Commissioning and performance of the SR suspensions of KAGRA

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On behalf of KAGRA collaboration.

National Astronomical Observatory of Japan

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Type B suspensions:

(1) **Mode identification for SR mirrors with SUMCON.**

(2) **Measured transfer functions of the system and zpk fitting.**

Software modifications and updates:

(3) **Remote reset for steppermotors.**

(4) **BS and SRs models splitting.**

(5) **Modifications to the control scheme and Guardian updates.**

Performance and work ongoing:

(6) **Damping of the modes stage by stage.**

(7) **RMS motion reduction at mirror level and decay time measurements.**

(8) **Meeting the requirements.**

(9) **Future work.**

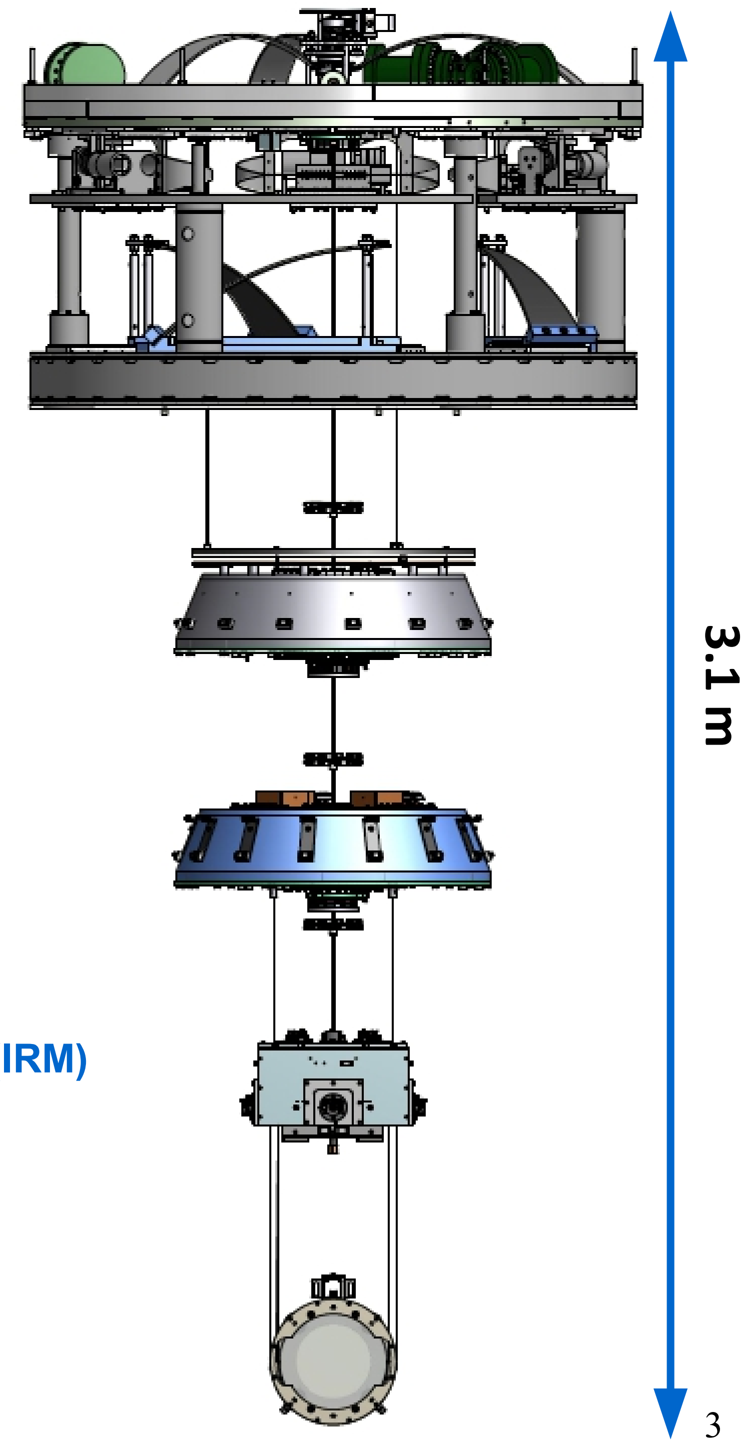
Type B suspensions

- BS
- SR2
- SR3
- SRM

Pre-Isolator
- Top Filter (TF)
- Filter0 (F0)
- Inverted Pendulum (IP)

GAS Filter Chain
- Magnetic Damper (MD)
- Standard Filter (SF)
- Bottom Filter (BF)

Payload
- Intermediate Recoil Mass (IRM)
- Intermediate Mass (IM)
- Recoil Mass (RM)
- Optics (SR)



Type B model in SUMCON

SUMCON spension odel structor in Mathematica

SUMCON Version:1.4

About SUMCON | Version Info | Refresh

New Model | Load Model | Save Model | TypeB_SRM_GAS_freq_IP_new_stiff_updated_20190209.m

Model Construction | Calculation Result | Export Model

Model Basic Information

Degrees of Freedom:

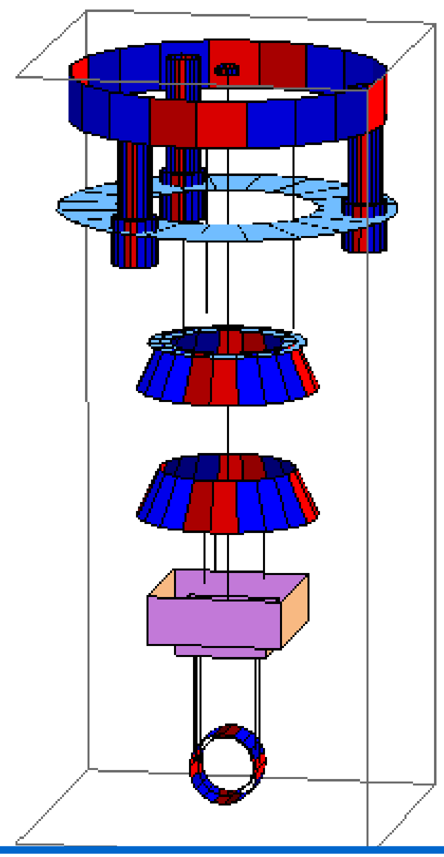
45 State Variables
6 Input Variables
3 Float Variables

Ground Position:

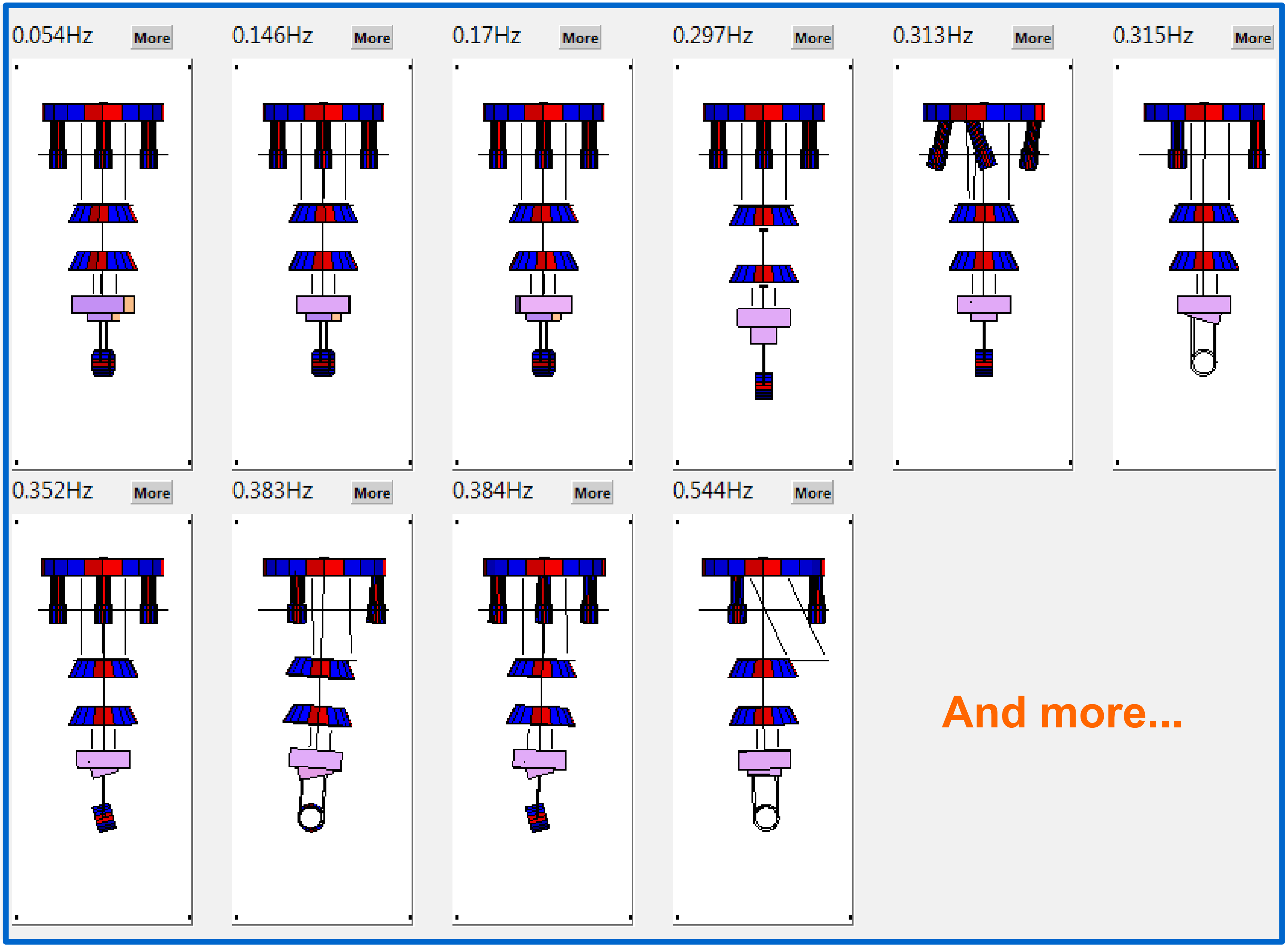
xg → 0. yg → 0. zg → 0. pitchg → 0. yawg → 0. rollg → 0.

Equilibrium Point:

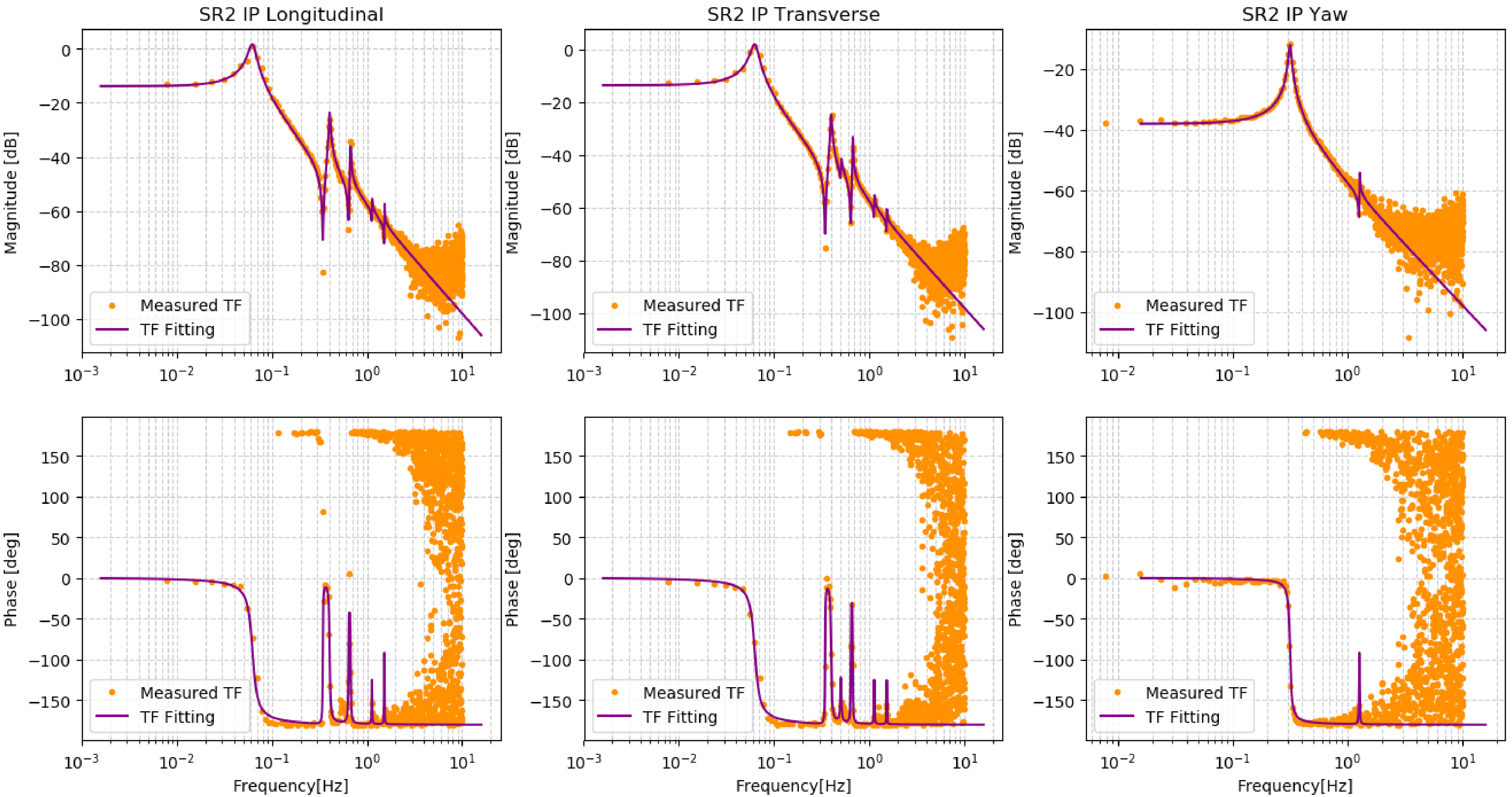
xF0 → 0.	zF0 → 0.	yawF0 → 0.	xMD → 0.	yMD → −0.5719	zMD → 0.
pitchMD → 0.	yawMD → 0.	rollMD → 0.	xF1 → 0.	yF1 → −0.6652	zF1 → 0.
pitchF1 → 0.	yawF1 → 0.	rollF1 → 0.	xF2 → 0.	yF2 → −1.2054	zF2 → 0.
pitchF2 → 0.	yawF2 → 0.	rollF2 → 0.	xIR → 0.	yIR → −1.708	zIR → 0.
pitchIR → 0.	yawIR → 0.	rollIR → 0.	xIM → 0.	yIM → −1.7841	zIM → 0.
pitchIM → 0.	yawIM → 0.	rollIM → 0.	xRM → 0.	yRM → −2.3709	zRM → 0.
pitchRM → 0.	yawRM → 0.	rollRM → 0.	xTM → 0.	yTM → −2.3686	zTM → 0.
pitchTM → 0.	yawTM → 0.	rollTM → 0.	hGAS0 → 0.	hGAS1 → 0.	hGAS2 → 0.



