Characterization and commissioning of the SR suspensions of KAGRA

Enzo Tapia S.
On behalf of KAGRA collaboration.

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(11) Future work.

Requirements

1. Calm-down phase

Requirement:
- Decay time < 1 min.

Settled

2. Lock-acquisition phase

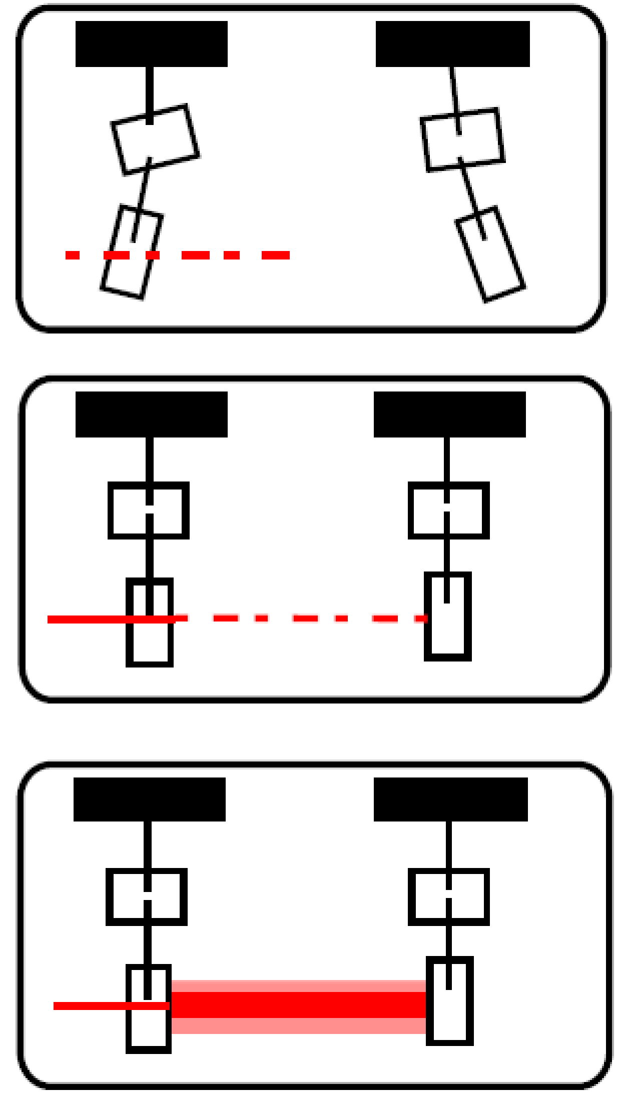
Requirement:
- RMS mirror velocity ≲ 1 um/s
- RMS mirror angle ≲ 1 urad

Interferometer locked

3. Observation phase

Requirement:
- Low control noise at >10 Hz

Large disturbances



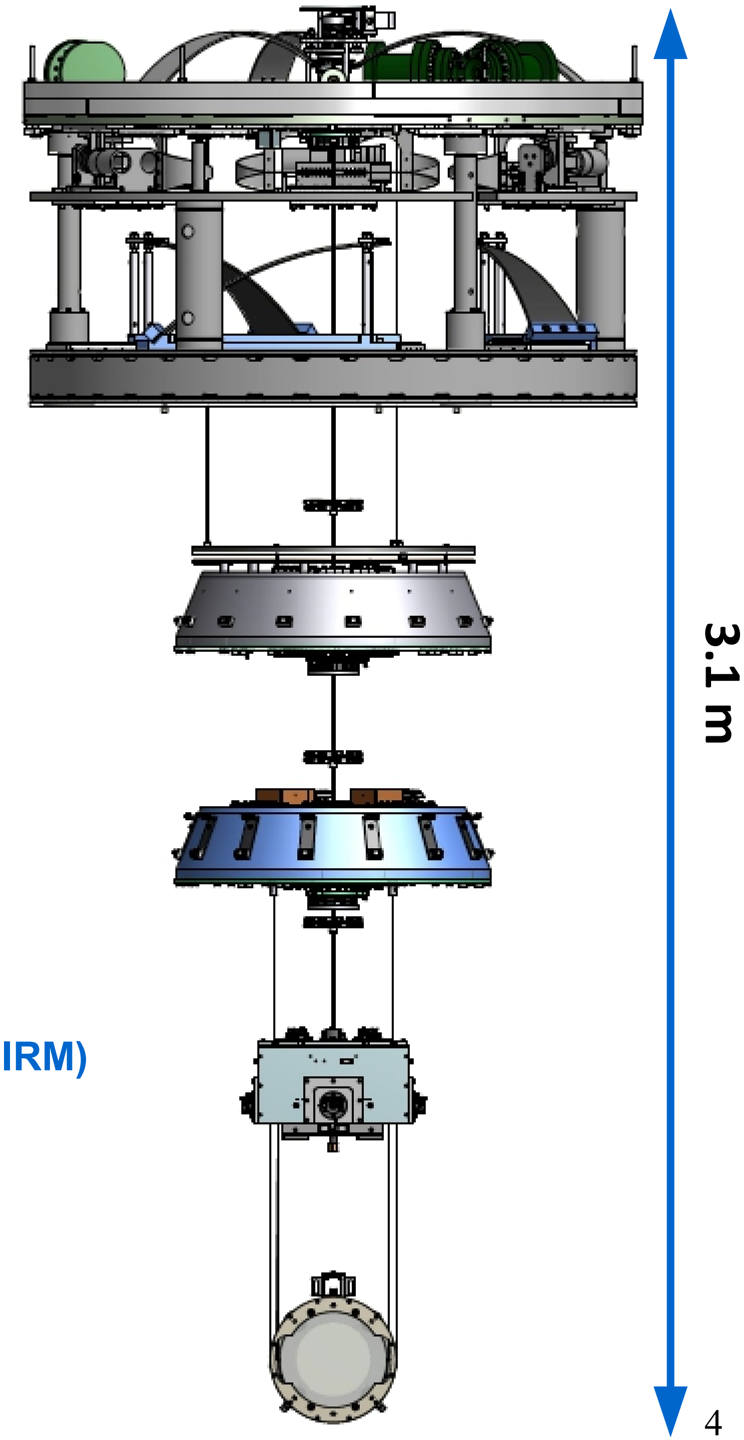
Type B suspensions

- 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)
- Mirror (SR)



Type B model in SUMCON

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:

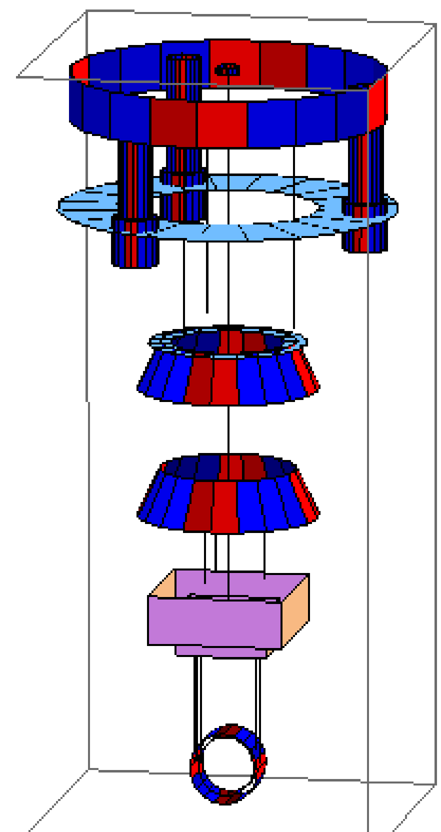
45 State Variables
6 Input Variables
3 Float Variables

Ground Position:

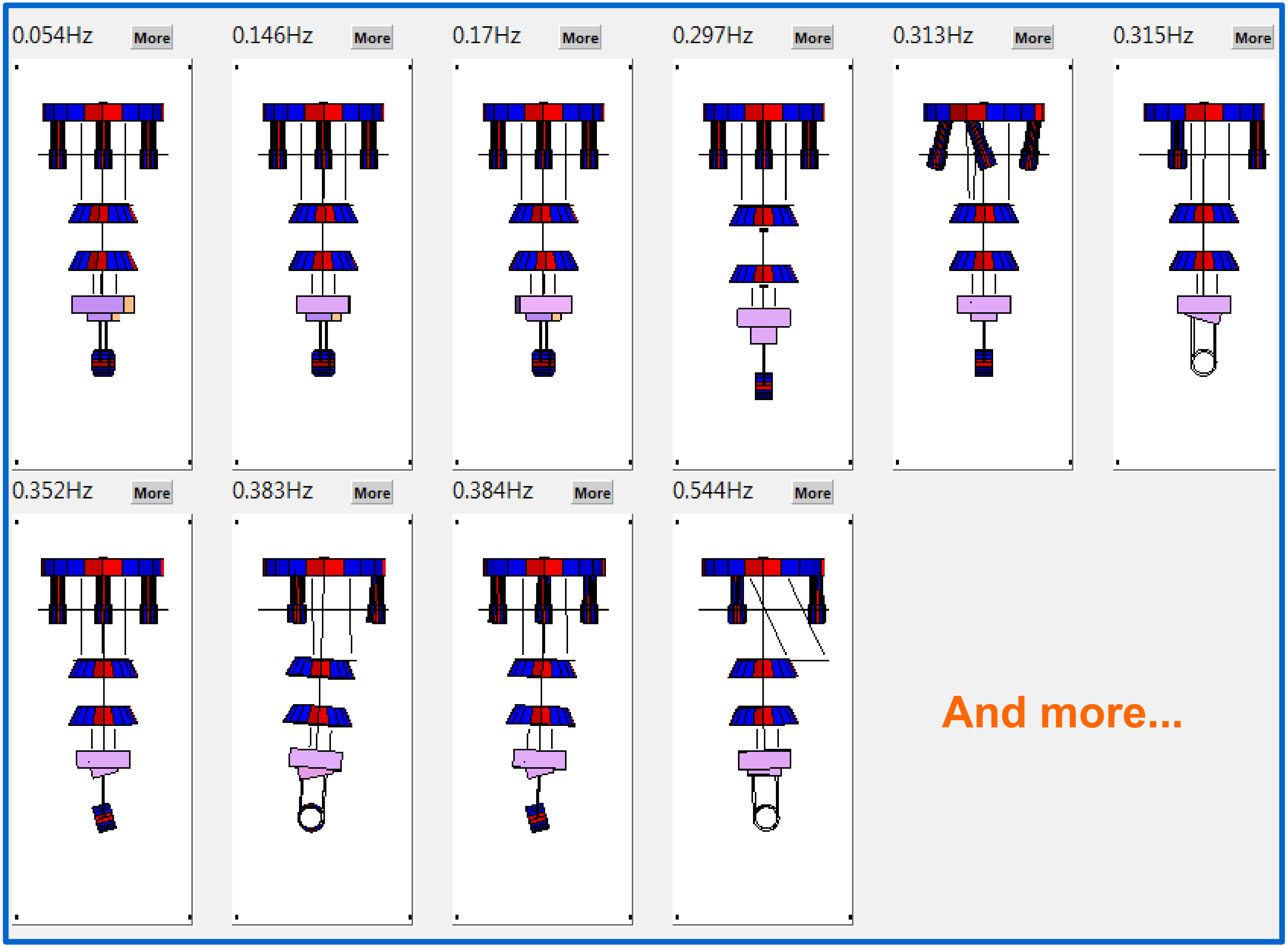
xg → 0. yg → 0. zg → 0. pitchg → 0. yawg → 0. rollg → 0.

