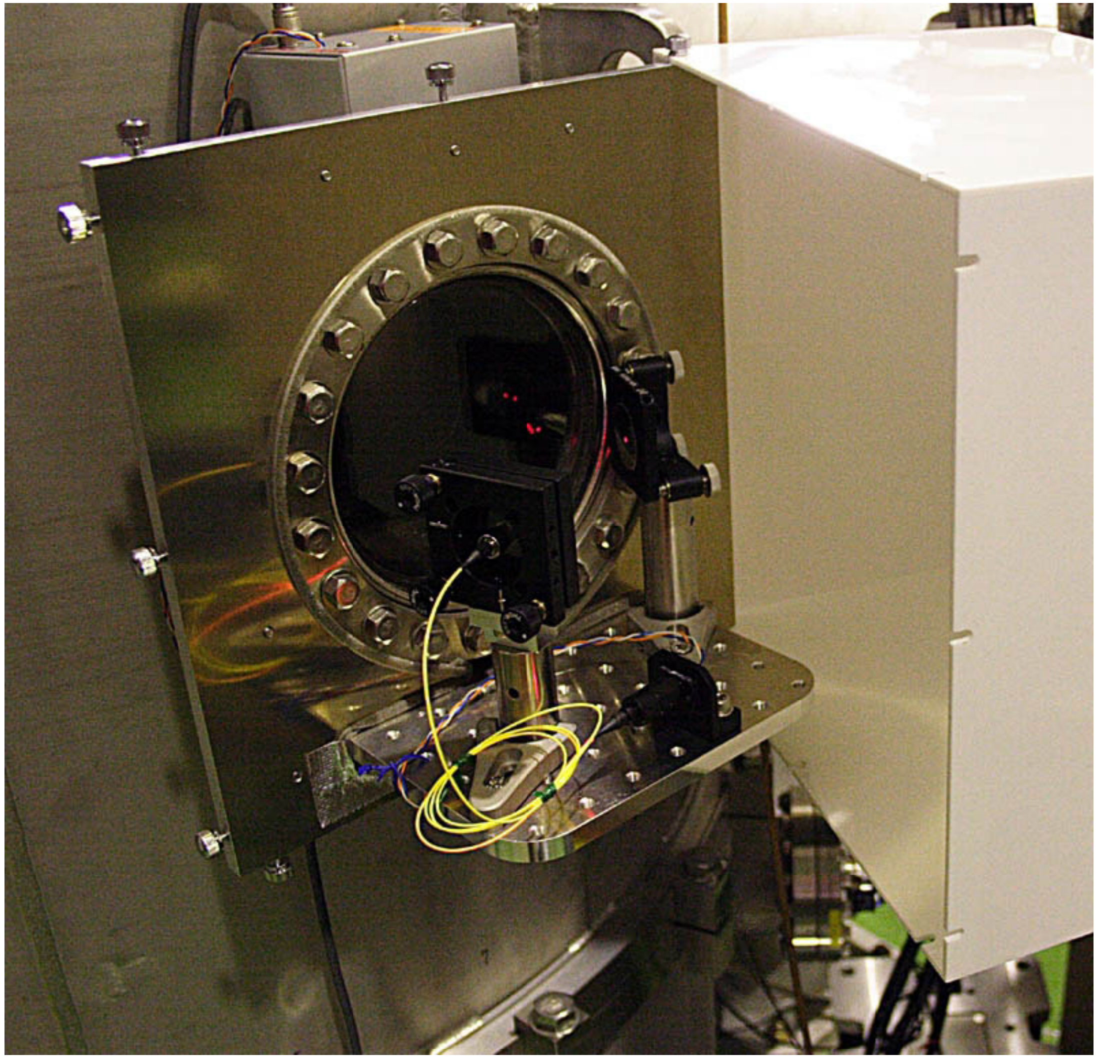
Summary

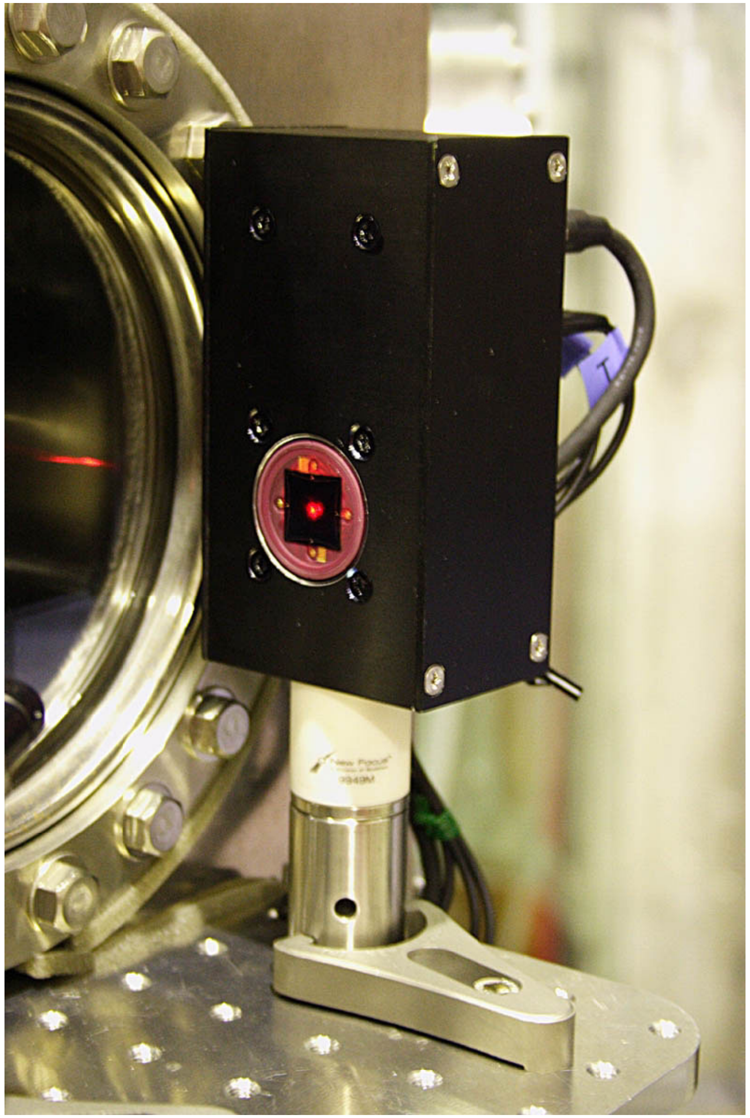
- **Current status**
  - SAS is now functioning
  - Shaking down of the detector system
    Underway. Still a lot of things to do.
  - Improvement was partially confirmed
    Between 0.1 to 150Hz
  - Gradually getting familiar with digital systems
- **Plan**
  - Improved binary range
    -> participation to AstroWatch campaign