Type B eigenmodes (SUMCON)

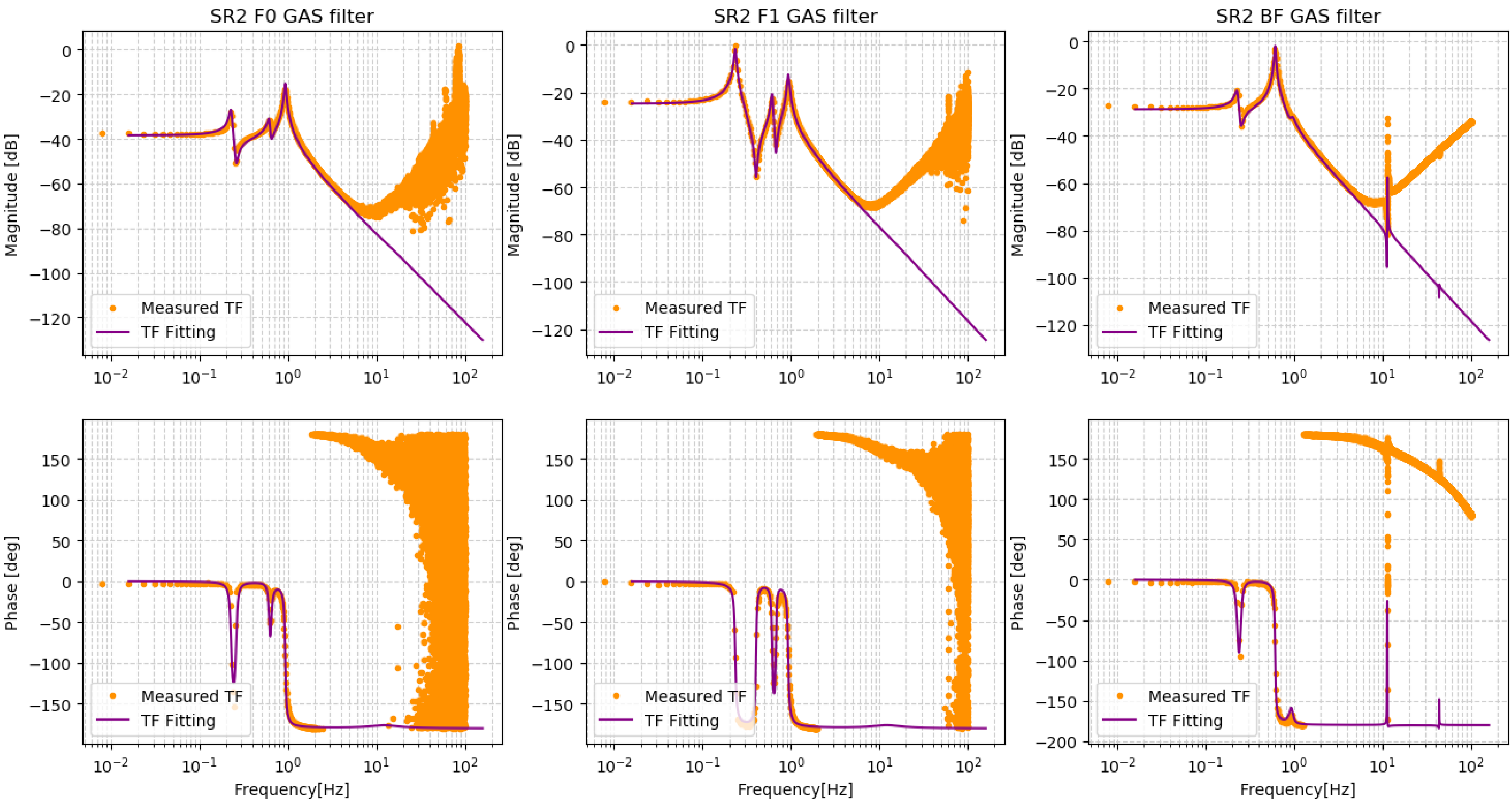


Transfer functions of the system



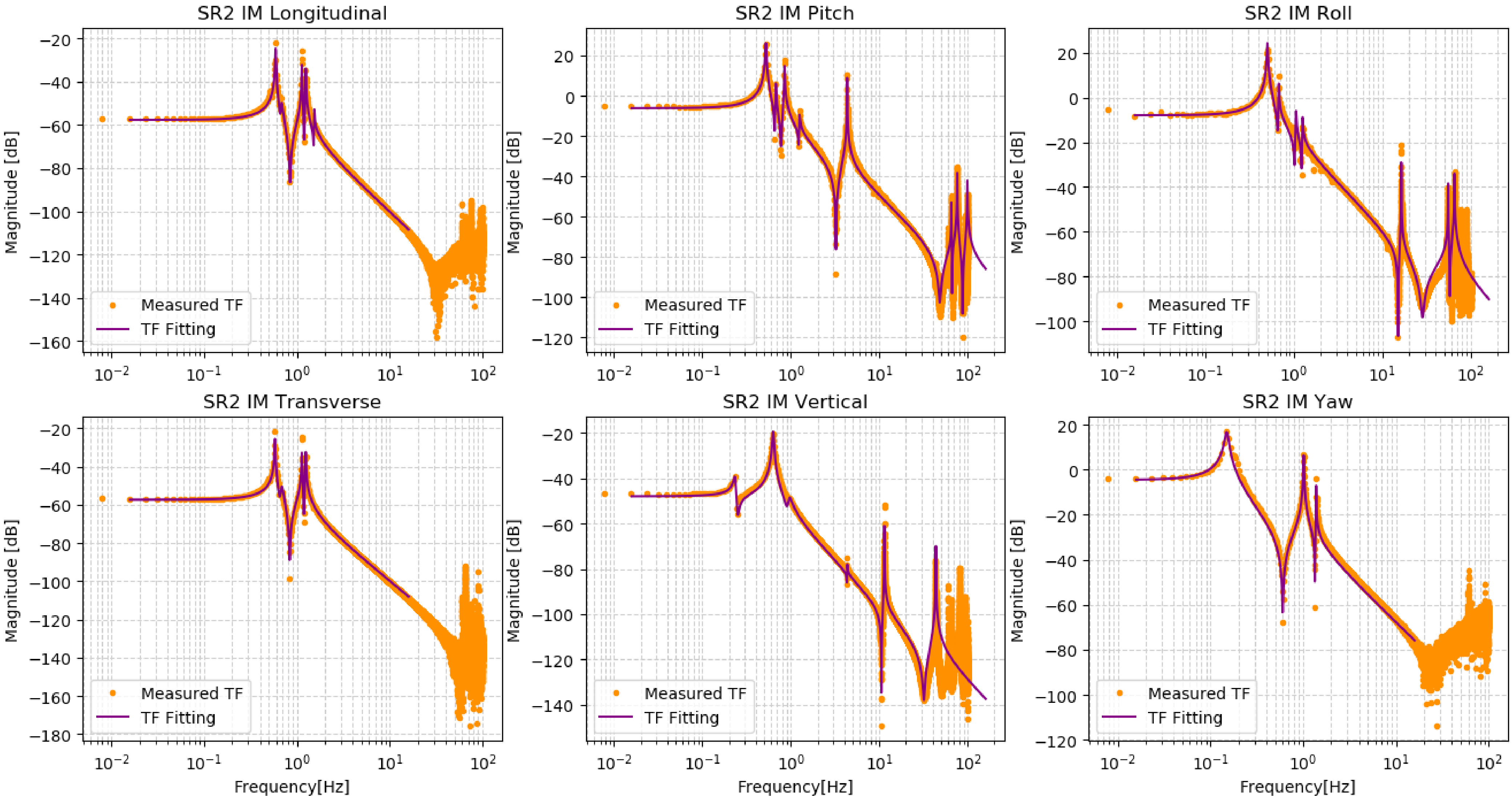
IP stage ZPK fitting to help with the design of active filters.

Transfer functions of the system



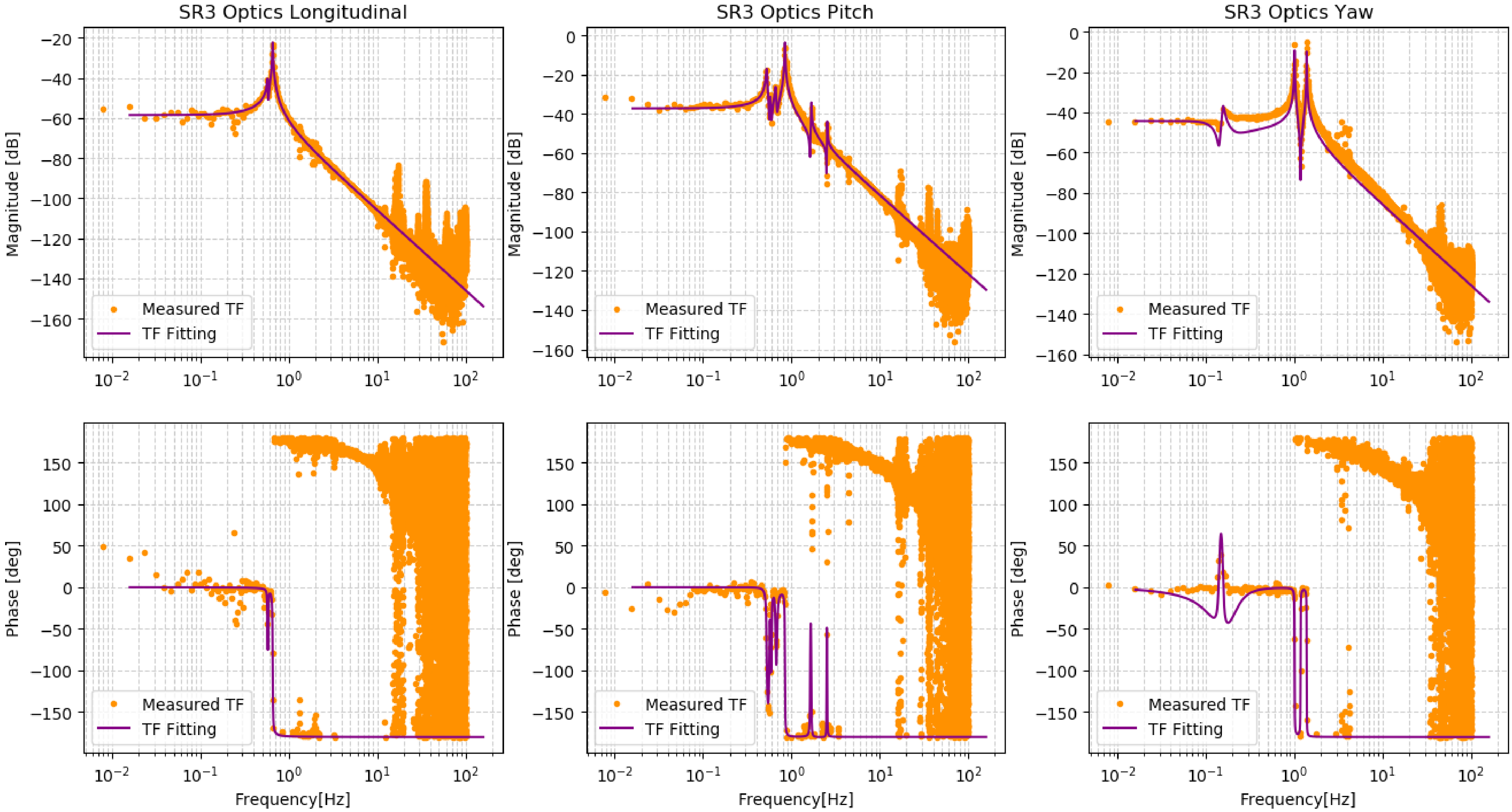
GAS Filter Chain ZPK fitting to help with the design of active filters.

Transfer functions of the system



IM stage ZPK fitting to help with the design of active filters.

Transfer functions of the system

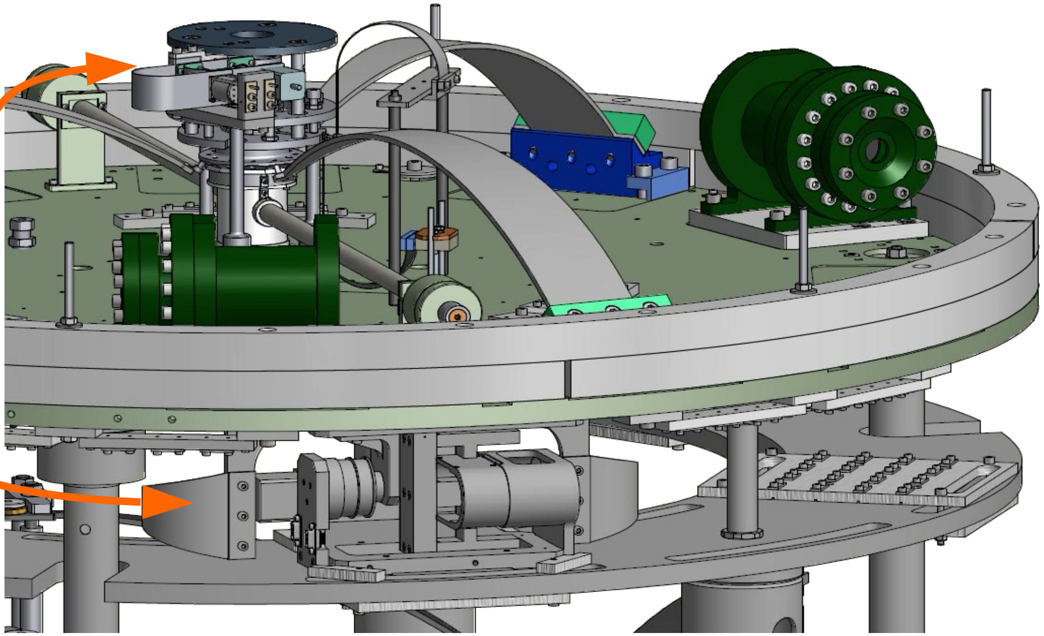


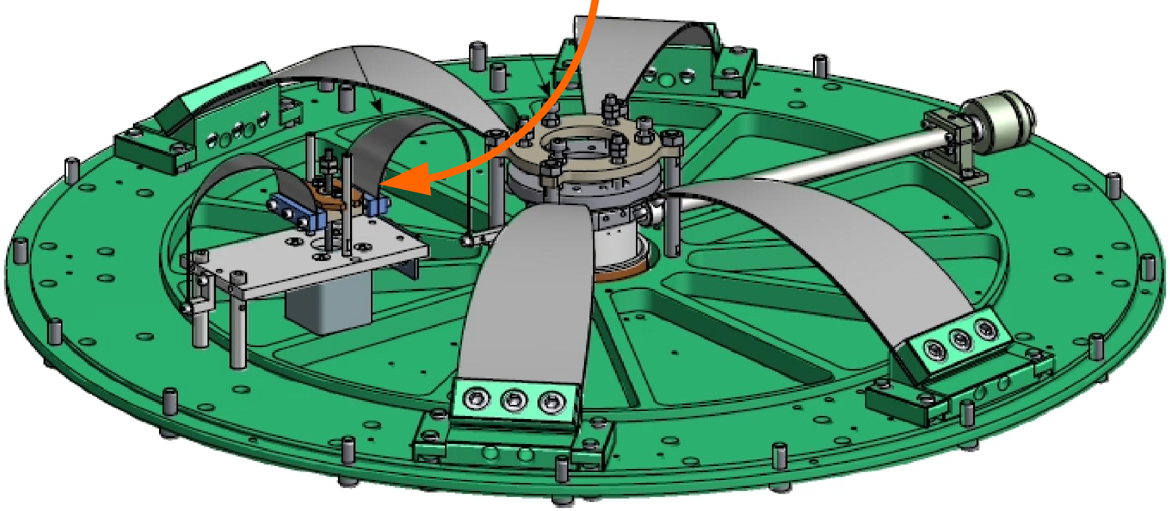
Mirror stage ZPK fitting to help with the design of active filters.

Modifications and updates

Remote reset for stepper motor.

- 1 motor to rotate the chain in yaw.
- 3 motors at IP stage.
- 1 motor at F0 GAS filter.
- 1 motor at F1 GAS filter.
- 1 motor at F1 GAS filter.