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.

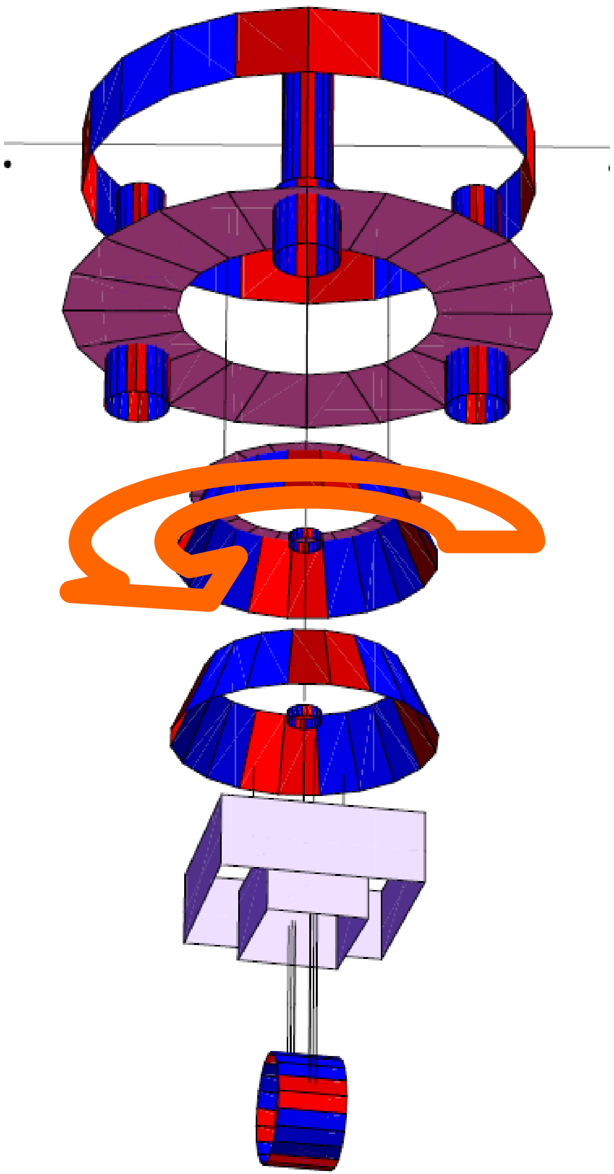


Type B eigenmodes

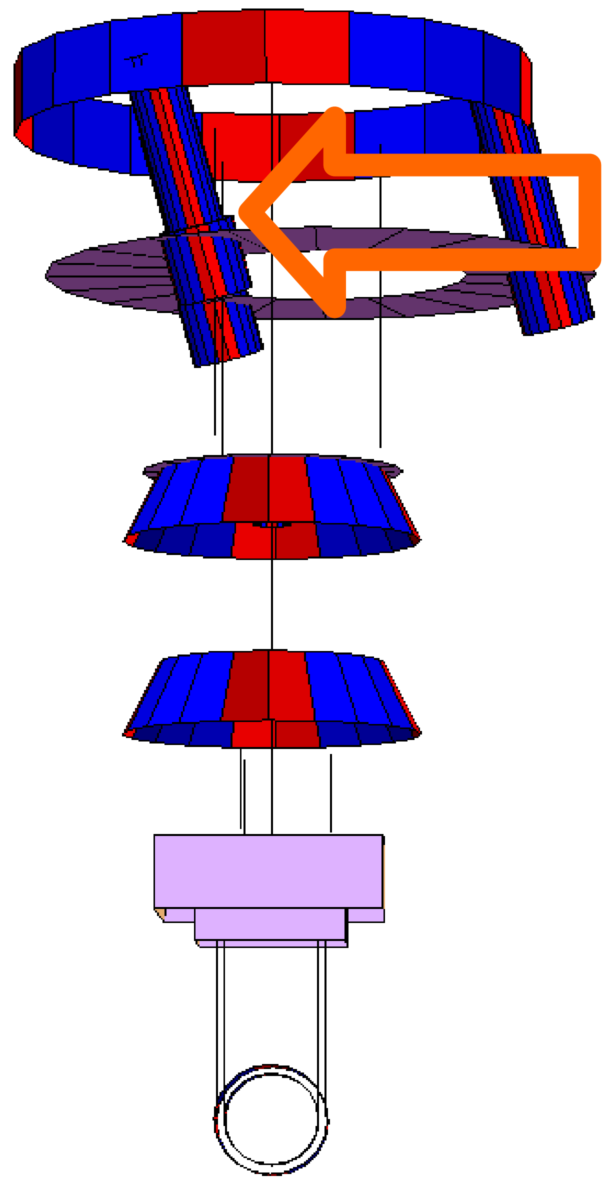


Type B eigenmodes (Individually)

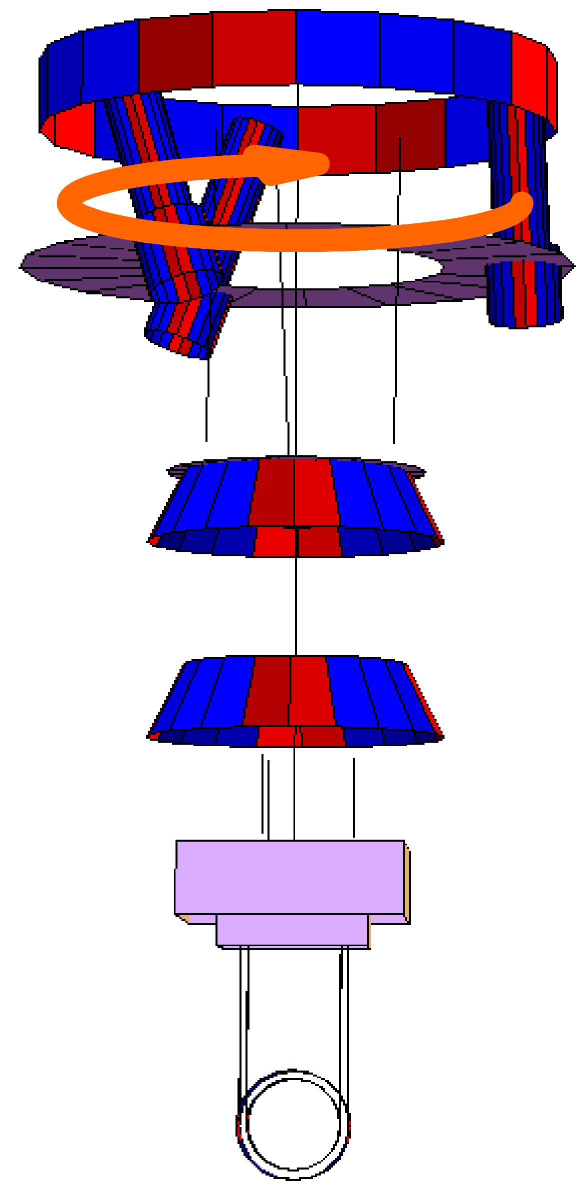
#1 Wire torsion (0.054 Hz)



#2, 3 IP Translation (0.063 Hz)