Optical Lever System

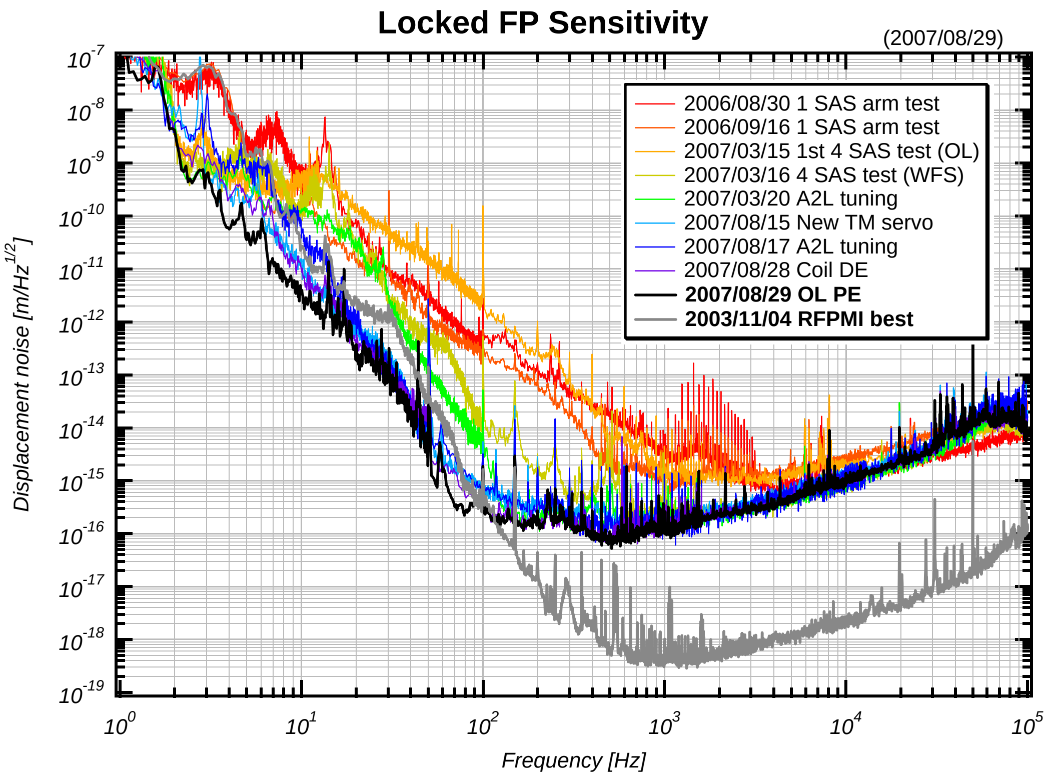
- **Diode Laser**

  optical table attached
  on the window frange

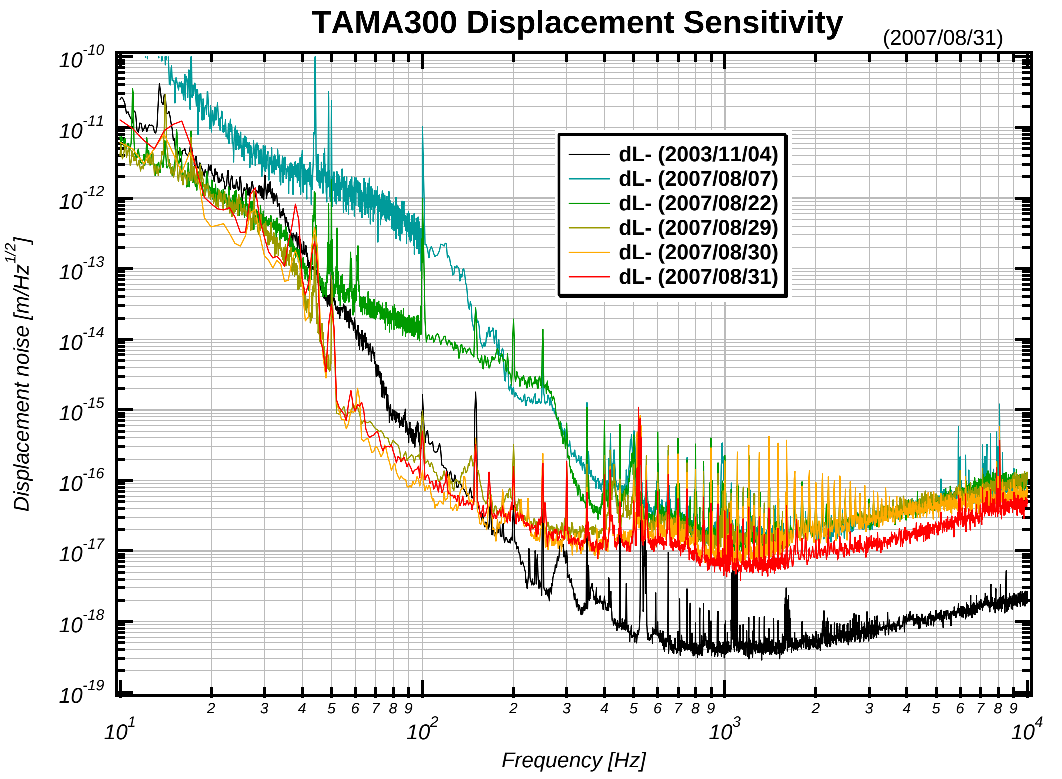




- **Position Sensitive Detector** Aperture size: 12mm x 12mm



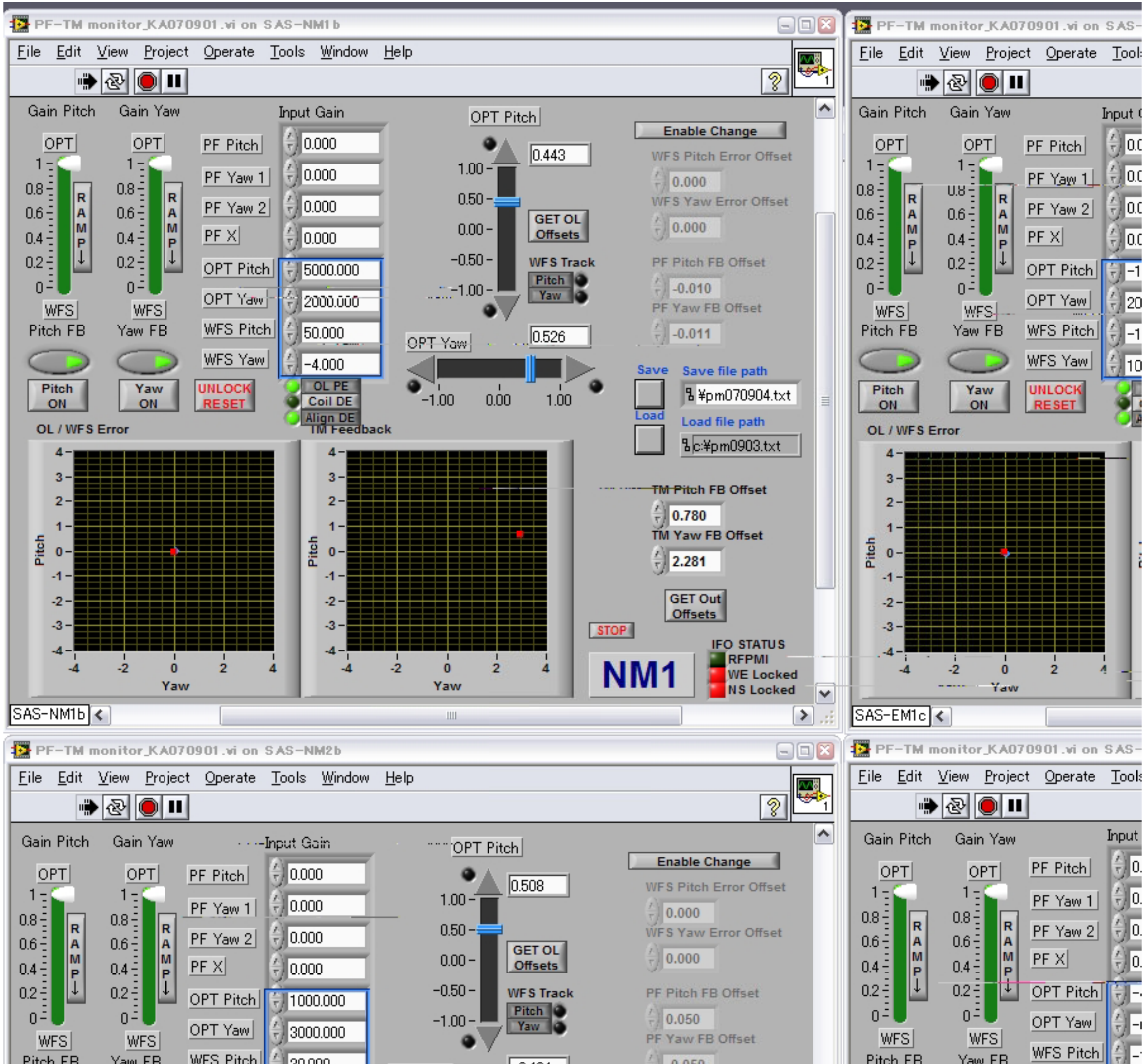
Locked FP Sensitivity
(2007/08/29)
2006/08/30 1 SAS arm test
2006/09/16 1 SAS arm test
2007/03/15 1st 4 SAS test (OL)
2007/03/16 4 SAS test (WFS)
2007/03/20 A2L tuning
2007/08/15 New TM servo
2007/08/17 A2L tuning
2007/08/28 Coil DE
2007/08/29 OL PE
2003/11/04 RFPMI best
Displacement noise [m/Hz^1/2]
Frequency [Hz]



TAMA300 Displacement Sensitivity
(2007/08/31)
dL- (2003/11/04)
dL- (2007/08/07)
dL- (2007/08/22)
dL- (2007/08/29)
dL- (2007/08/30)
dL- (2007/08/31)
Displacement noise [m/Hz^1/2]
Frequency [Hz]
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^1
10^2
10^3
10^4