Modifications and updates

Preventive measures:
- **Model splitting of BS, SR2, SR3 and SRM.**
- **Down-sampling of the models.**

SRM RTM rate: 16K

- **IP stage**
- **GAS filter chain**
- **IM stage**
- **Optics stage**
- **BIO**

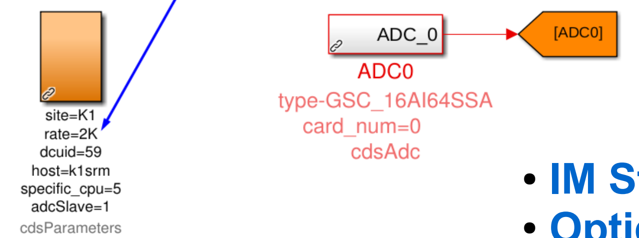
KAGRA SRM top stage Model

Sample rate: 2K

- **IP Stage.**
- **GAS filter chain.**

KAGRA SRM Payload Model

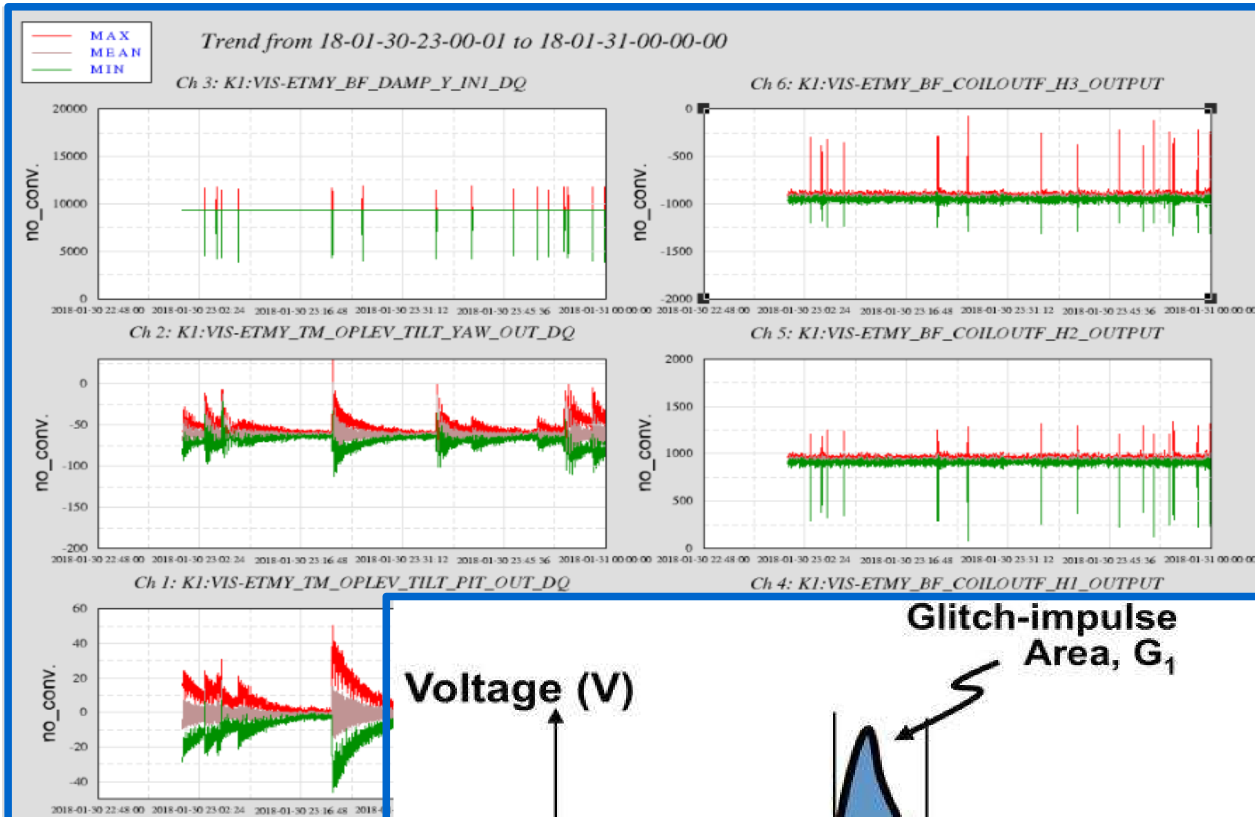
Sample rate: 2K

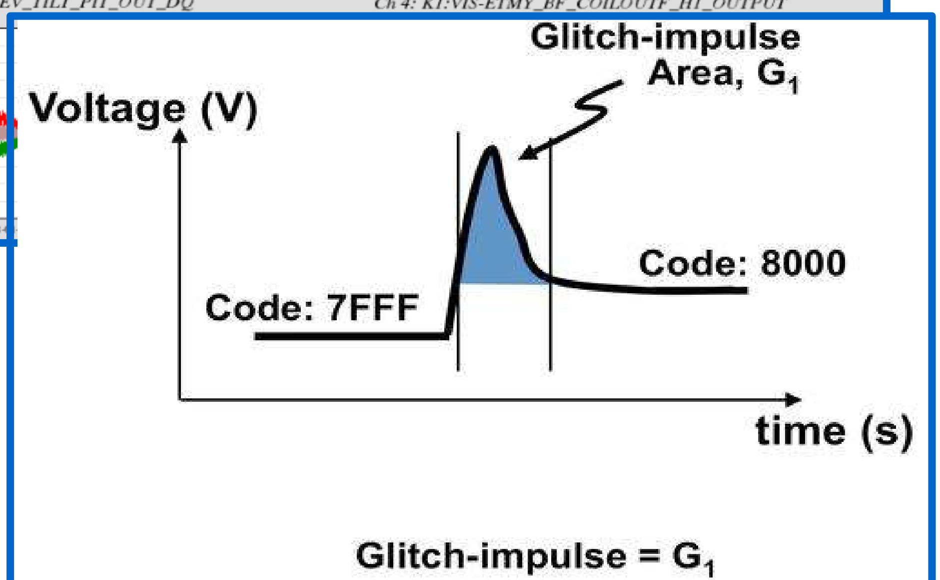


- **IM Stage.**
- **Optics Stage.**

Splitting real-time model of BS and SRs

DAC Glitches found at ETMY. Klog4072.





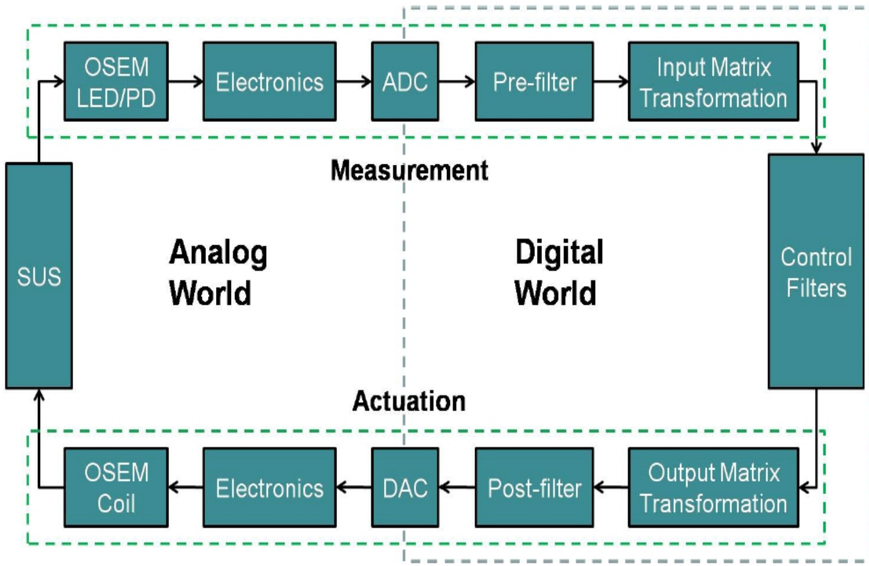
Glitches are a common issue in high speed D/A converters.

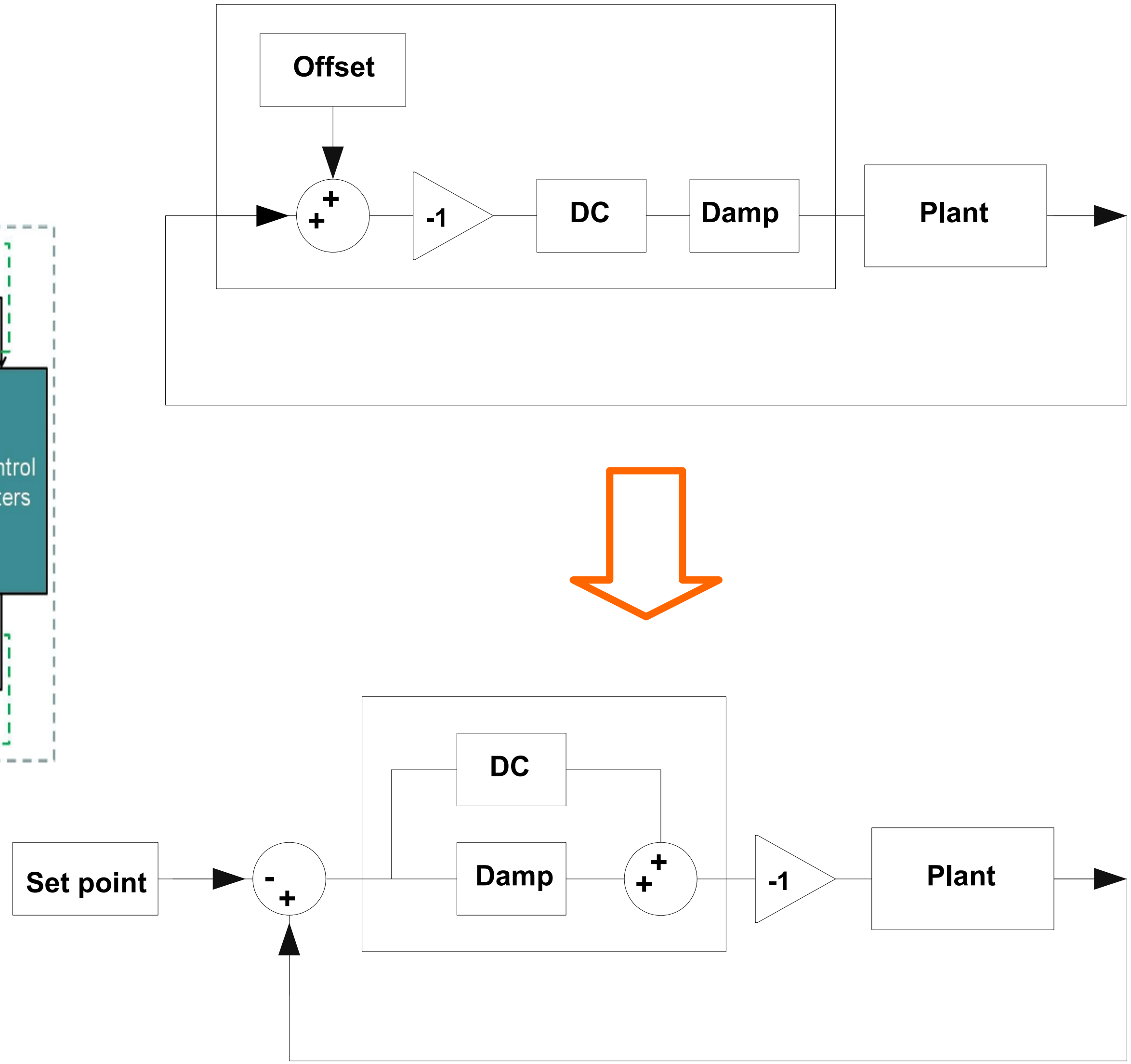
Some causes:

- Time skew between bits of incoming data.
- Major- carry transition of bits.
- Timing difference in the operation of the switches of the internal architecture.

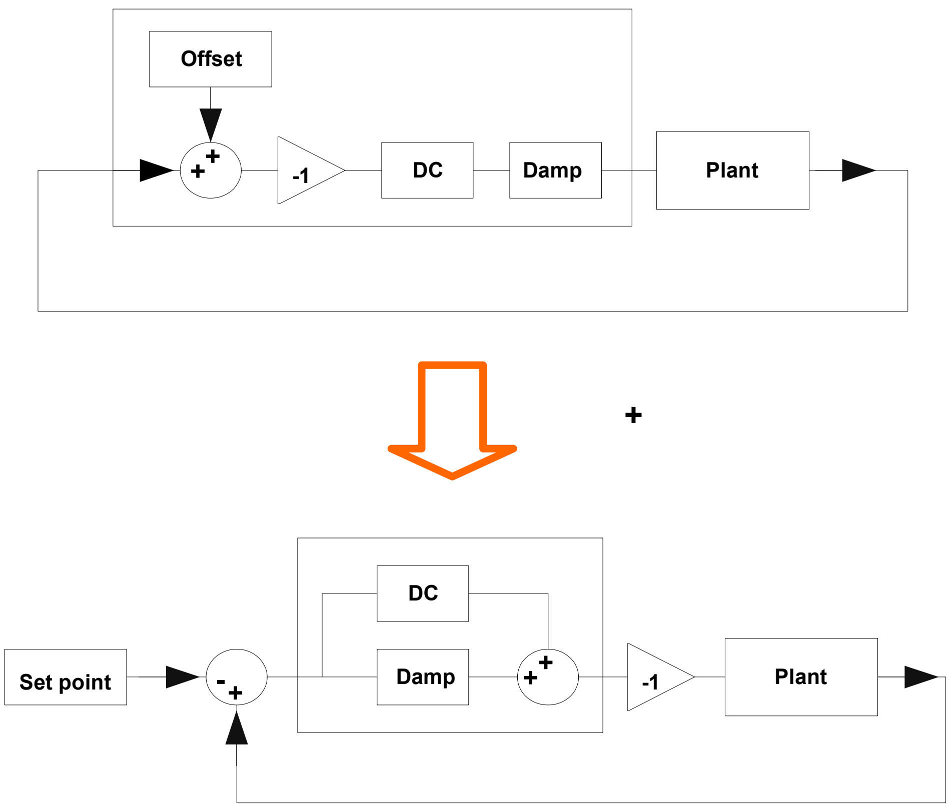
Study other solutions if necessary...

Modifications in the control scheme

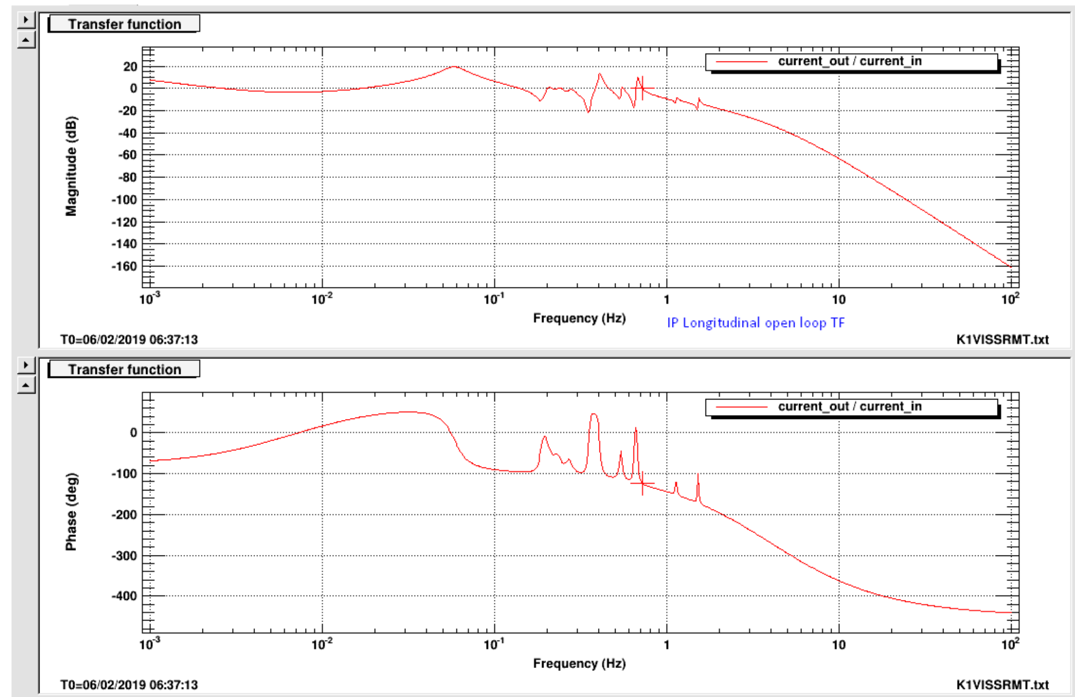




Check of control loop stability



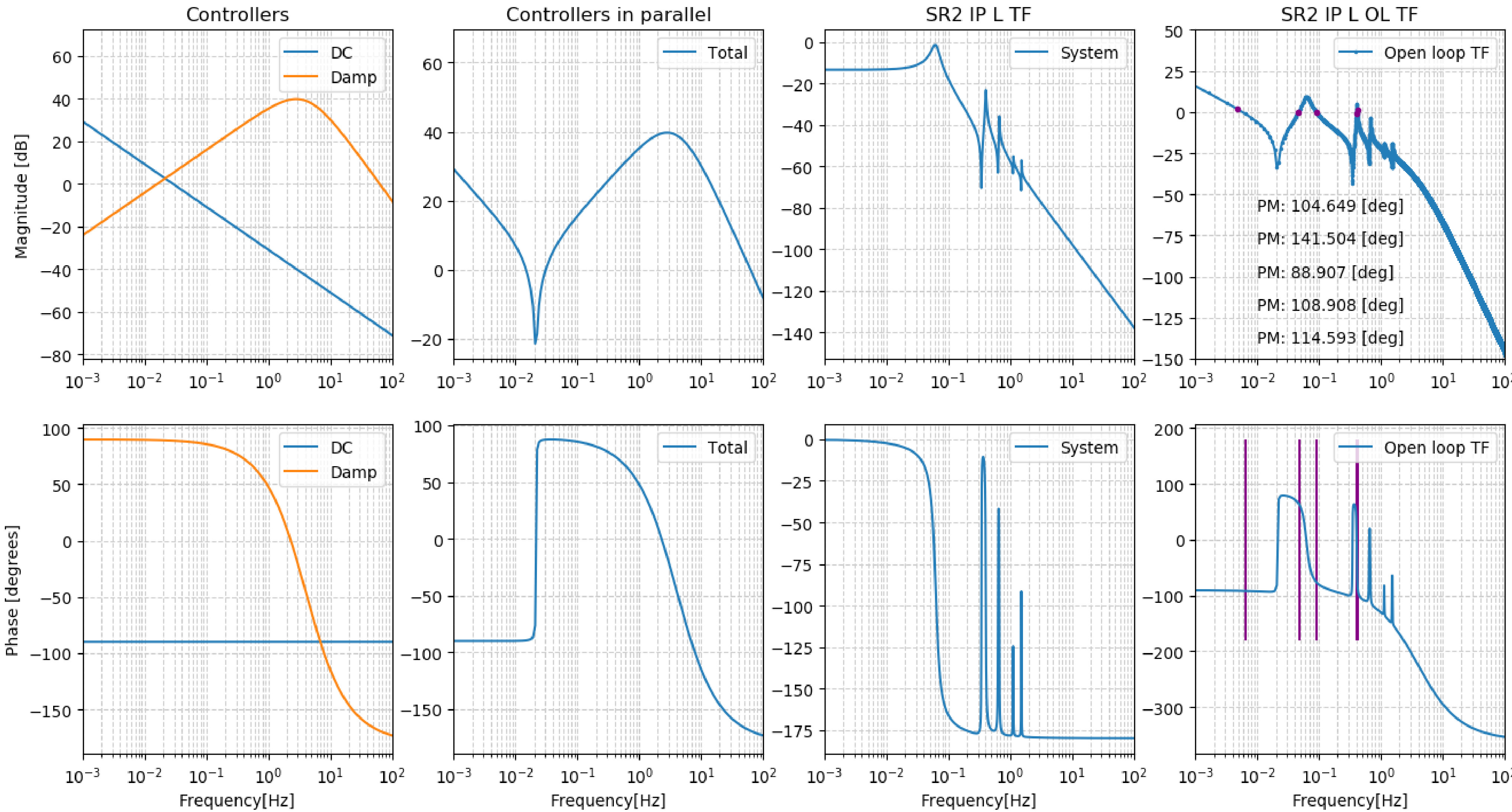
With the previous scheme it was easy to check stability in Foton.