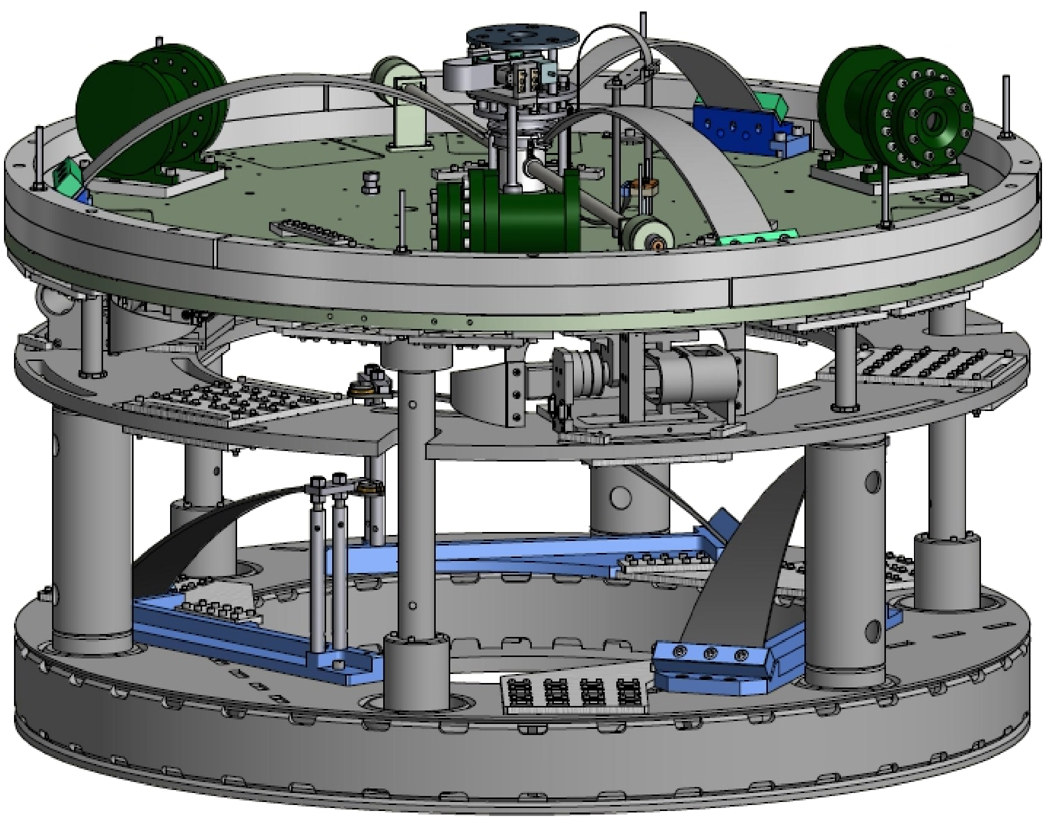


#7 IP Rotation (0.31 Hz)



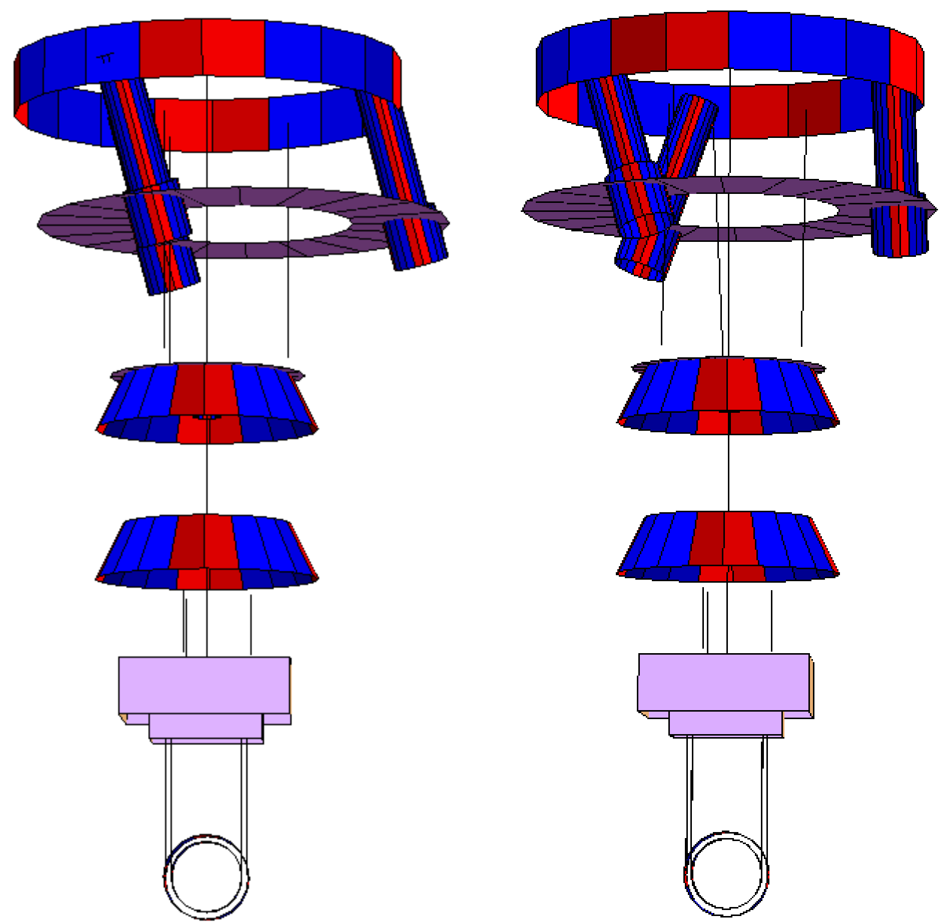
Cross-coupling on the IP stage

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)

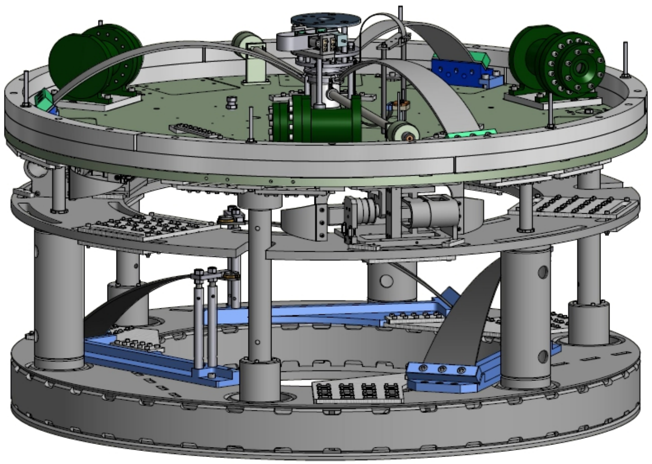
#7 IP Rotation (0.31 Hz)