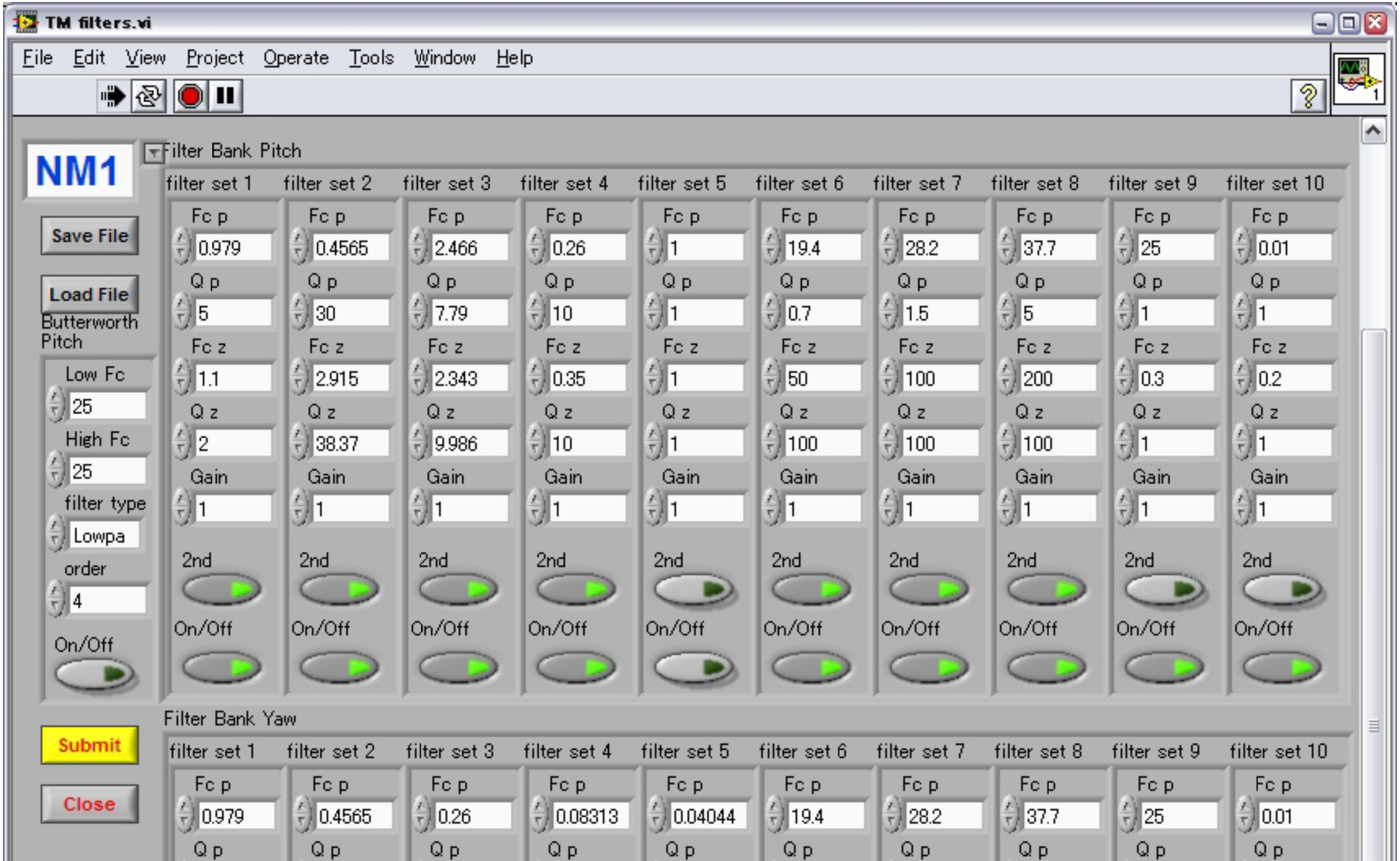
Interferometer Automatization by LabView