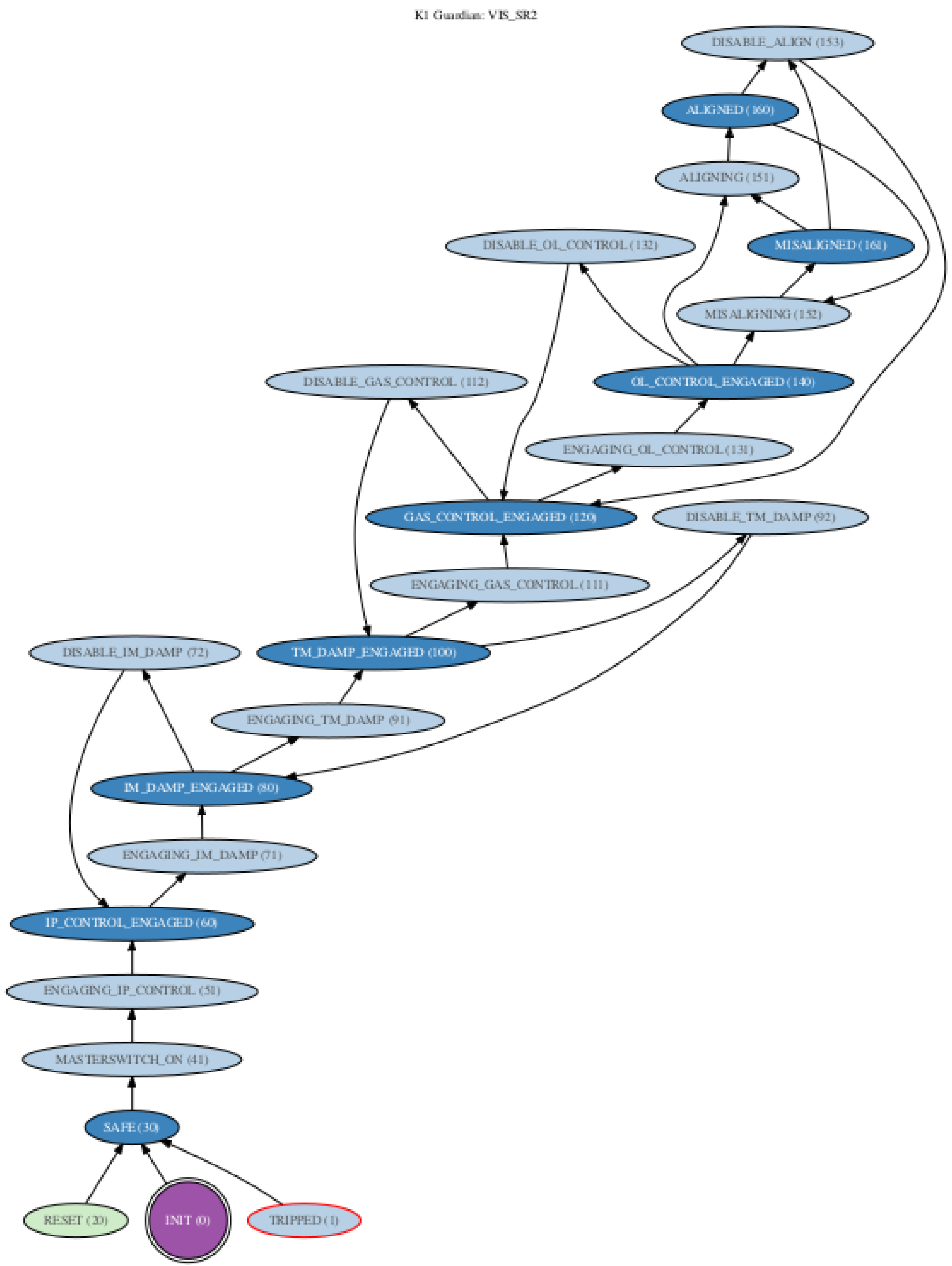


The new scheme requires another way to check the stability of the loop.

Check of control loop stability

Example: SR2 IP Longitudinal.

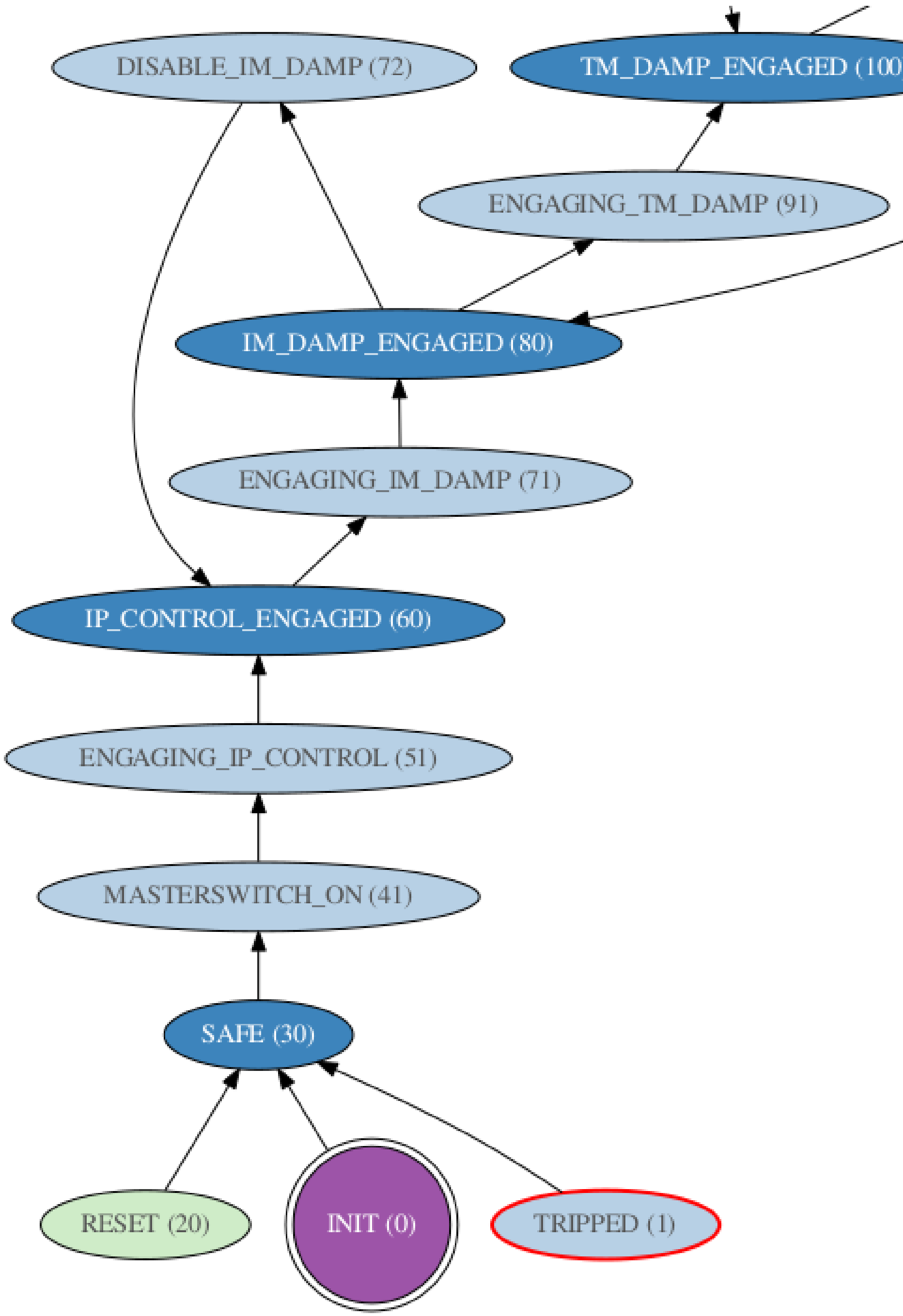




Guardian updates

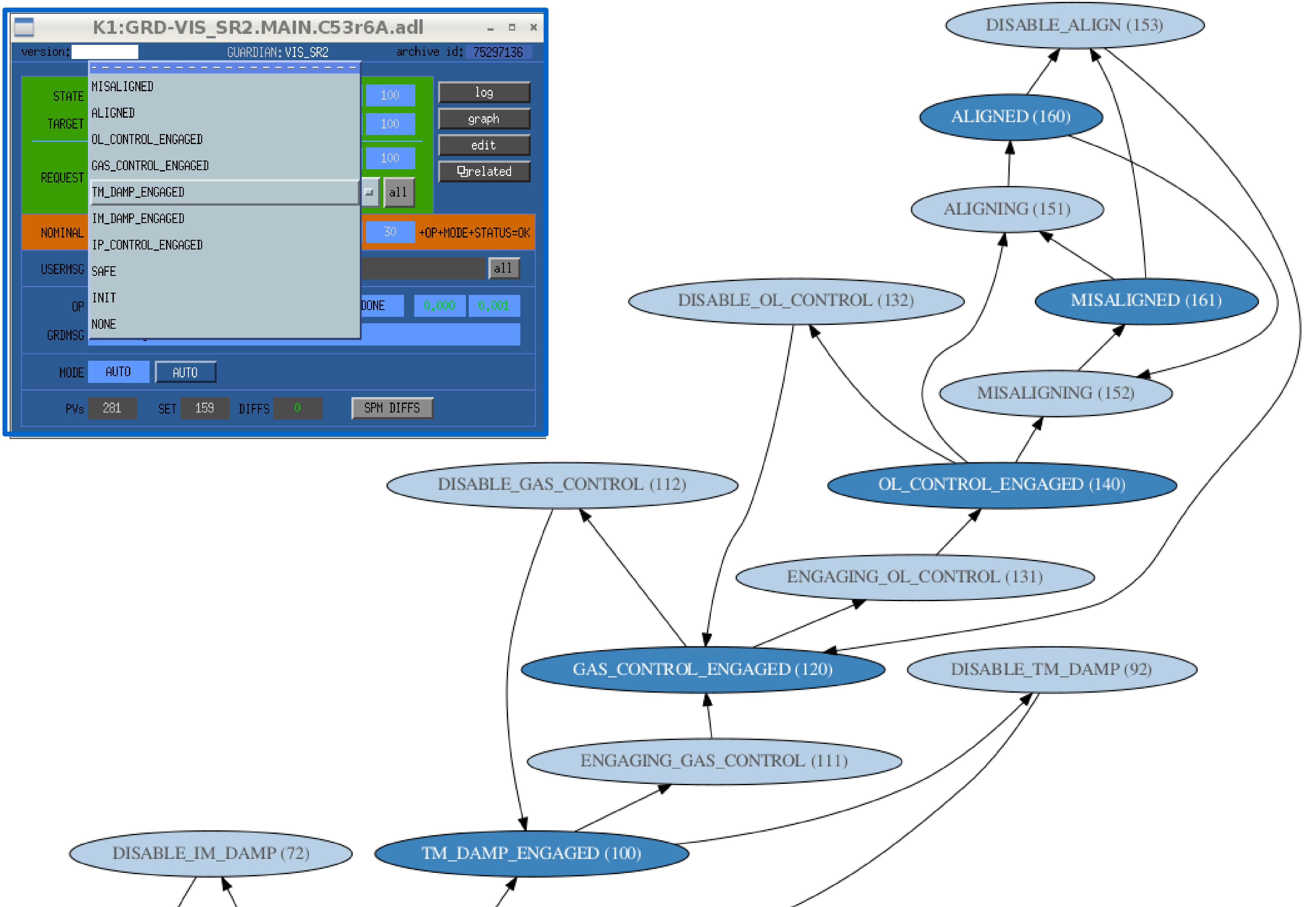
- Additional states.
- Snapshot to save settings at different states.
- New control sequence:
  IP – IM – Optics – GAS filters.
- Differentiated ramp times for engage and disable of the controls.

Details in klog8151 and klog8212.

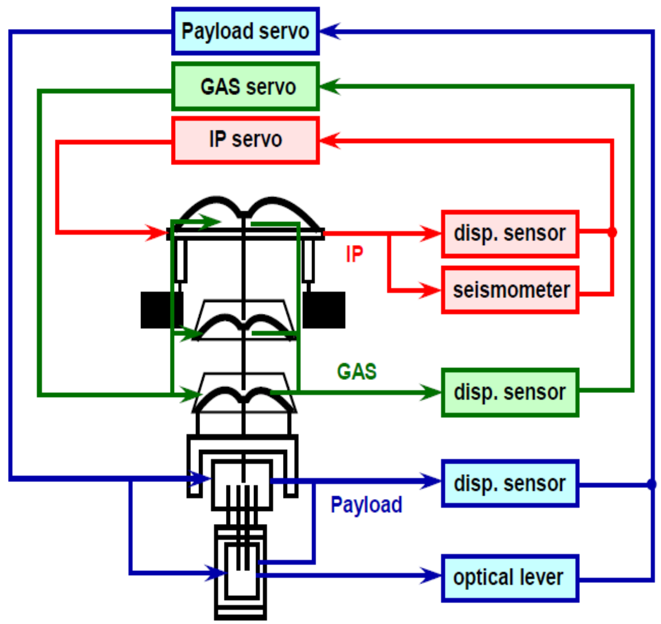

DISABLE_IM_DAMP (72)
TM_DAMP_ENGAGED (100)
ENGAGING_TM_DAMP (91)
IM_DAMP_ENGAGED (80)
ENGAGING_IM_DAMP (71)
IP_CONTROL_ENGAGED (60)
ENGAGING_IP_CONTROL (51)
MASTERSWITCH_ON (41)
SAFE (30)
RESET (20)
INIT (0)
TRIPPED (1)


K1:GRD-VIS_SR2.MAIN.C53r6A.adl
version:
GUARDIAN:VIS_SR2
archive id: 75297136
STATE
TARGET
REQUEST
MISALIGNED
ALIGNED
OL_CONTROL_ENGAGED
GAS_CONTROL_ENGAGED
TM_DAMP_ENGAGED
IM_DAMP_ENGAGED
IP_CONTROL_ENGAGED
SAFE
INIT
NONE
100
100
100
all
log
graph
edit
related
NOMINAL
30
+OP+MODE+STATUS=OK
USERMSG
all
OP
DONE
0.000
0.001
GRDMSG
MODE
AUTO
AUTO
PVs
281
SET
159
DIFFS
0
SPM DIFFS