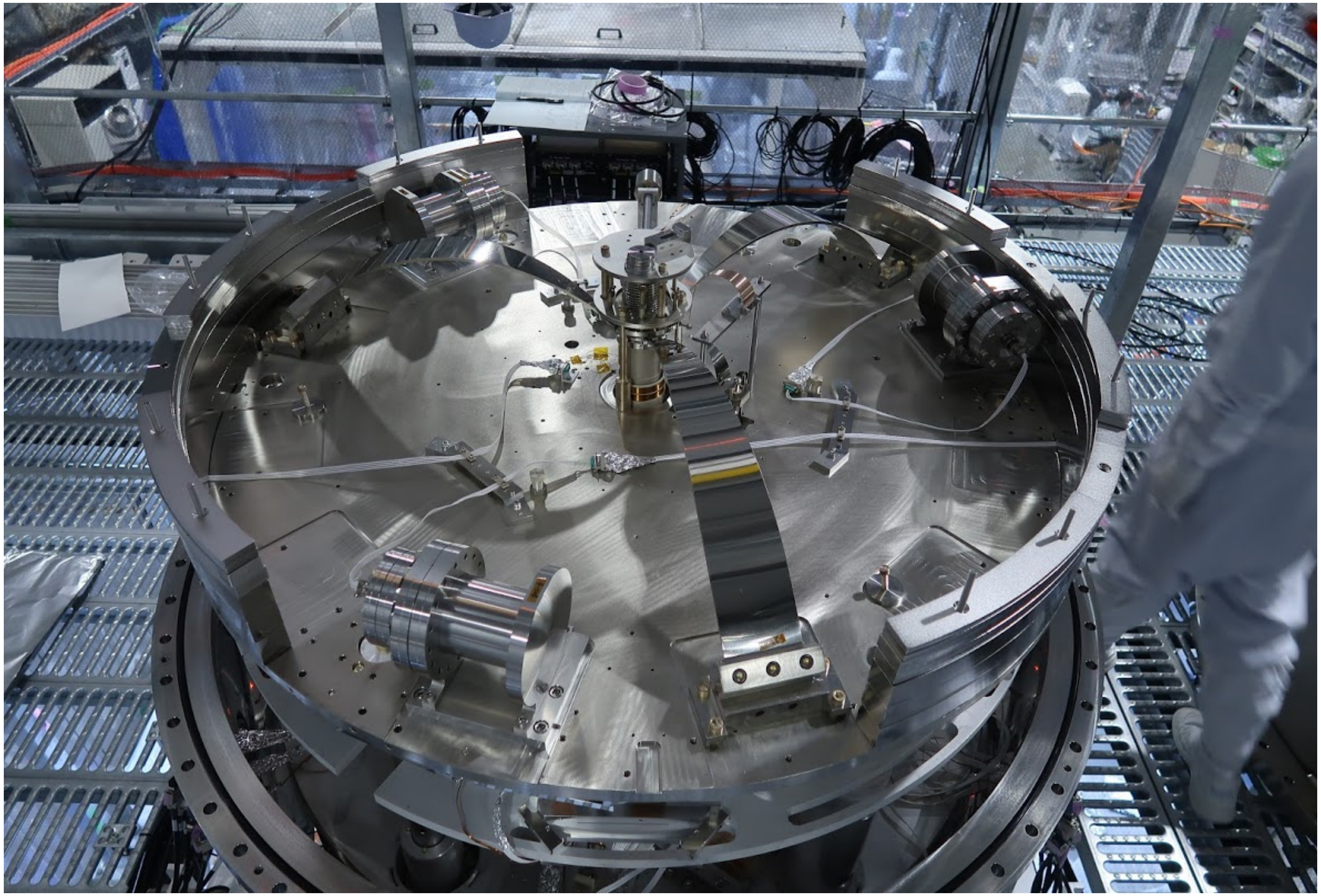


IP frequency tuning

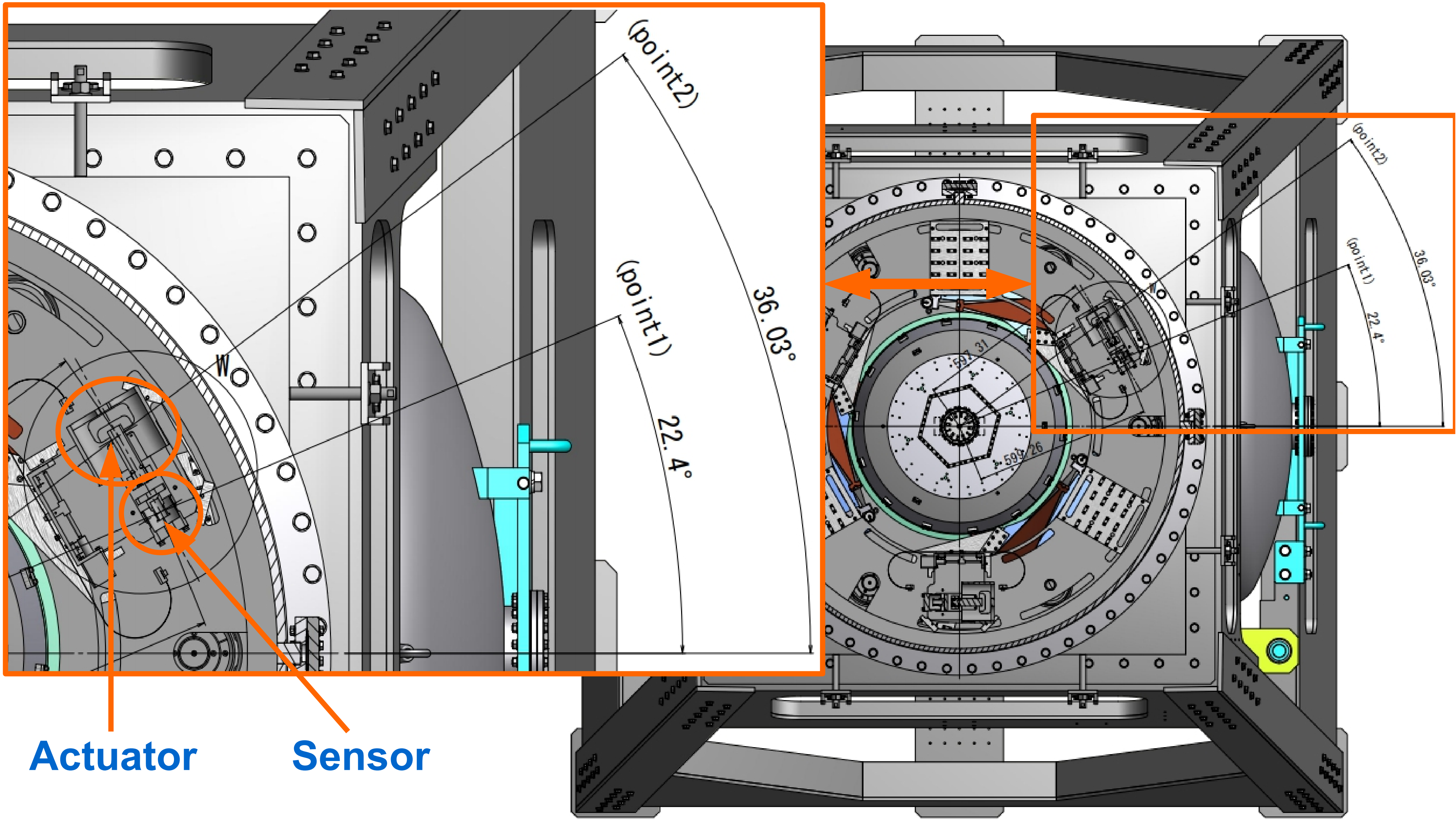
But first...

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

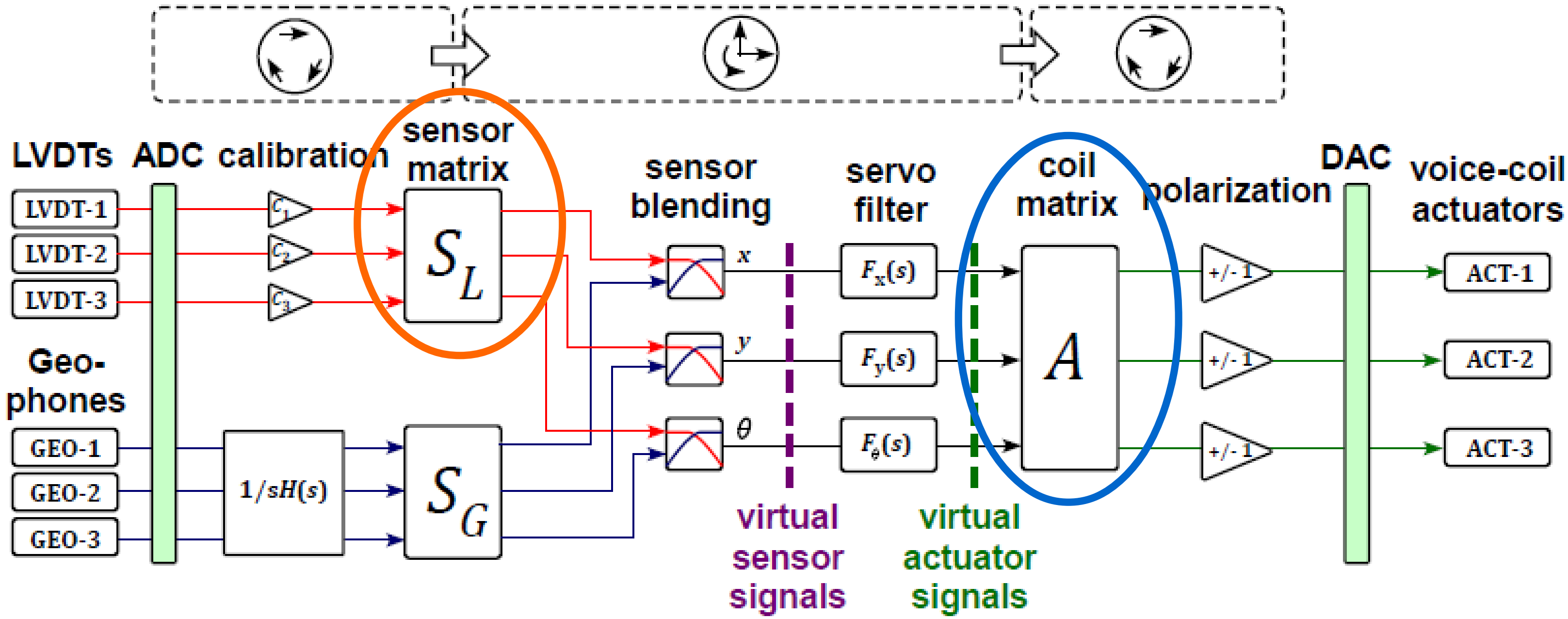
Safety band for diagonalization

Eigenmode list of SRM.

Useful gap for diagonalization.