Digital Servo
/ Supervising



Interferometer Automatization by LabView

Dynamic changing of servo parameters

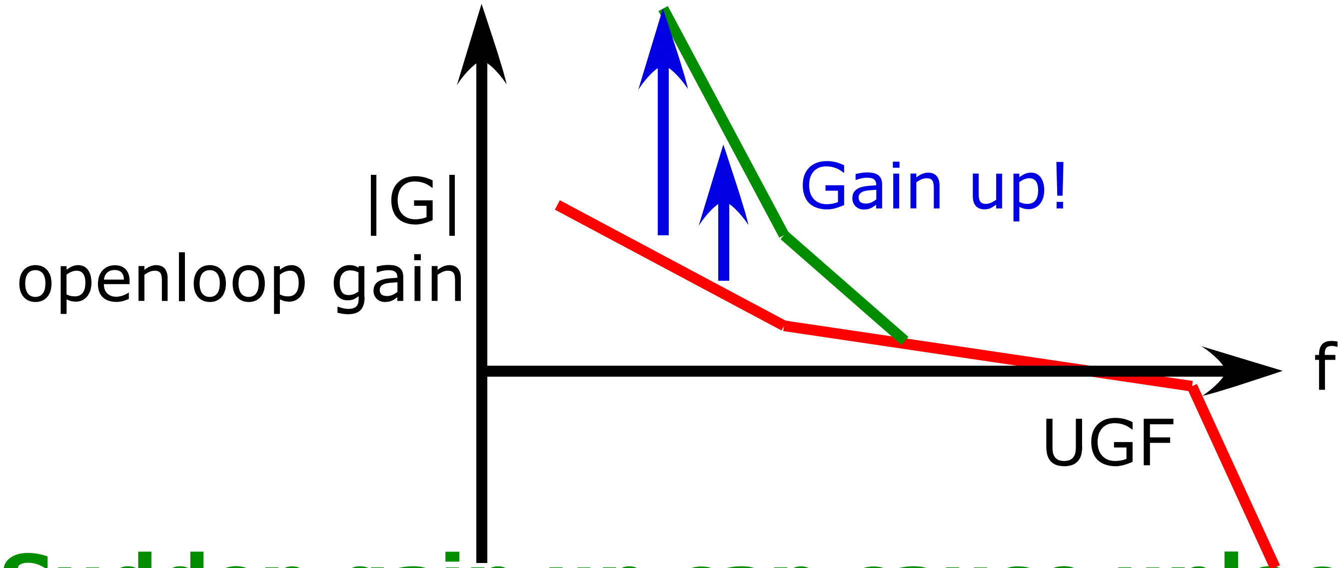


Digital Filter ~ gain up issue

o Low frequency gain boost at the lock

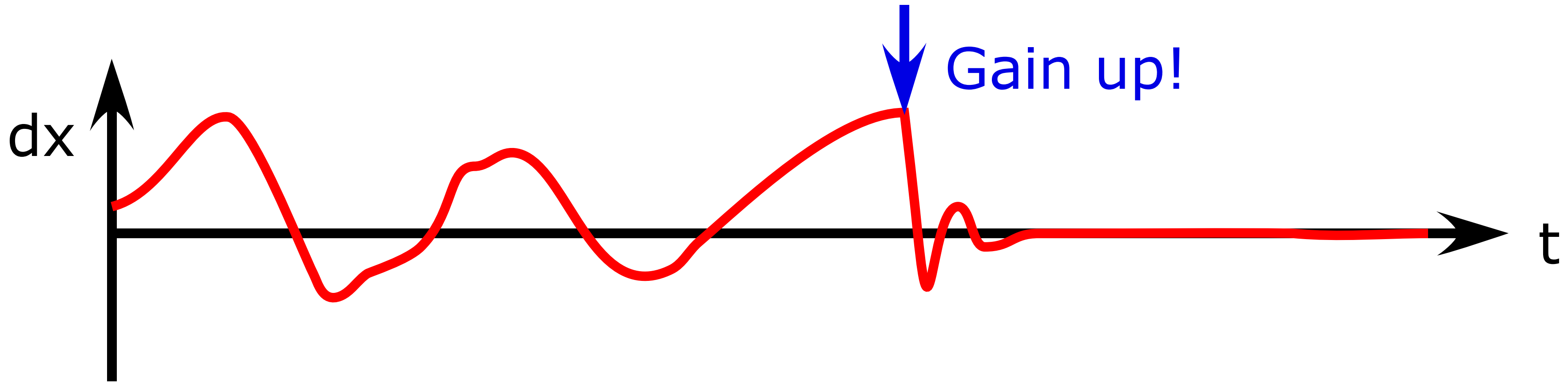
lock acquisition with large gain mergin

=>low freq gain boost for larger control gain after the lock



o Sudden gain up can cause unlock

Sudden increase of suppression



Digital Filter ~ gain up issue

o adaptive change of digital filter coefficient

Initial State

$$H(z) = 1$$

Final State

$$H(z) = \frac{1 + b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}}$$

2nd order zero (numerator)

2nd order pole (denominator)

$$H(z) = \frac{1 + b_1 z^{-1} + b_2 z^{-2}}{1 + [a_1\alpha + b_1(1-\alpha)] z^{-1} + [a_2\alpha + b_2(1-\alpha)] z^{-2}}$$

$\alpha=0$: initial state

$\alpha=1$: final state

Digital Filter ~ gain up issue

o What happens in between?