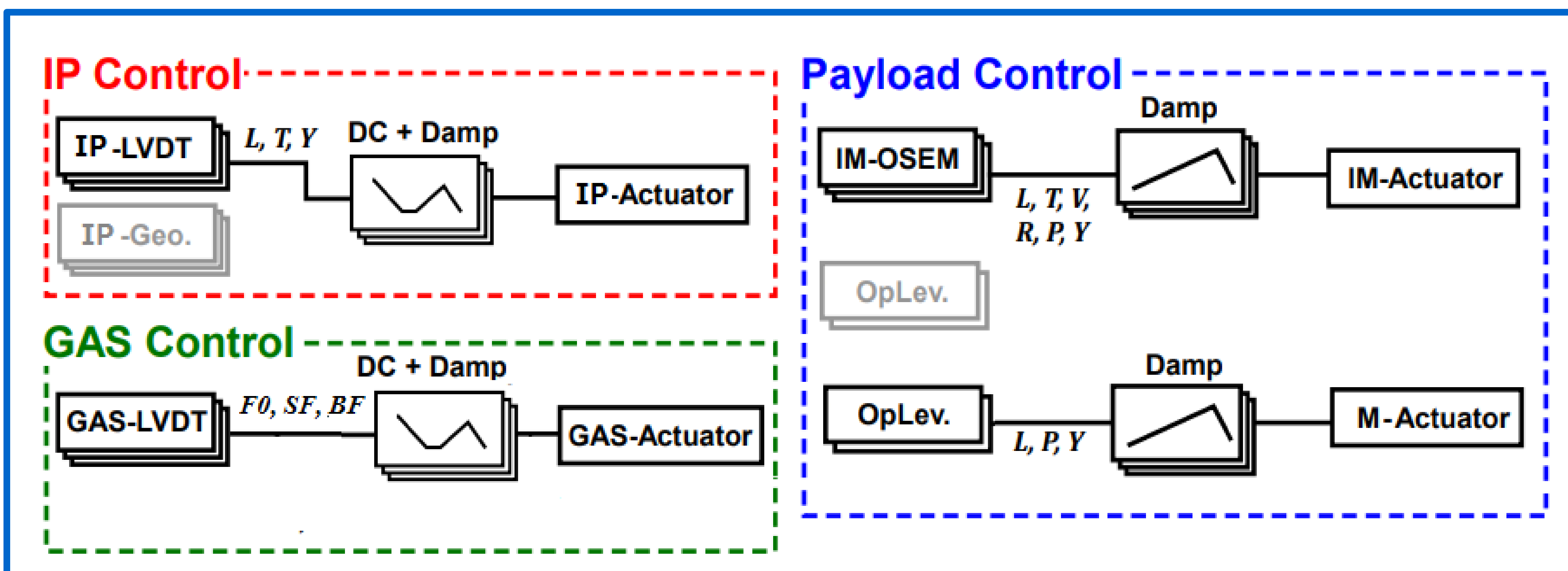
K1 Guardian: VIS_SR2



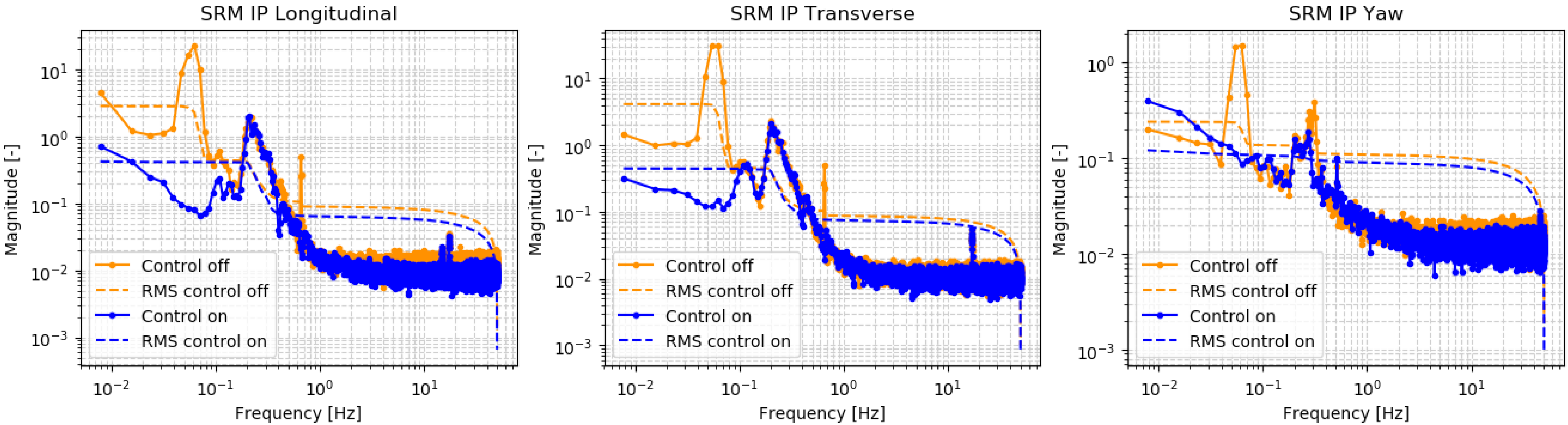
Damping of the modes stage by stage

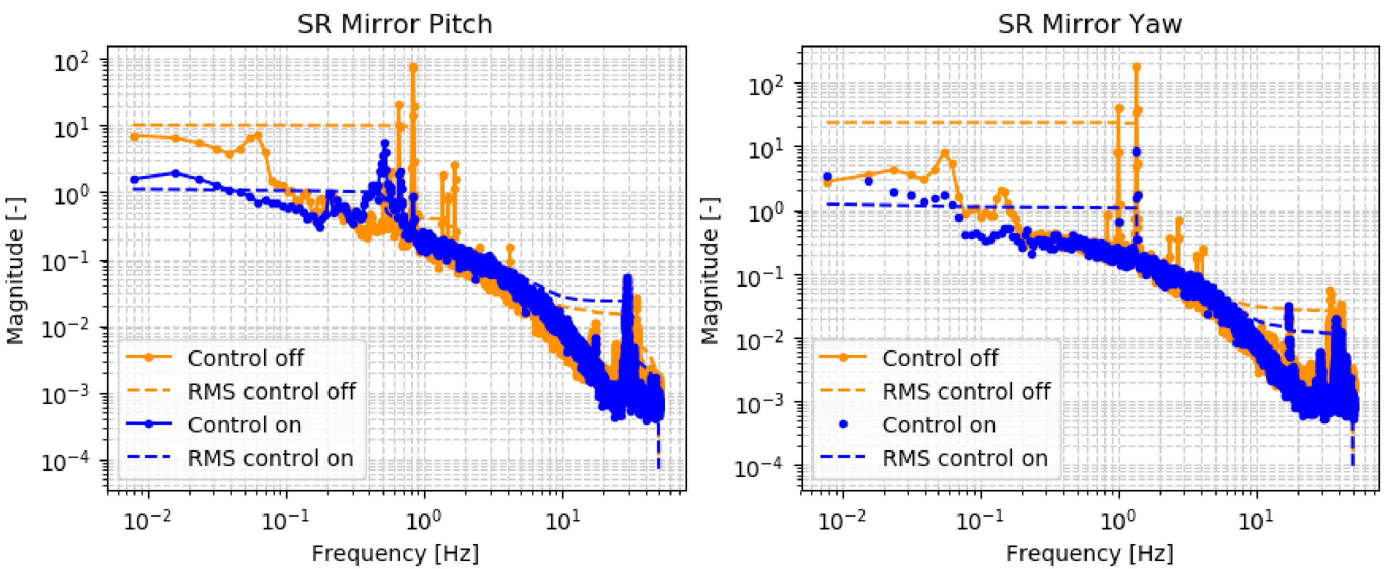


Sensors and active filter control used at each stage.



Damping of the modes stage by stage

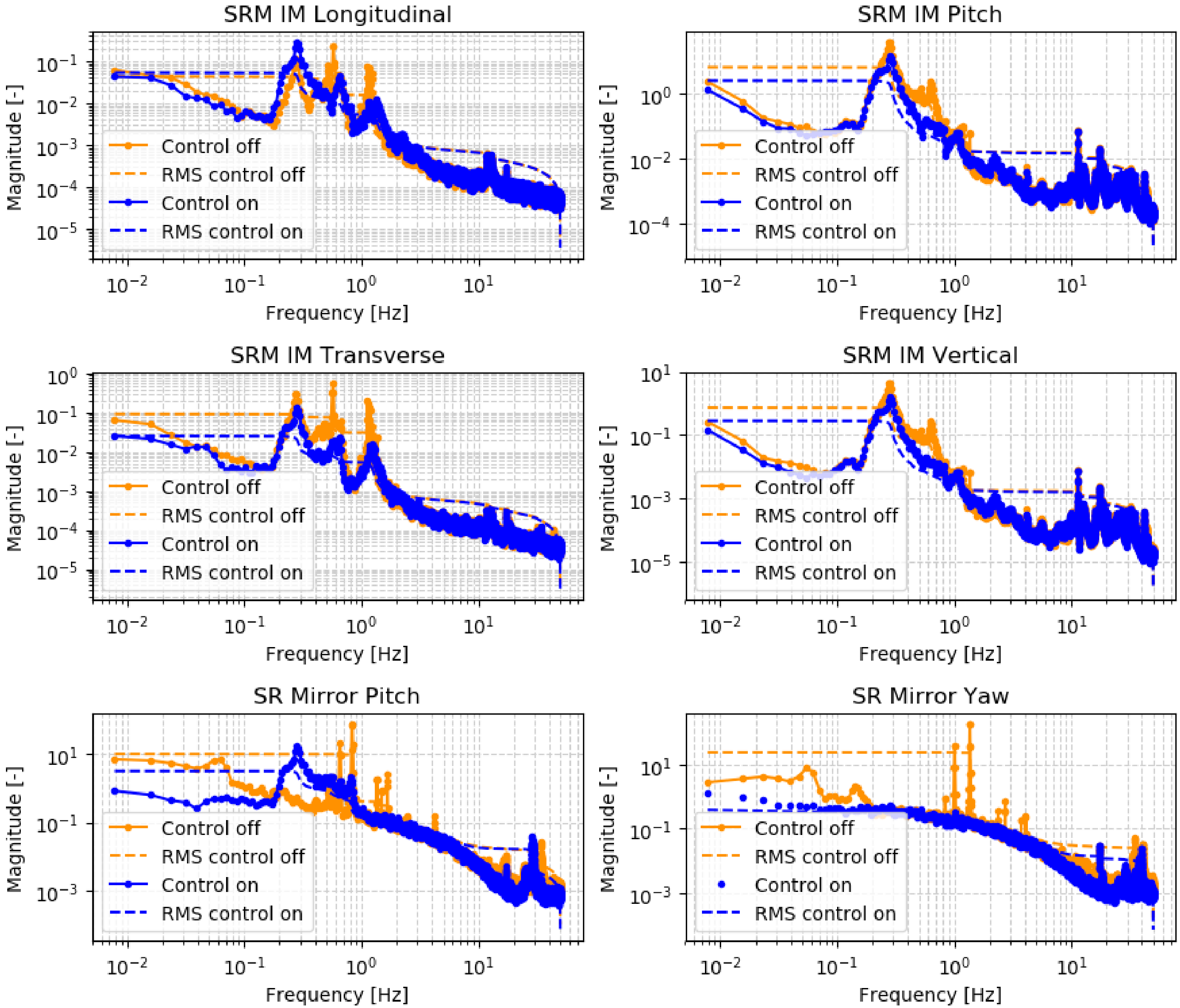




Only IP stage with position control on.

Angular fluctation of SRM.
Pitch: 10.3μrad --> 1.17μrad.
Yaw: 24.4μrad --> 1.18μrad.

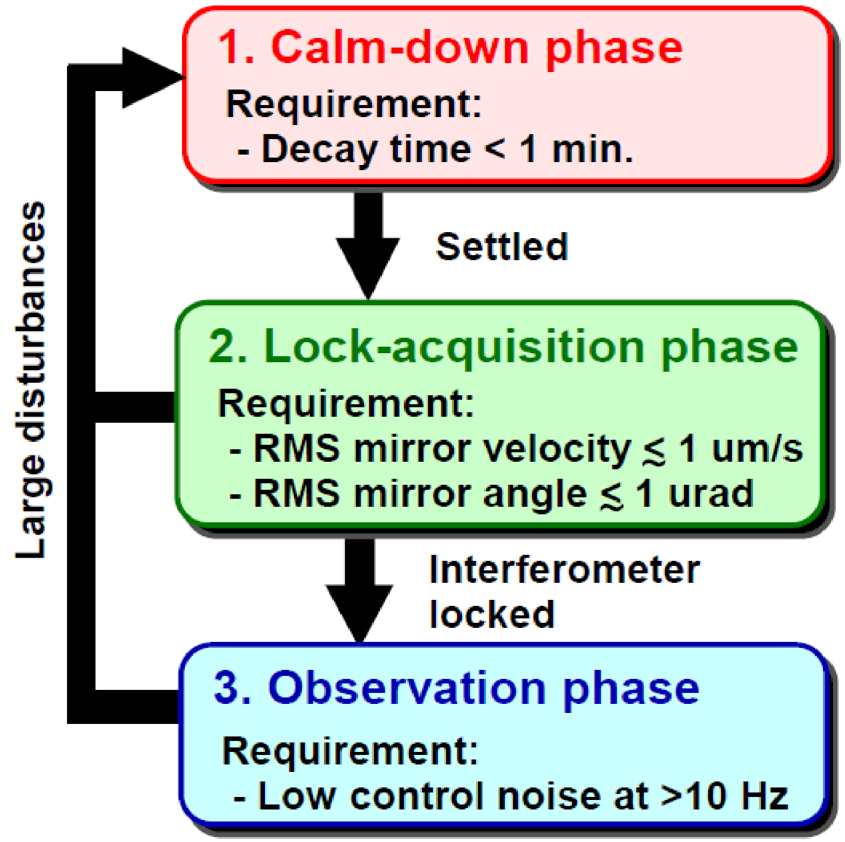
Damping of the modes stage by stage



IP and IM stage with controls on.

Angular fluctation of SRM.
Pitch: 10.3μrad --> 3.3μrad.
Yaw: 24.4μrad --> 0.4μrad.

Meeting the requirements



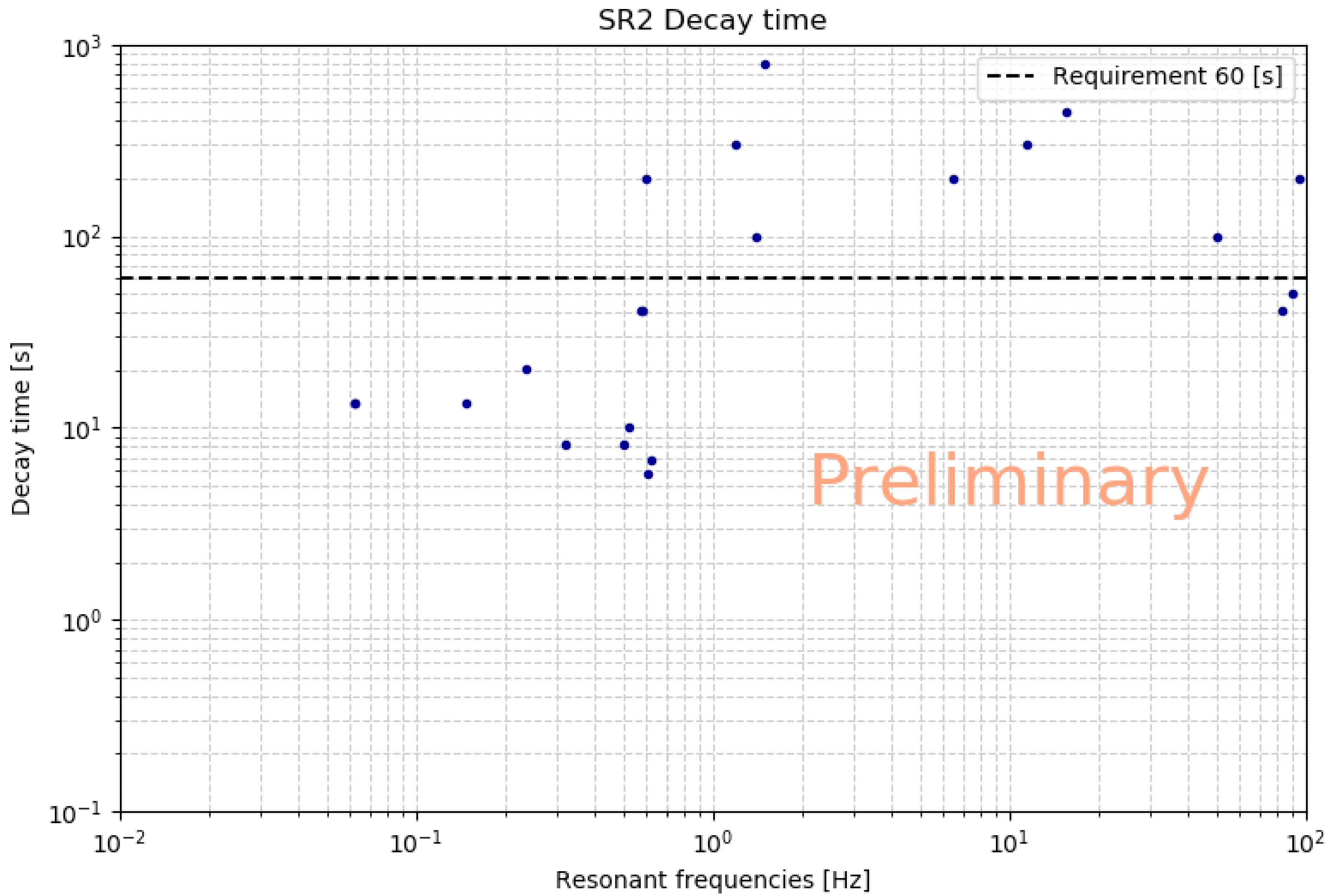
Angular fluctation of SRM.
Pitch: 10.3μrad --> 1.17μrad.
Yaw: 24.4μrad --> 1.18μrad.