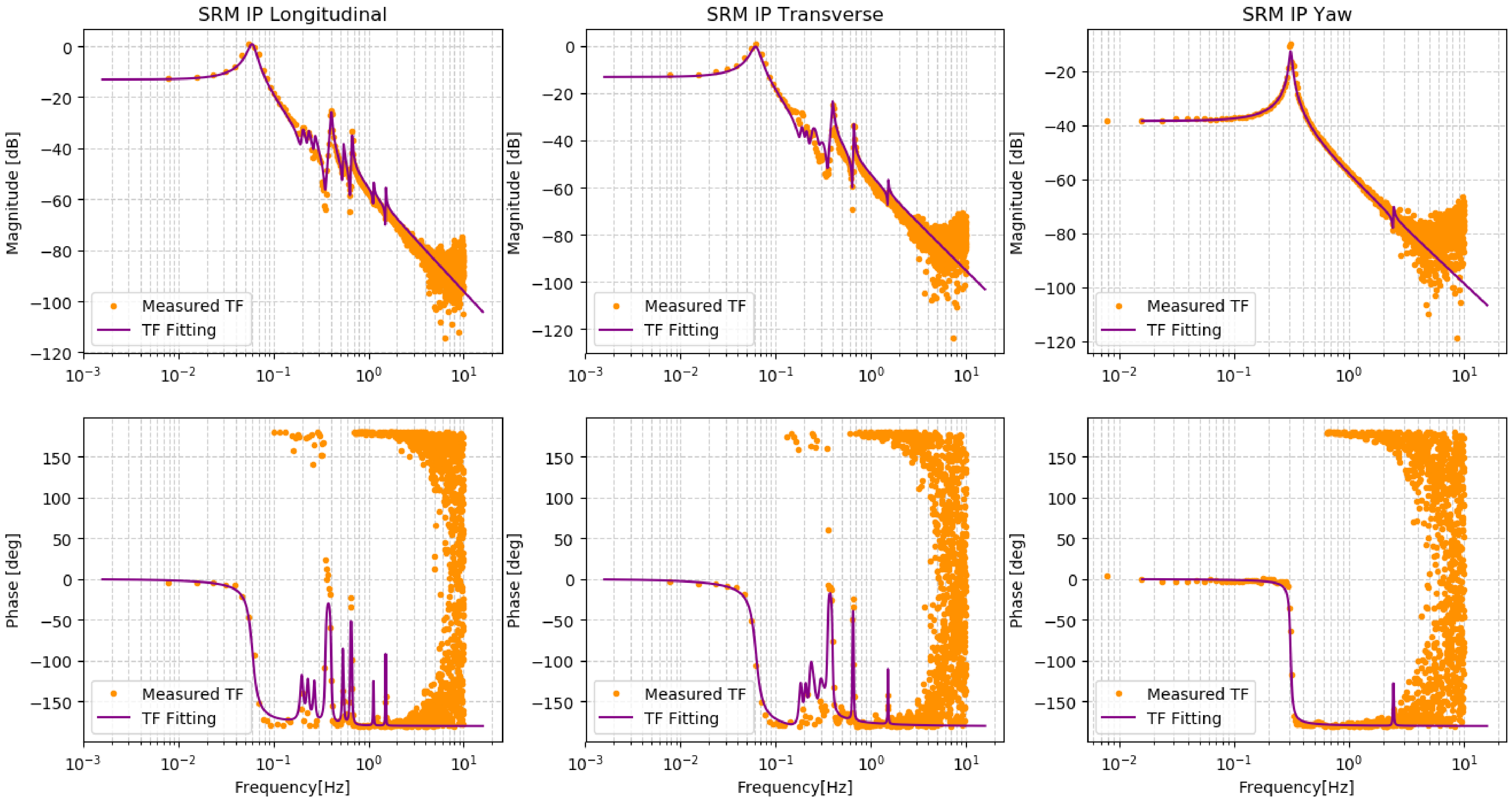
#29	1.1705	PF2, LIR, PIR, LIM, PIM, LRM, PRM, LTM.	IM pendulum
#30	1.2328	PF2, RF2, TIR, LIR, PIR, RIR.	F2 pitch roll
#31	1.2341	PF2, RF2, TIR, LIR, PIR, RIR.	F2 pitch roll
#32	1.3749	YIM, YRM, YTM.	TM yaw
#33	1.5218	TF1, LF1, PF1, RF1, TF2, LF2, PF2, RF2, TIR, LIR, PIR, RIR, TIM, LIM.	pendulum
#34	1.5251	TF1, LF1, PF1, RF1, TF2, LF2, PF2, RF2, TIR, LIR, PIR, RIR, TIM, LIM.	pendulum
#35	5.0066	PIM, PRM.	RM pitch
#36	11.6134	VIM, VRM, VTM.	TM vertical
#37	15.9279	RRM, RTM.	TM roll
#38	49.4722	VIM, VRM.	IM vertical
#39	52.0648	VMD.	MD vertical
#40	52.4298	PMD.	MD pitch
#41	52.4634	RMD.	MD roll
#42	65.9552	RIM, RRM.	IM roll

IP sensor/actuator diagonalization



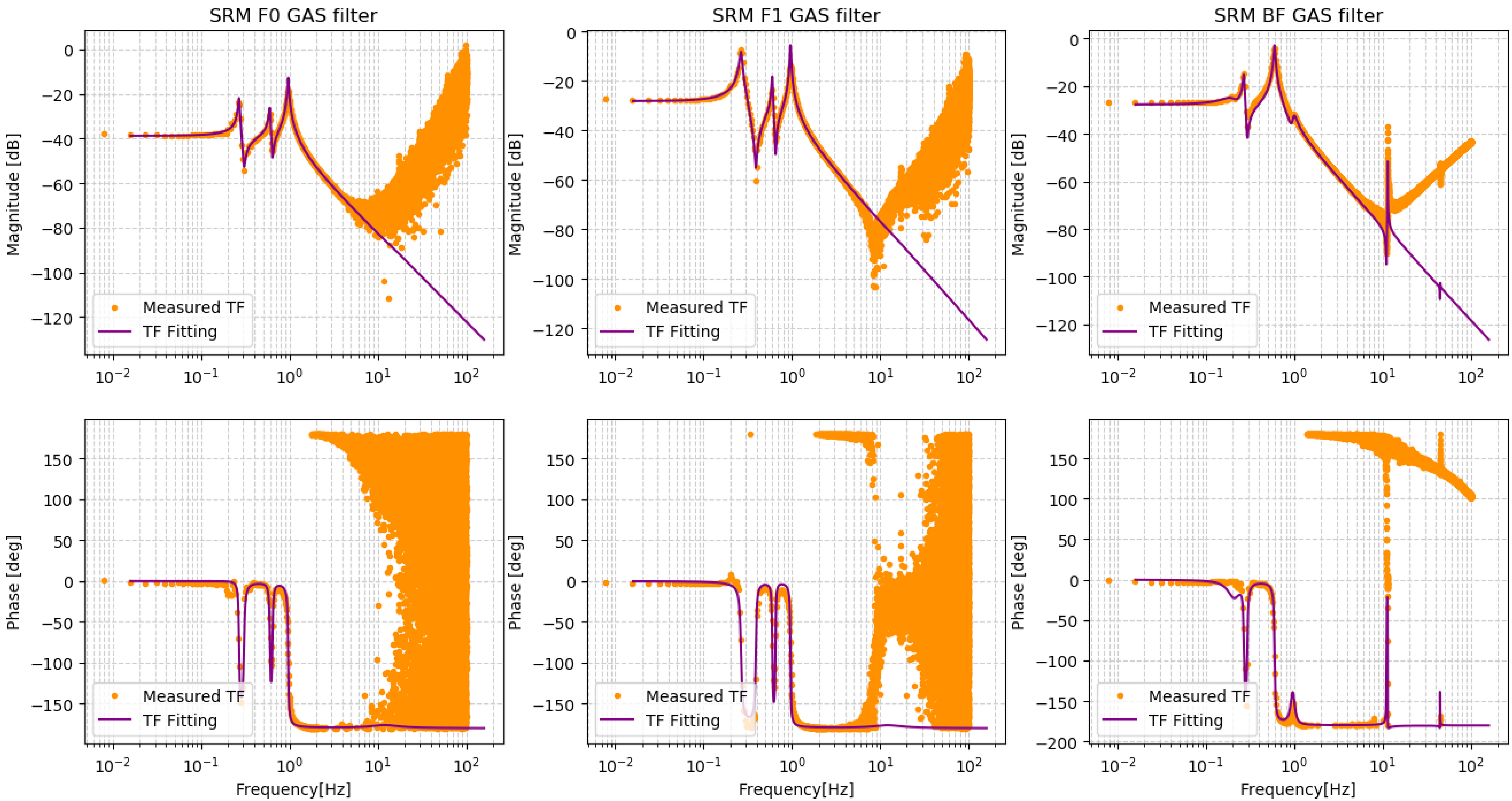
Measure the motion of the IP stage when injecting a signal at a single frequency within the 'safety band' at each coil, using the sensing matrix.
Get the TF coefficients for each DoF and compute the TF coefficients matrix. Use the inverse of this matrix as the new coil matrix.

Transfer functions of the system



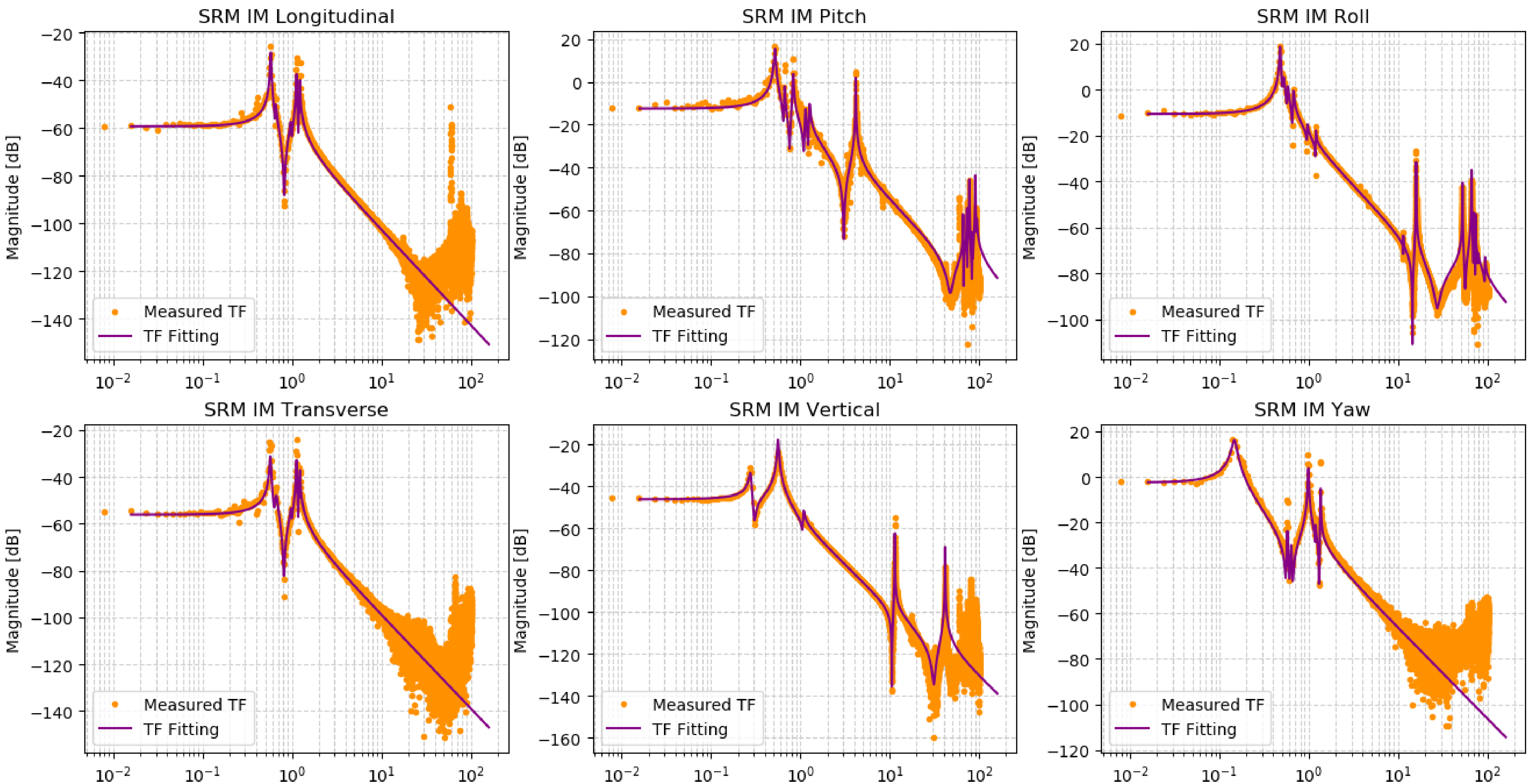
IP stage ZPK fitting to help with the design of active filters.