=> modest change of pole freq and Q

o Supression ratio

= inverse of DC gain

= $[(f_{pole}/f_{zero})^2]^{-1}$

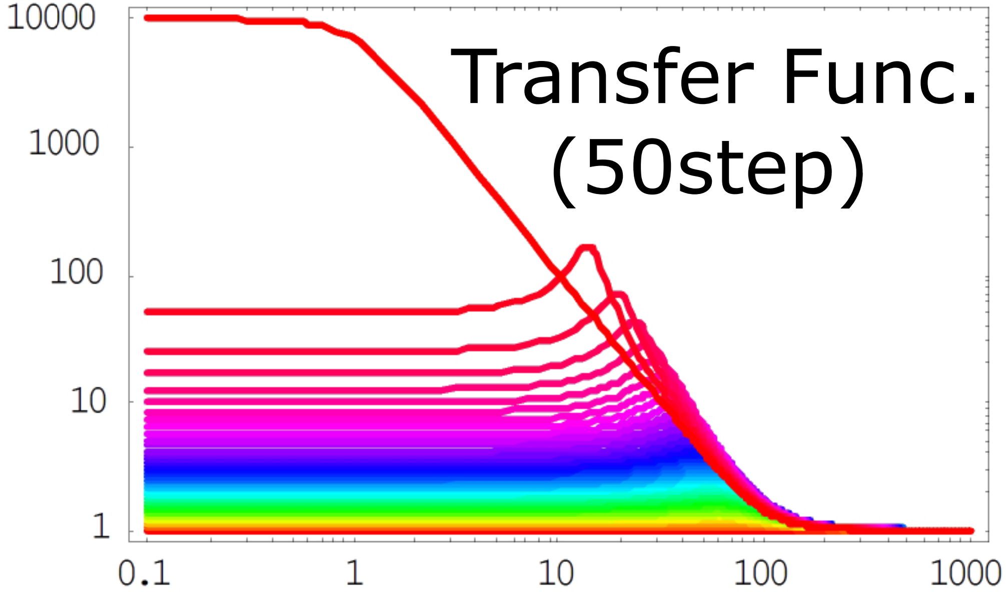
linear change of α

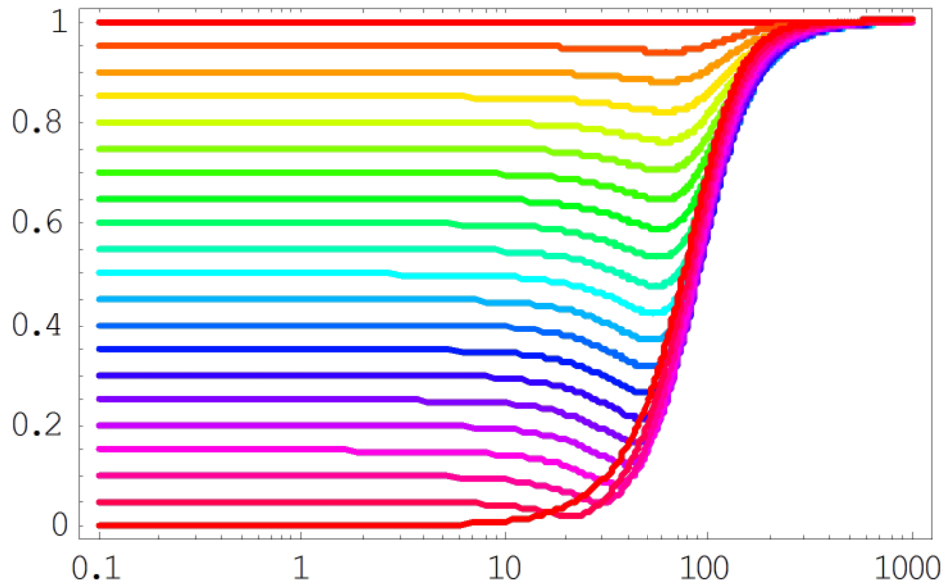
=> linear change of suppression

This is ideal!

low computation cost

=> useful for fast digital control





Suppression Ratio