⇩

Angular fluctation of SRM.
Pitch: 10.3μrad --> 3.3μrad.
Yaw: 24.4μrad --> 0.4μrad.

We need to work on the tuning of the controls.
Double check the lock-acquisition phase requirements using the recently implemented control scheme.

Ongoing: Decay time measurements



We still need to complete the list of all the modes and we also need to measure the decay time with the controls on.

Future Work (February)

Hardware

- Debug remote switch for stepper motor drivers. ✓
- Revisit length sensing oplev. ✓

Characterization

- IM stage diagonalization. *
- Include signal from Geophones. *

Controls

- Implement IP stage inertial damping (geophone). *
- Revisit optical lever and GAS filter controls. * ✓
- Coupling cancellation filters for payload. *
- Sort out Guardian for Type B suspensions. ✓

Real time model

- Split the models of SR2 and SR3 suspensions. ✓

Remaining Work

Characterization

- IM stage diagonalization.
- Include signal from Geophones.

Documentation

- Type B suspensions paper.

Controls

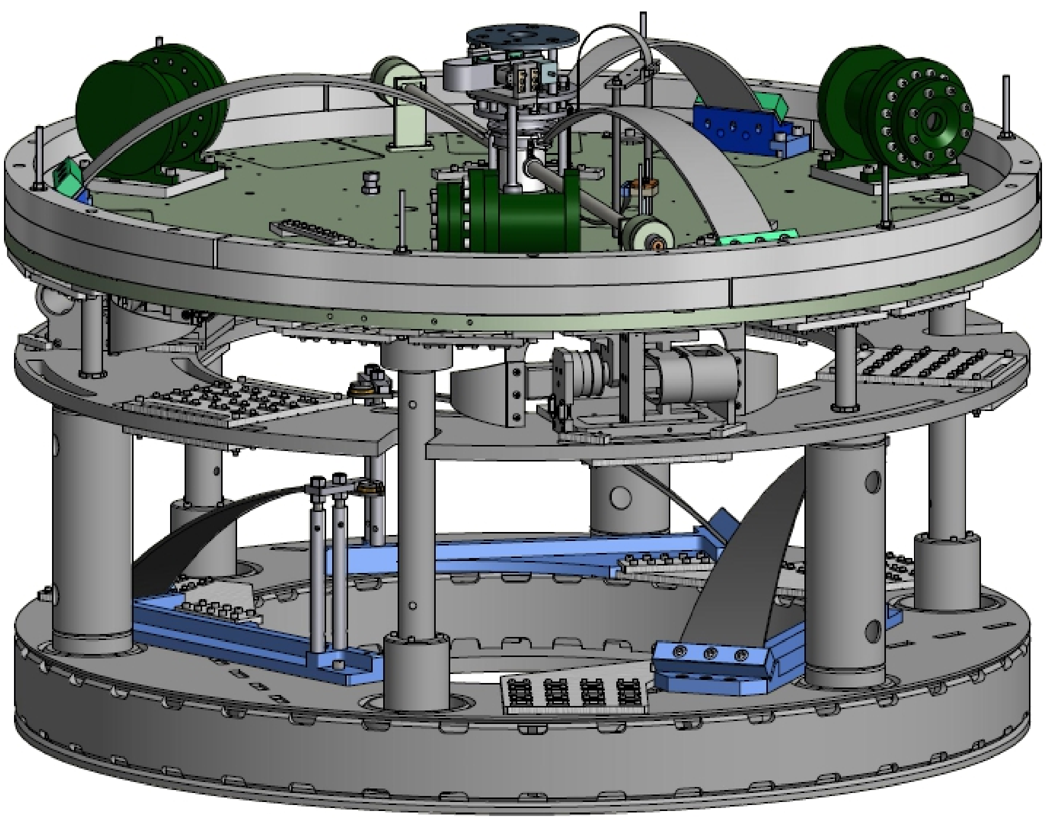
- Implement IP stage inertial damping (geophone).
- Revisit optical lever controls.
- Coupling cancellation filters for payload.

Thank you!

Extras

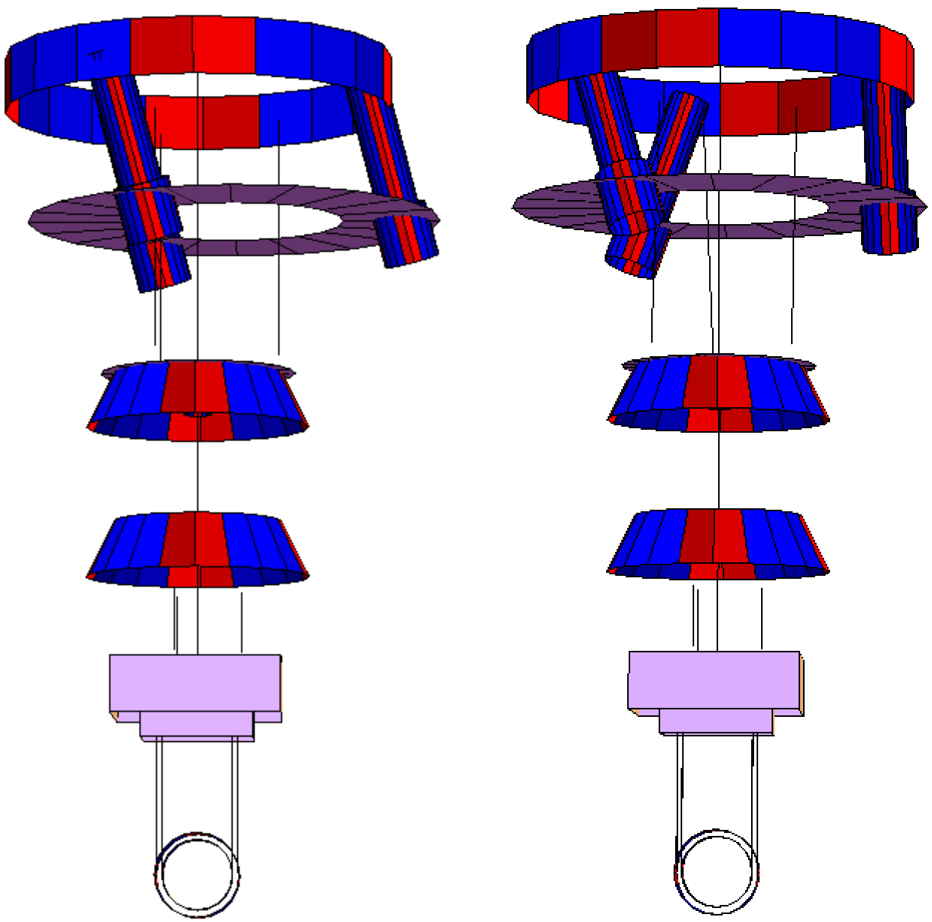
Cross-coupling on the IP stage

Unlike the ideal system, the suspensions exhibit cross-coupling in their stages. It is necessary to decouple the DoFs.



#2, 3 IP Translation (0.063 Hz)

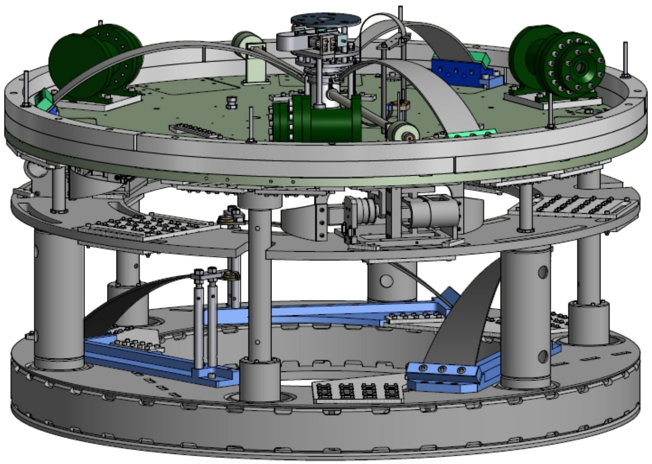
#7 IP Rotation (0.31 Hz)

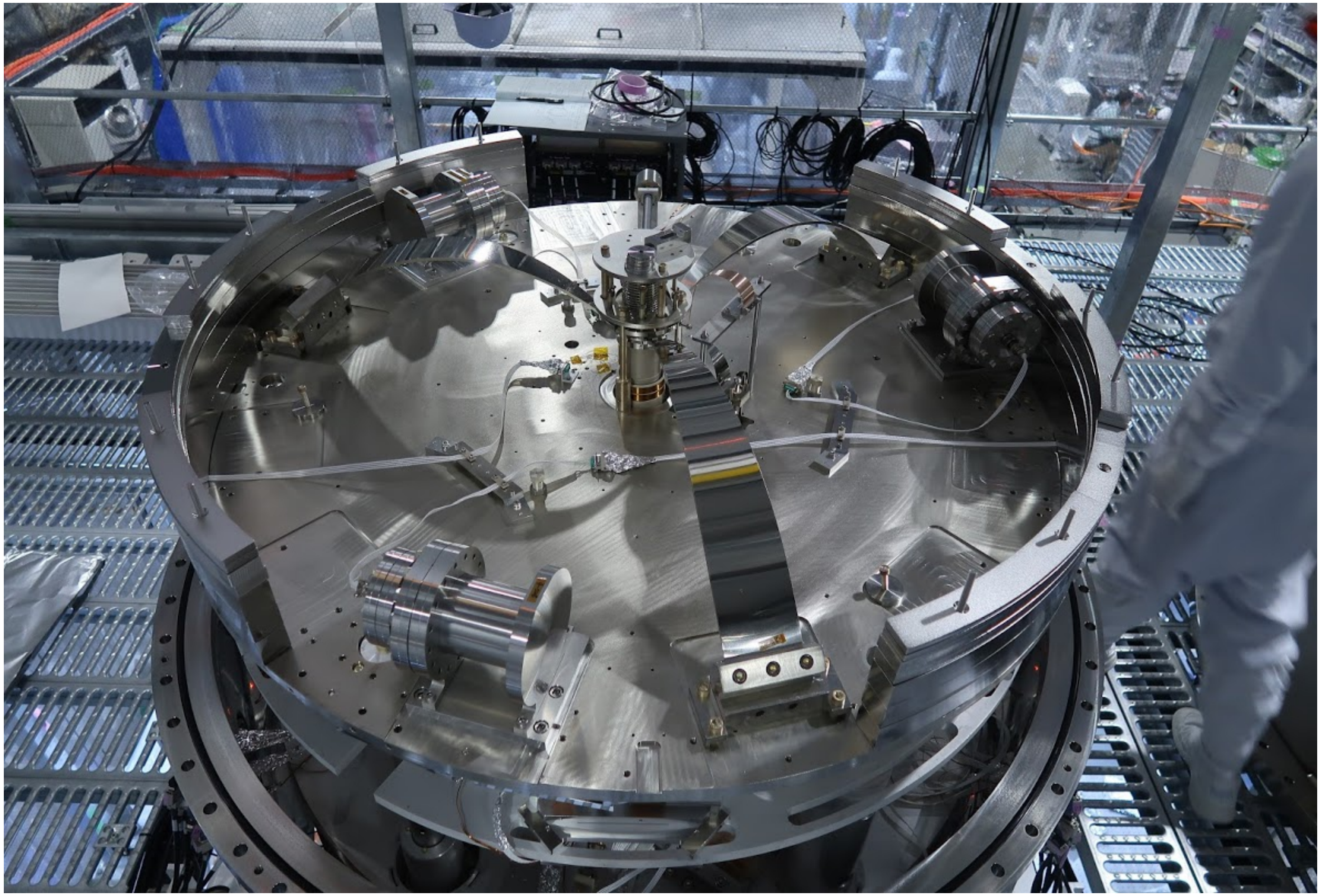


IP frequency tuning

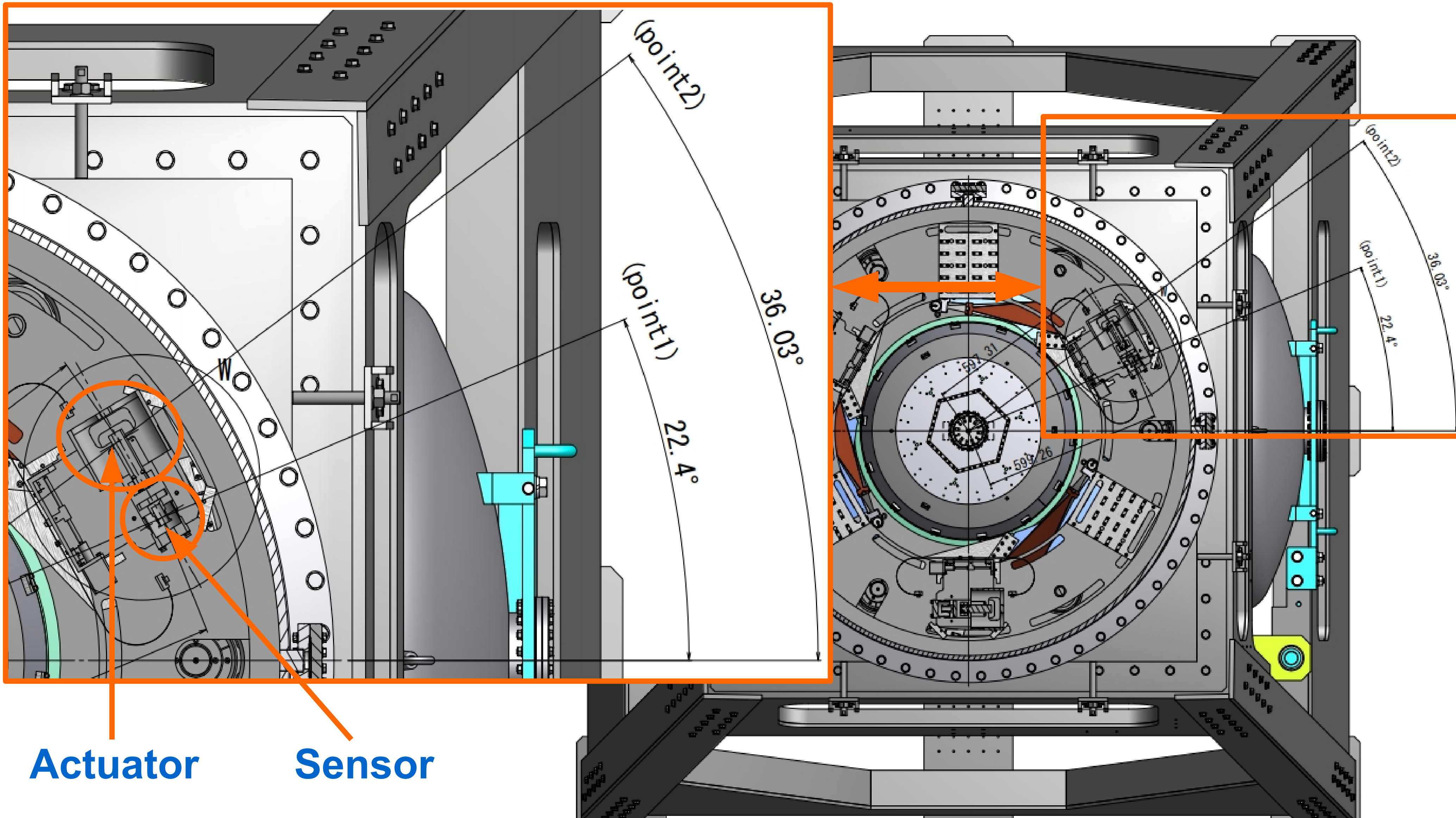
But first...