Transfer functions of the system



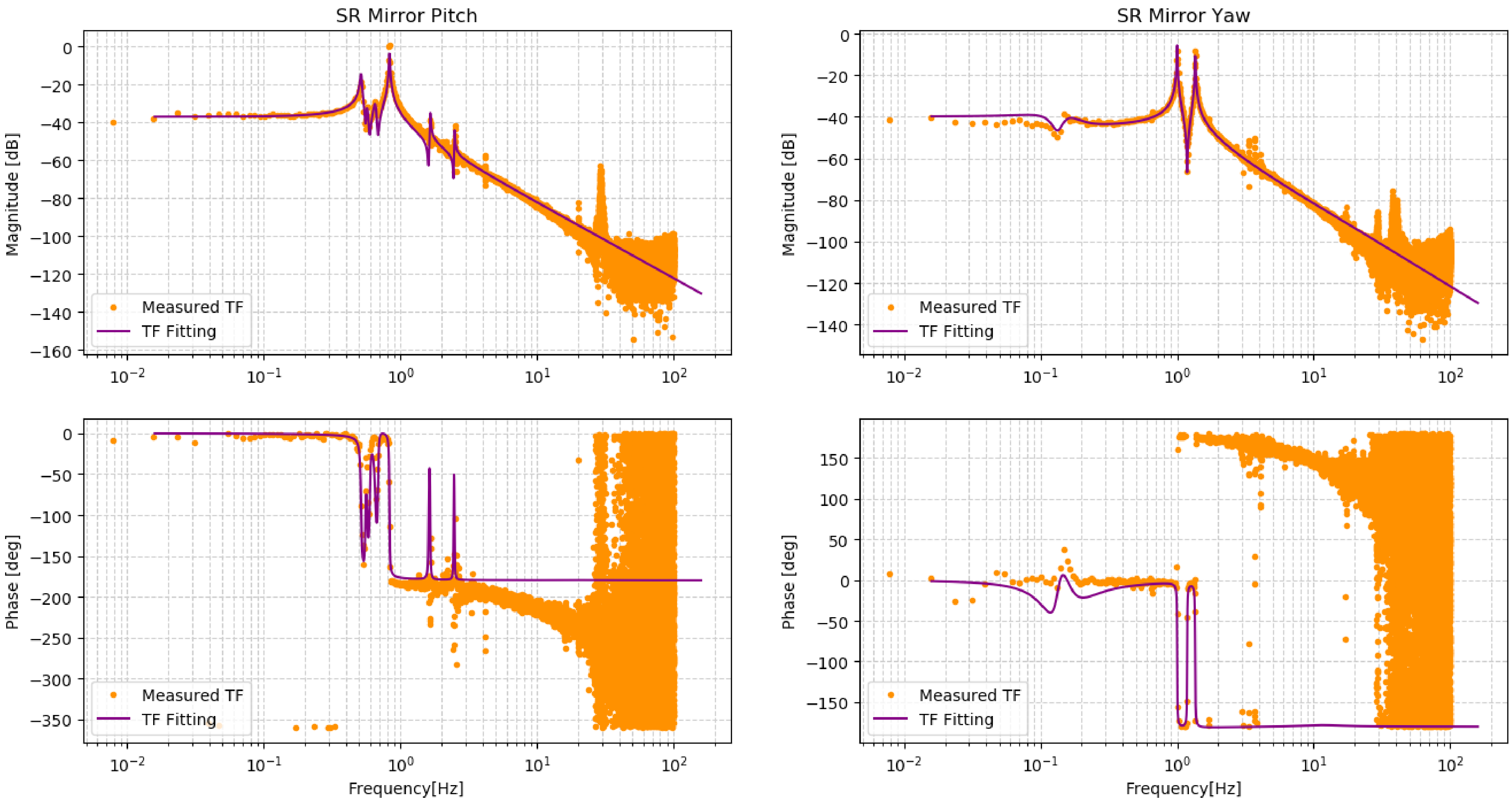
GAS Filter Chain ZPK fitting to help with the design of active filters.

Transfer functions of the system



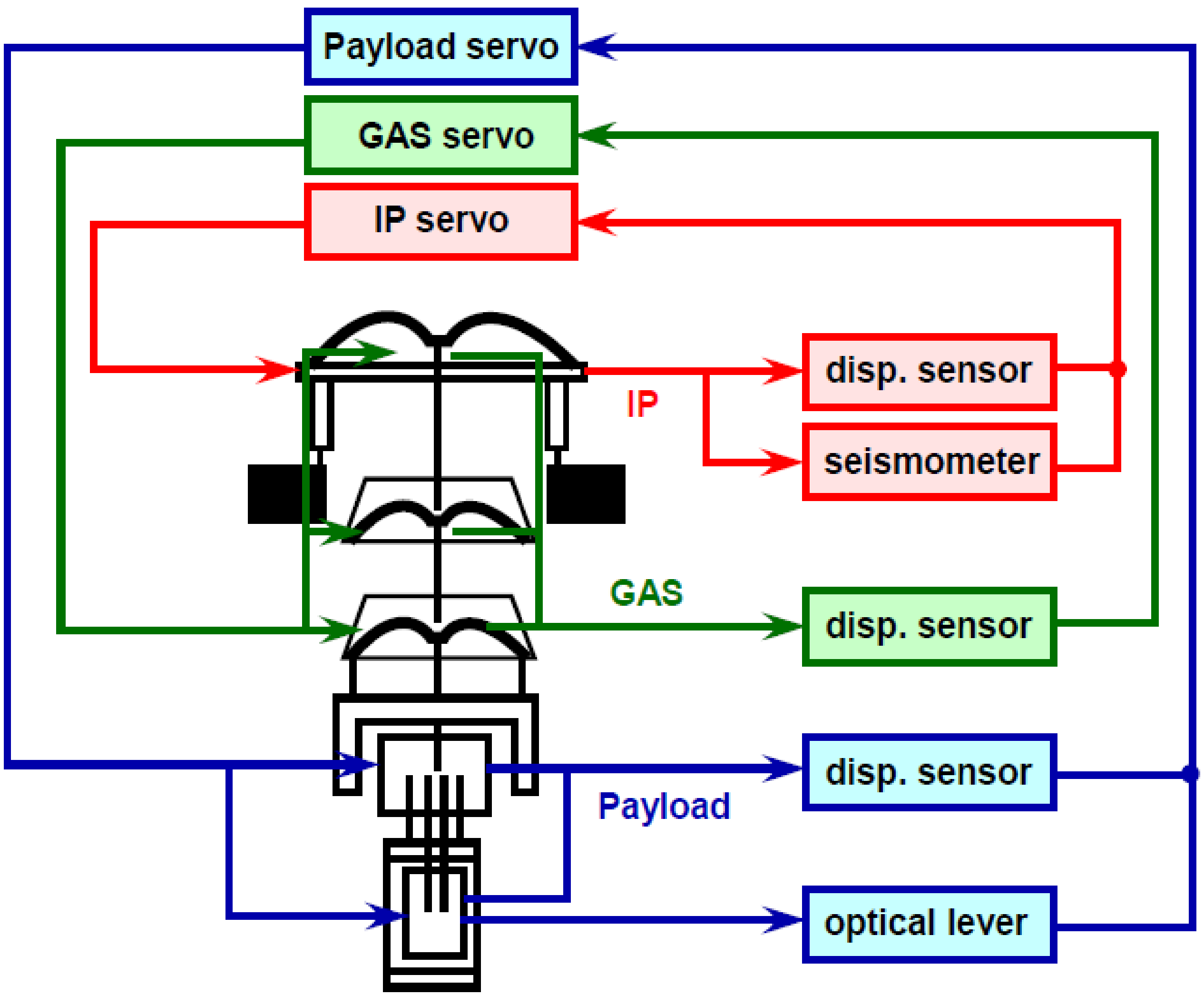
IM stage ZPK fitting to help with the design of active filters.