Add mass on the IP table to get a lower resonant frequency.





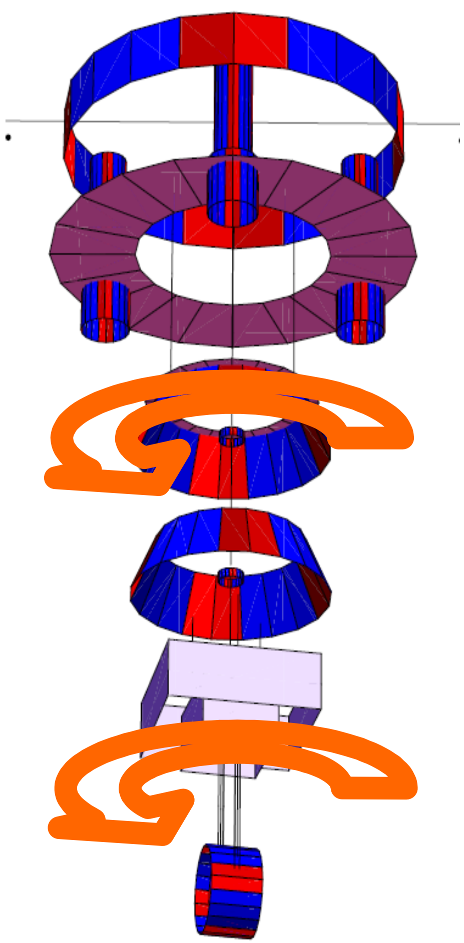
IP sensor/actuator diagonalization

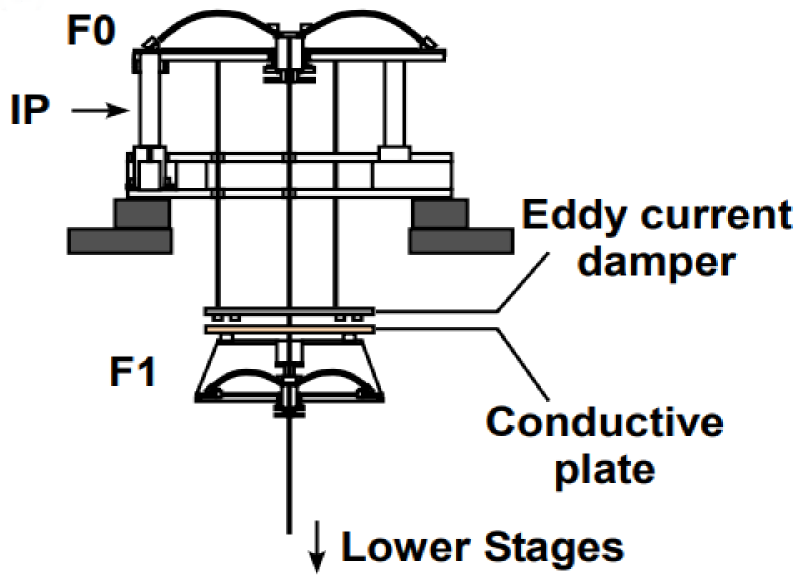


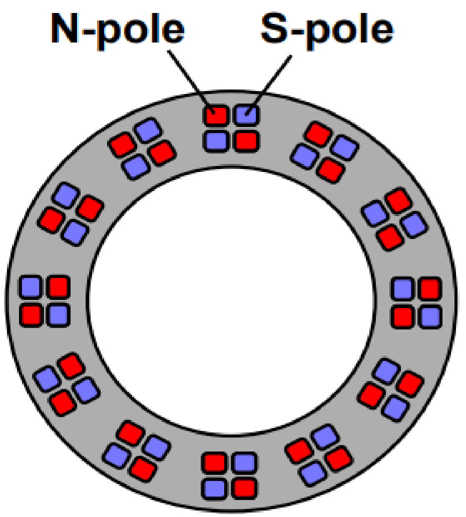
Sensors and actuators of the IP at different positions

Damping of the torsion mode (#1)

#1 Wire torsion (0.054 Hz)



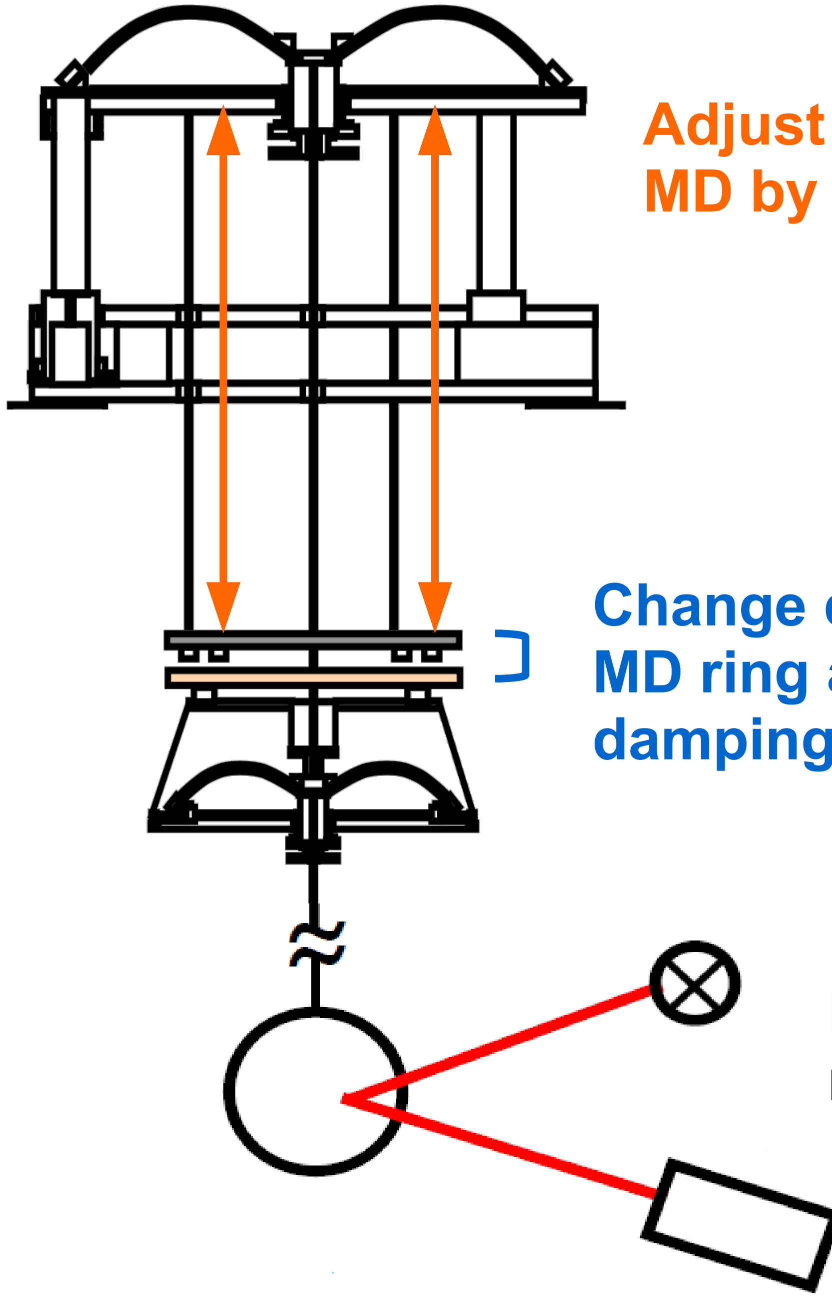




High quality factor. Long decay time.

Torsion mode is passively damped by the eddy current damper.

Damping of the torsion mode (#1)

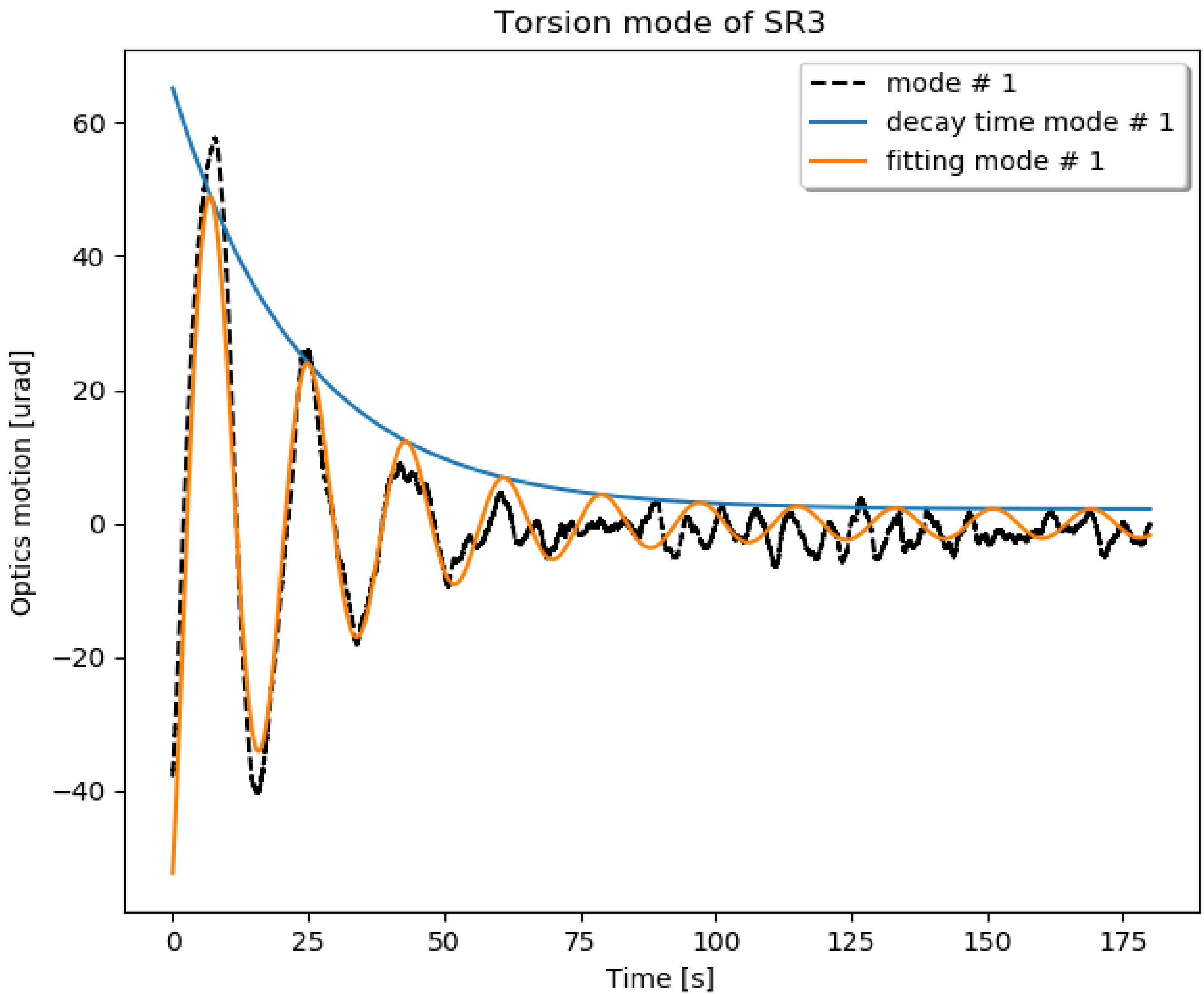


Adjust the height of the MD by lifting the rods.

Change distance between MD ring and SF to tune the damping for this mode.

Measure motion of the mirror with the optical lever.

Damping of the torsion mode (SR3)



Decay time <60[s]

Freq. Simulation: 0.054 [Hz]

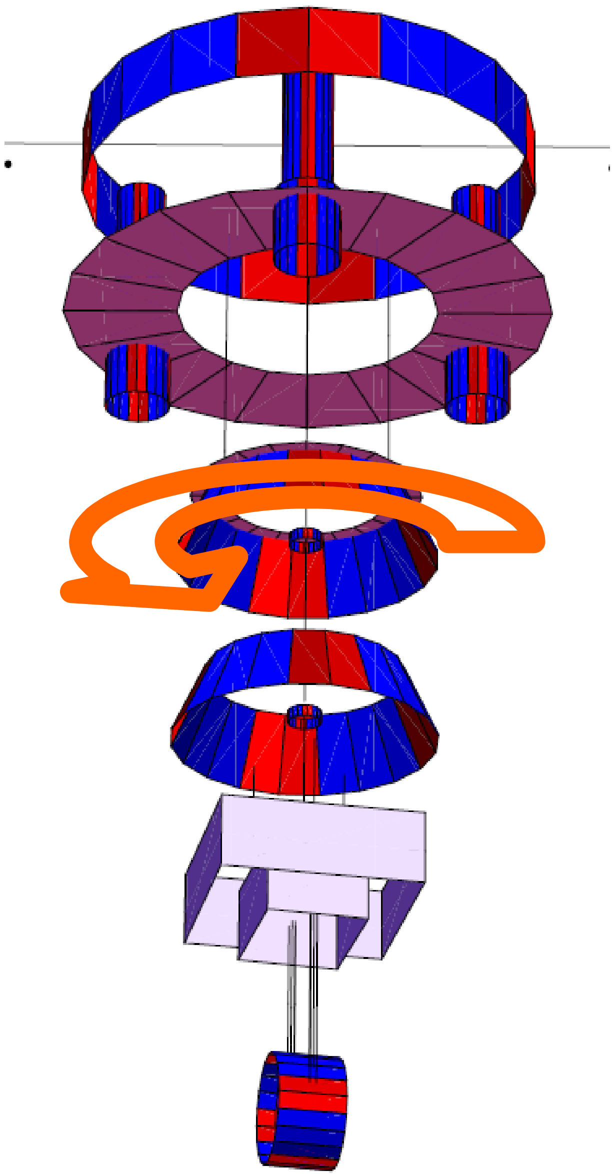
Freq. Measured: 0.055 [Hz]

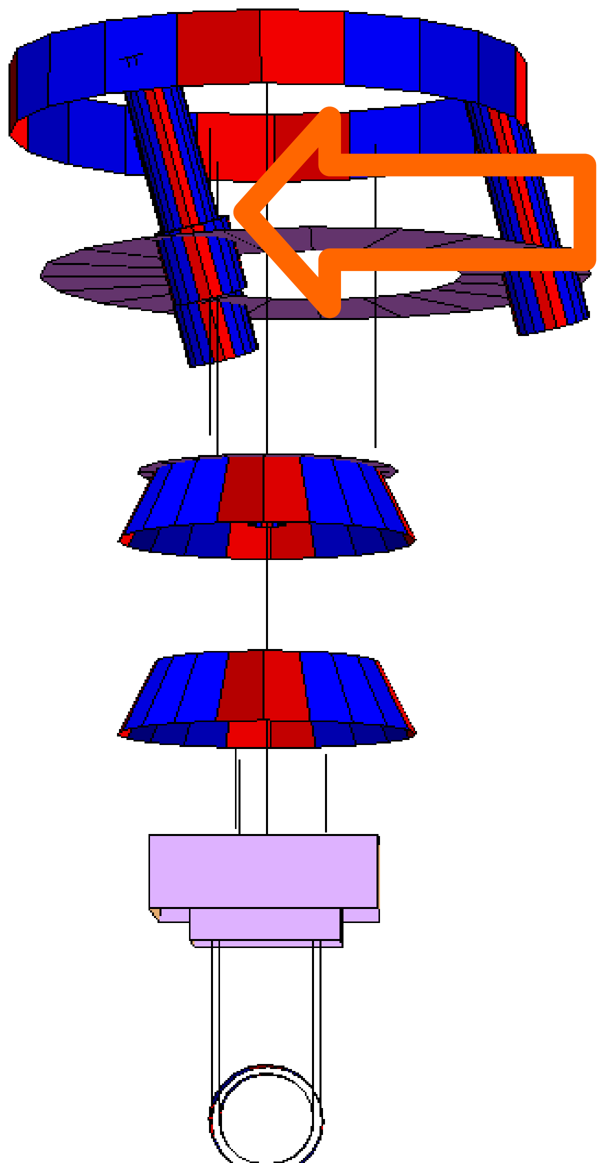
Type B eigenmodes

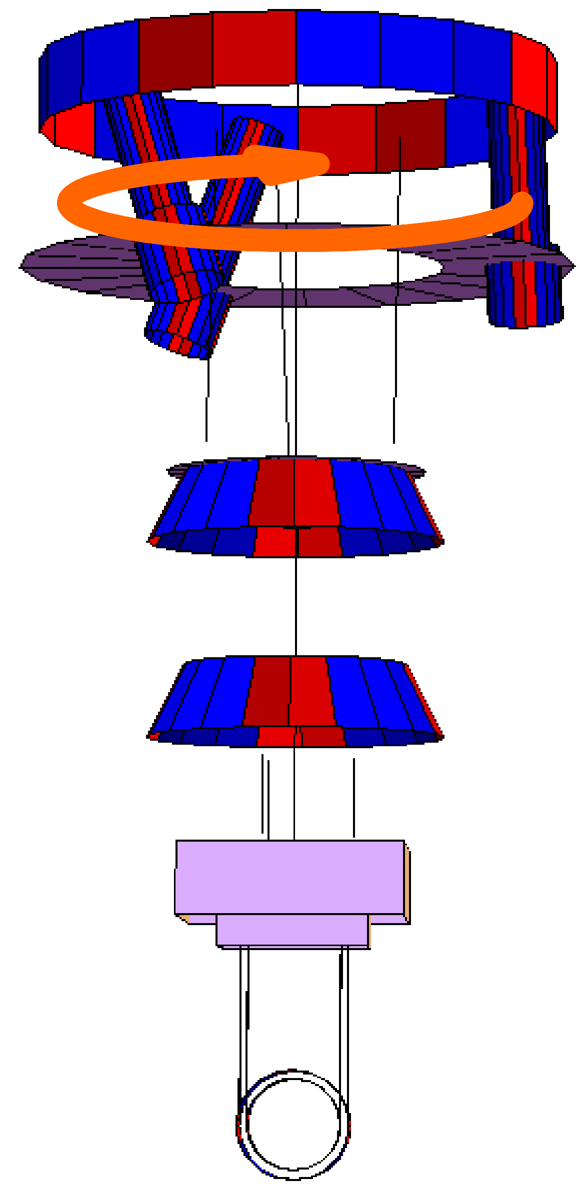
#1 Wire torsion (0.054 Hz)

#2, 3 IP Translation (0.063 Hz)

#7 IP Rotation (0.31 Hz)







Requirements

Large disturbances

1. Calm-down phase

Requirement:
- Decay time < 1 min.