Transfer functions of the system



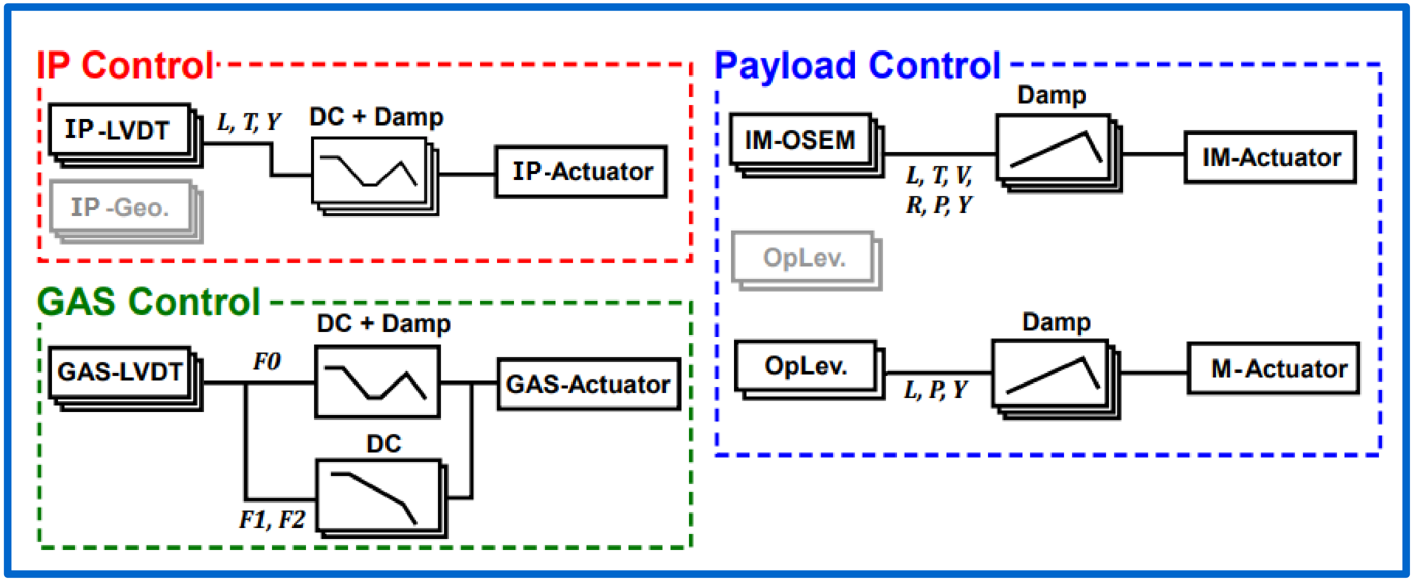
Mirror stage ZPK fitting to help with the design of active filters.

Damping of the modes stage by stage

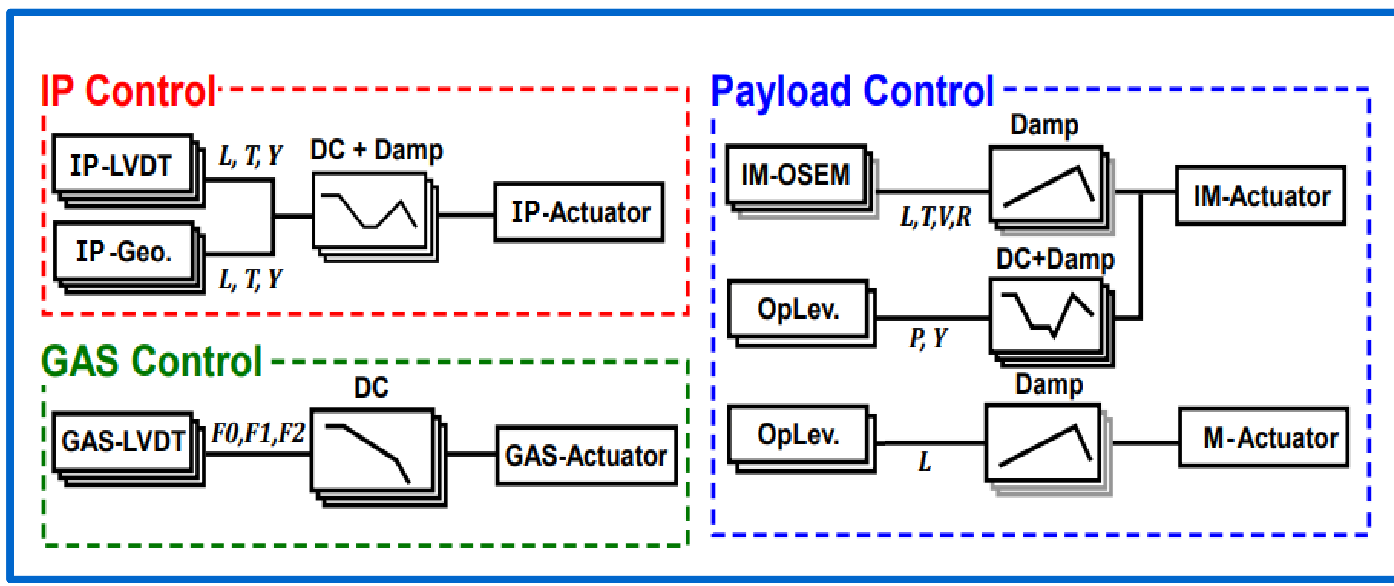


Sensors used at each stage and its active filter control.

Damping of the modes stage by stage

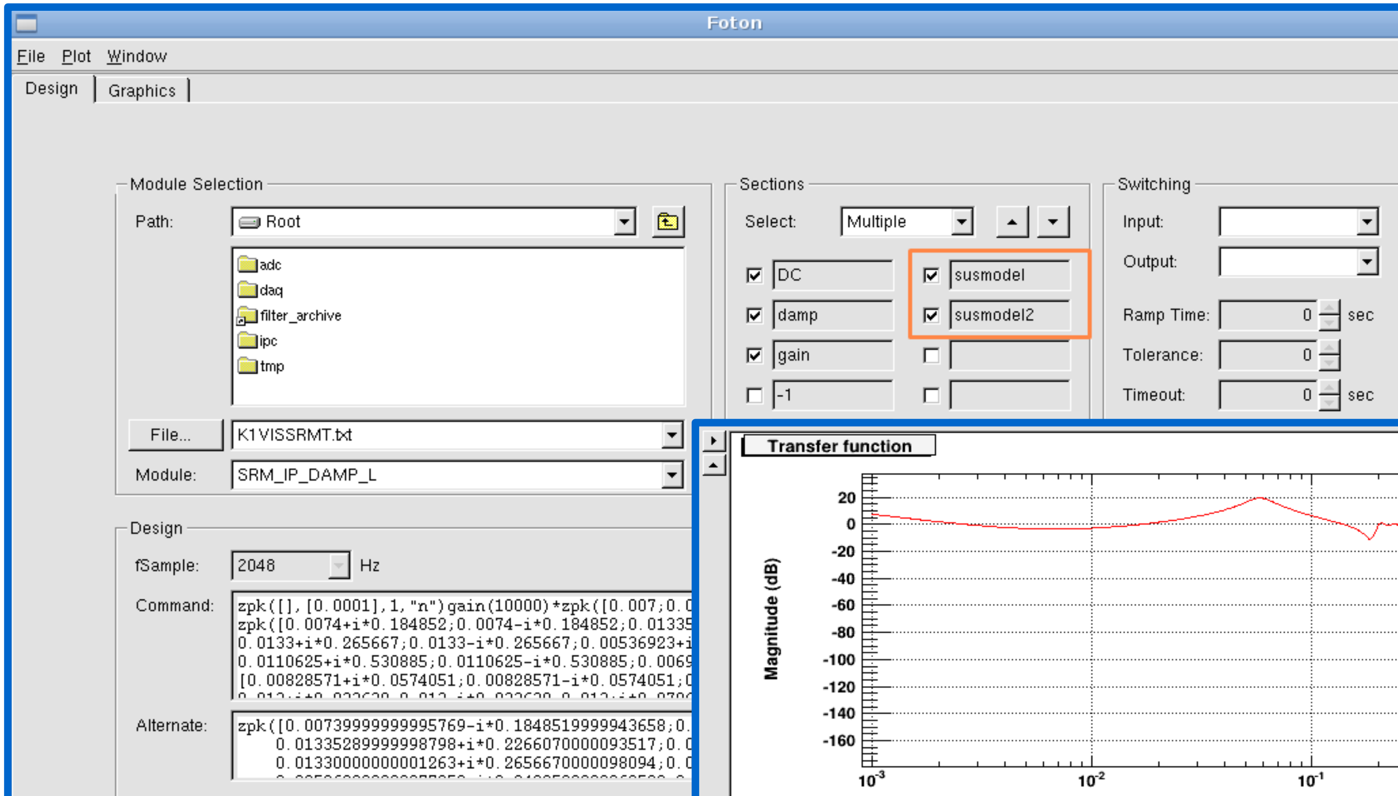


Control filters for Calm-down phase.