↓ Settled

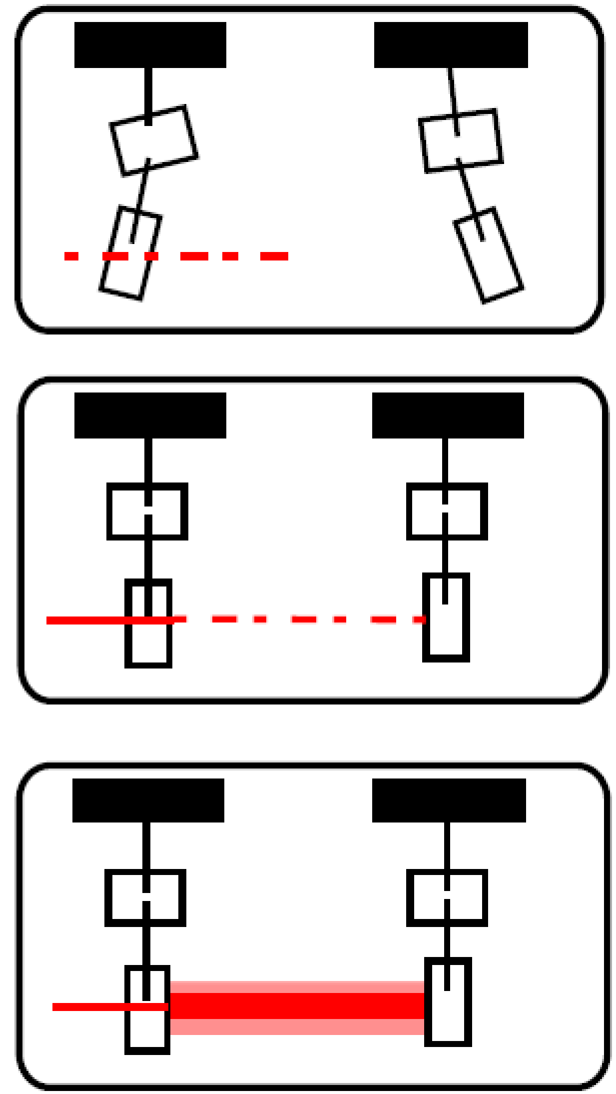
2. Lock-acquisition phase

Requirement:
- RMS mirror velocity ≲ 1 um/s
- RMS mirror angle ≲ 1 urad

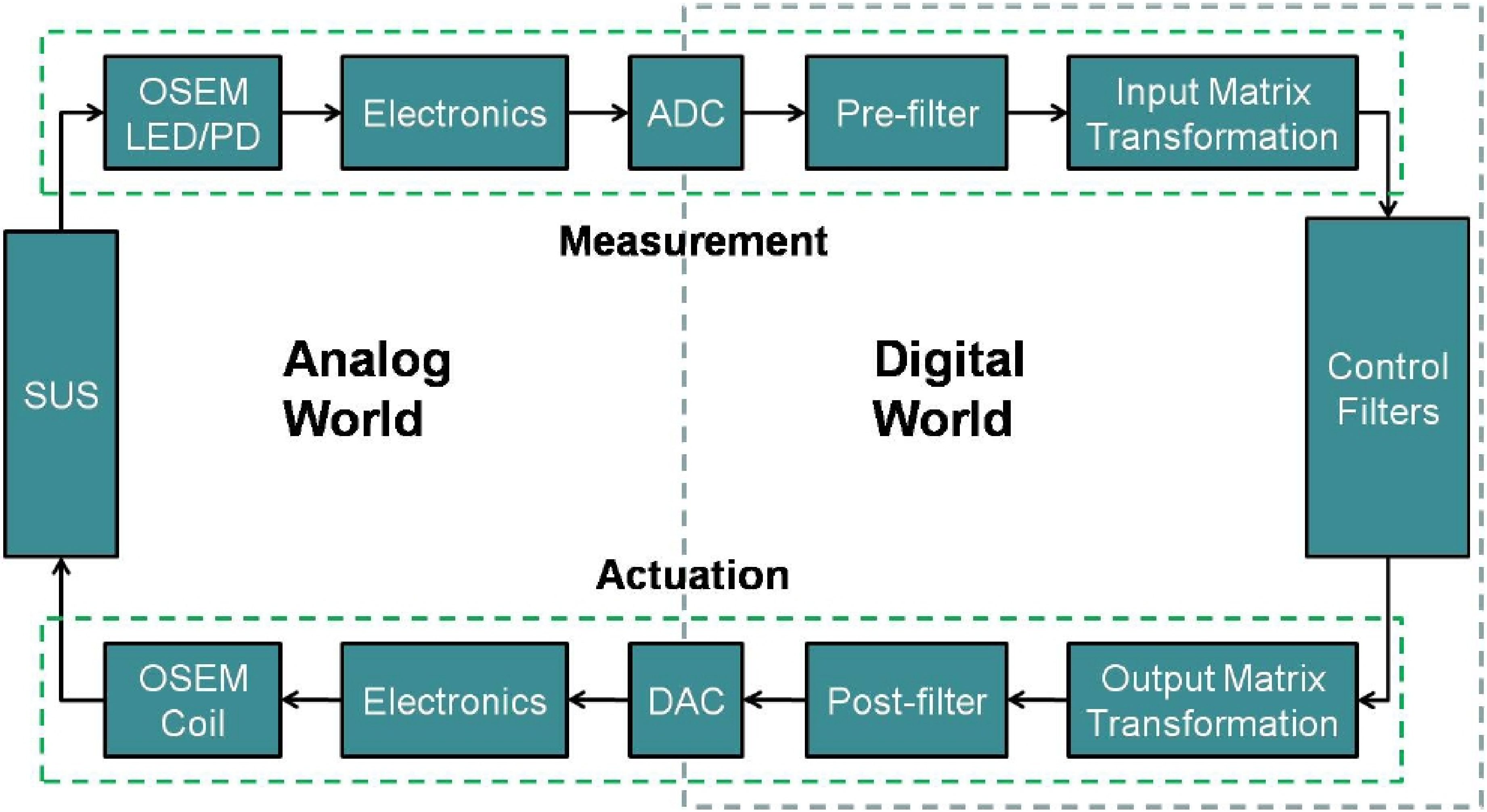
↓ Interferometer locked

3. Observation phase

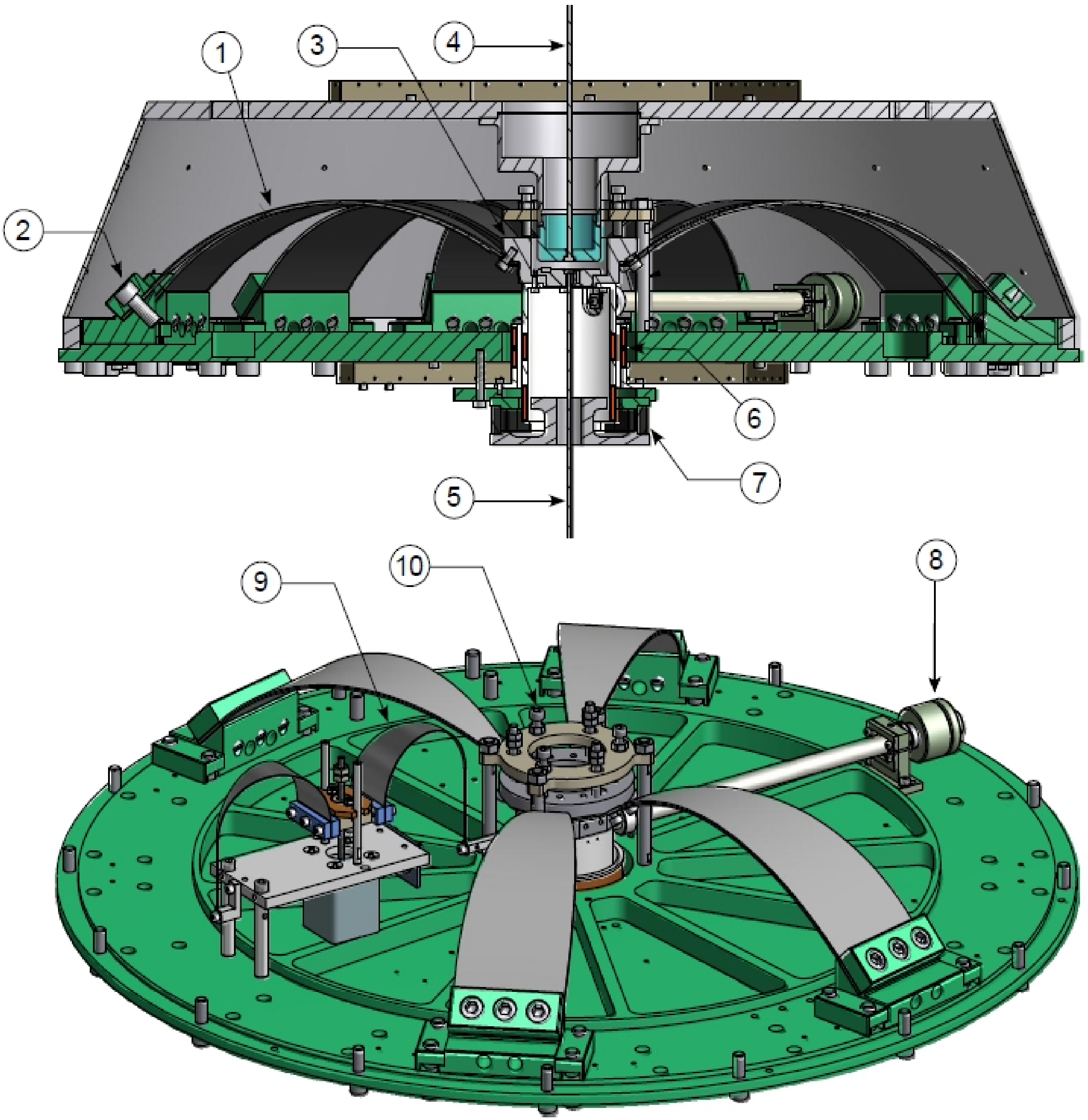
Requirement:
- Low control noise at >10 Hz



Analog-Digital diagram



GAS (Geometric Anti-Spring) filter



(1) Blades.

(2) Blade attachment to the base.

(3) Keystone.

(4) Upper rod supporting the weight to the GAS filter and the mass below it.

(5) Lower rod connected to the lower stage (It moves the Keystone).

(6) LVDT (it measures the displacement of the Keystone).

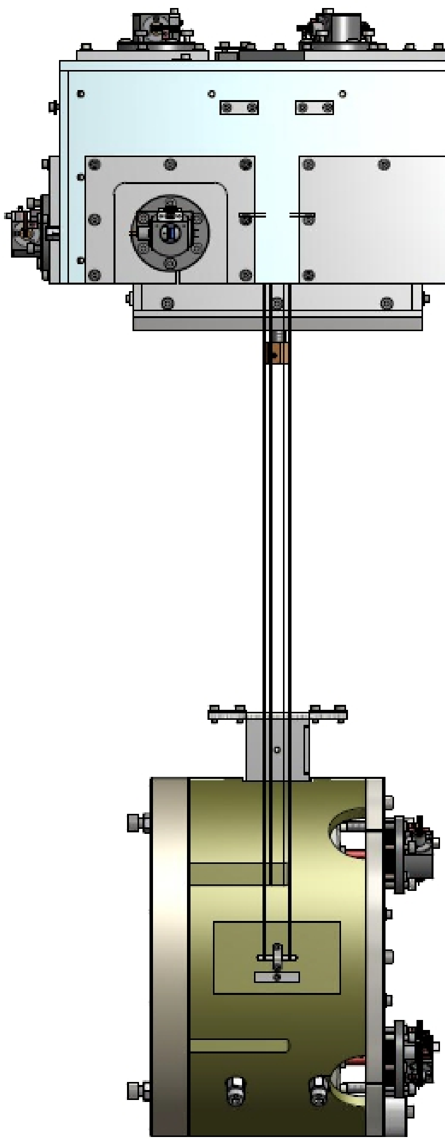
(7) Coil magnet actuator.

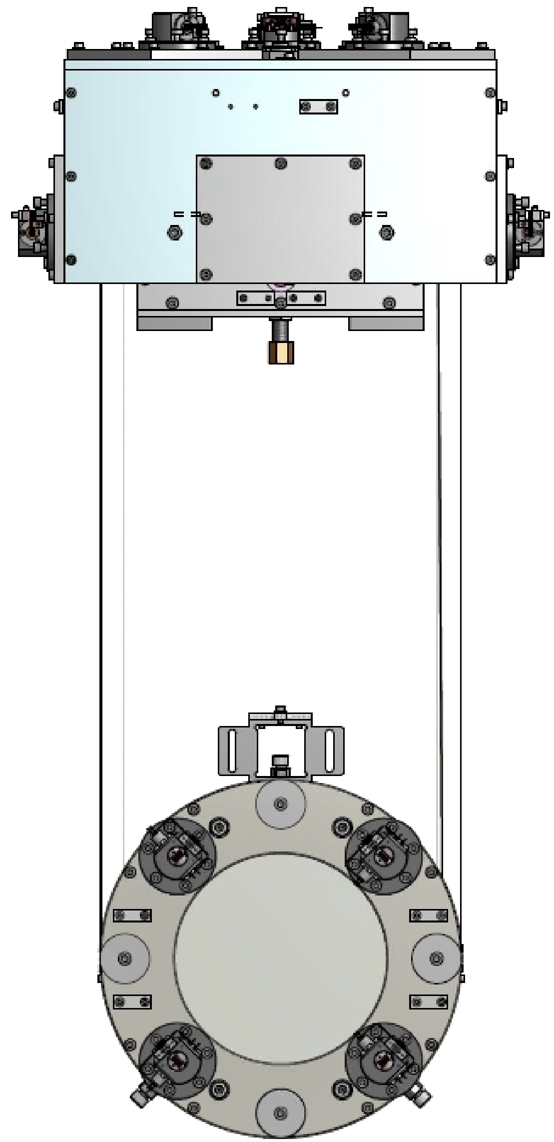
(8) Magic wand (to improve the saturation value of isolation)

(9) Fishing rod (to move the Keystone).

(10) Locking system screws.

IM OSEMs and TM coil actuators





6 OSEMs at the IM stage (sensor and actuator).

4 Coil actuators at the optic stage.