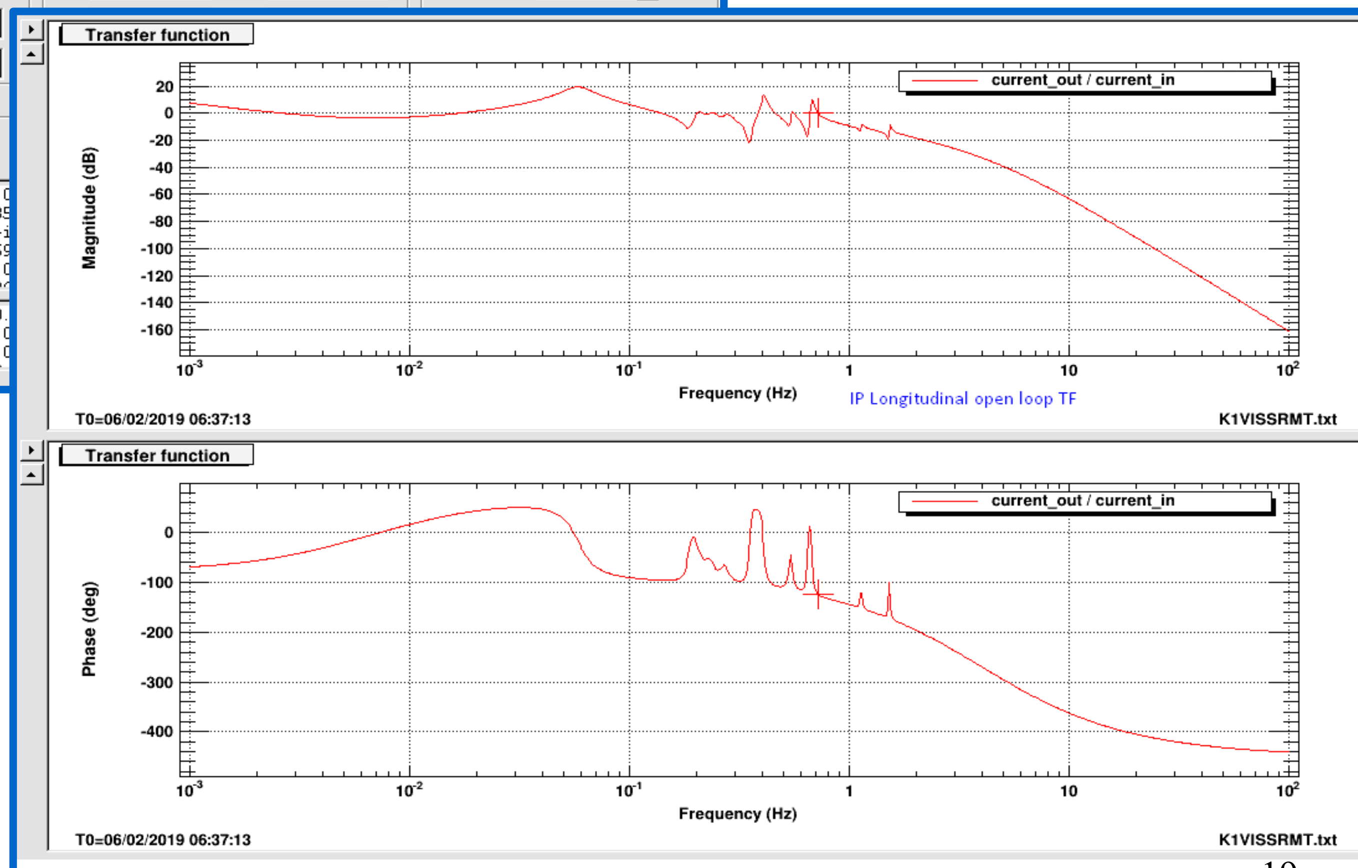


Control filters for Lock-acquisition phase.

Damping of the modes stage by stage

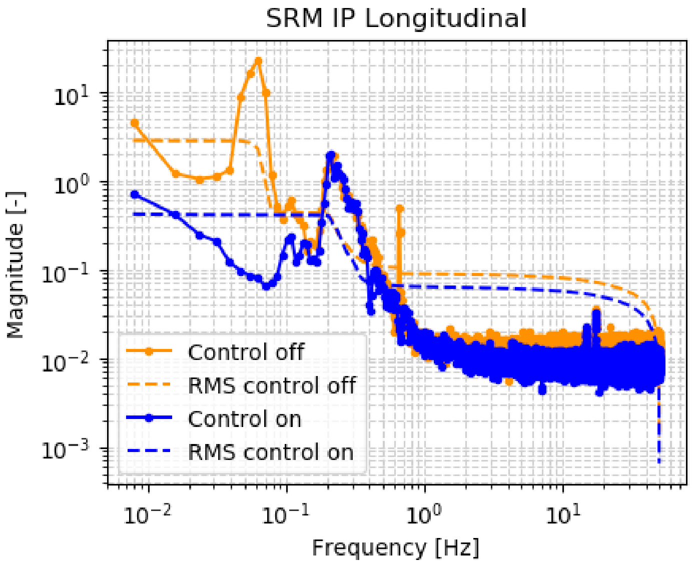


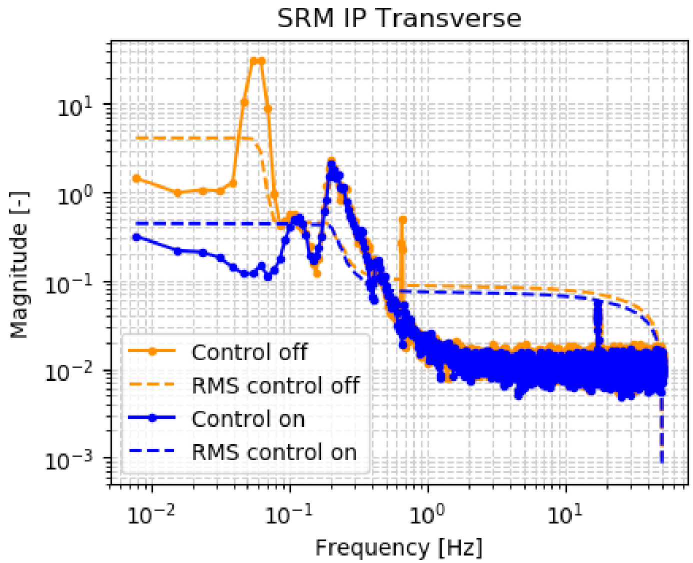
Insert the ZPK model obtained before in the filter bank.

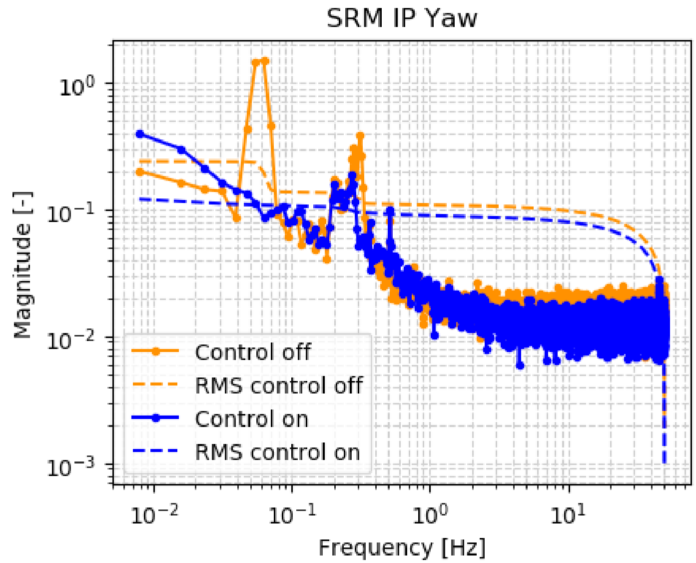


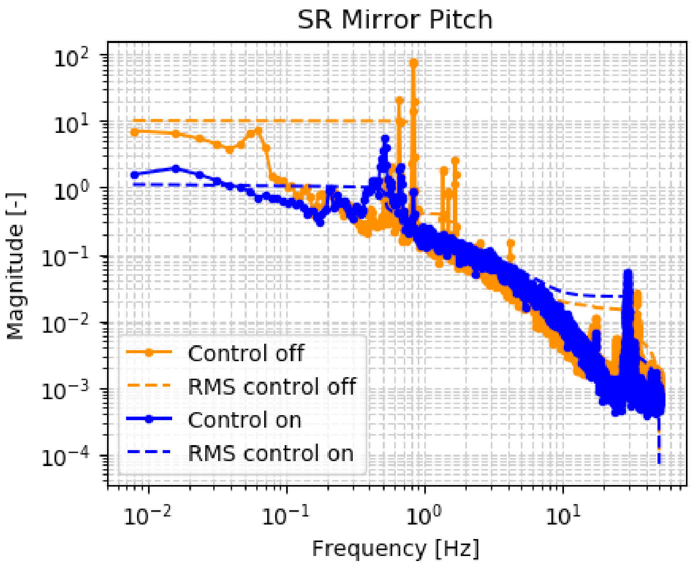
Study of closed-loop stability based on the open-loop TF using 'Foton'.

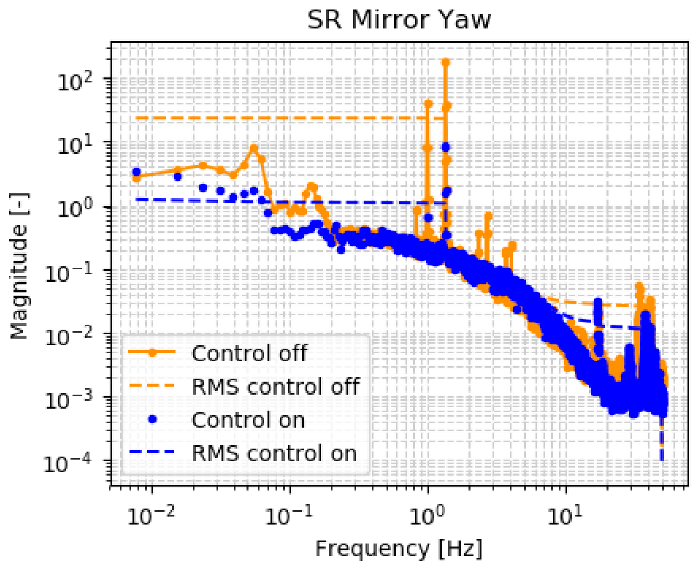
Damping of the modes stage by stage







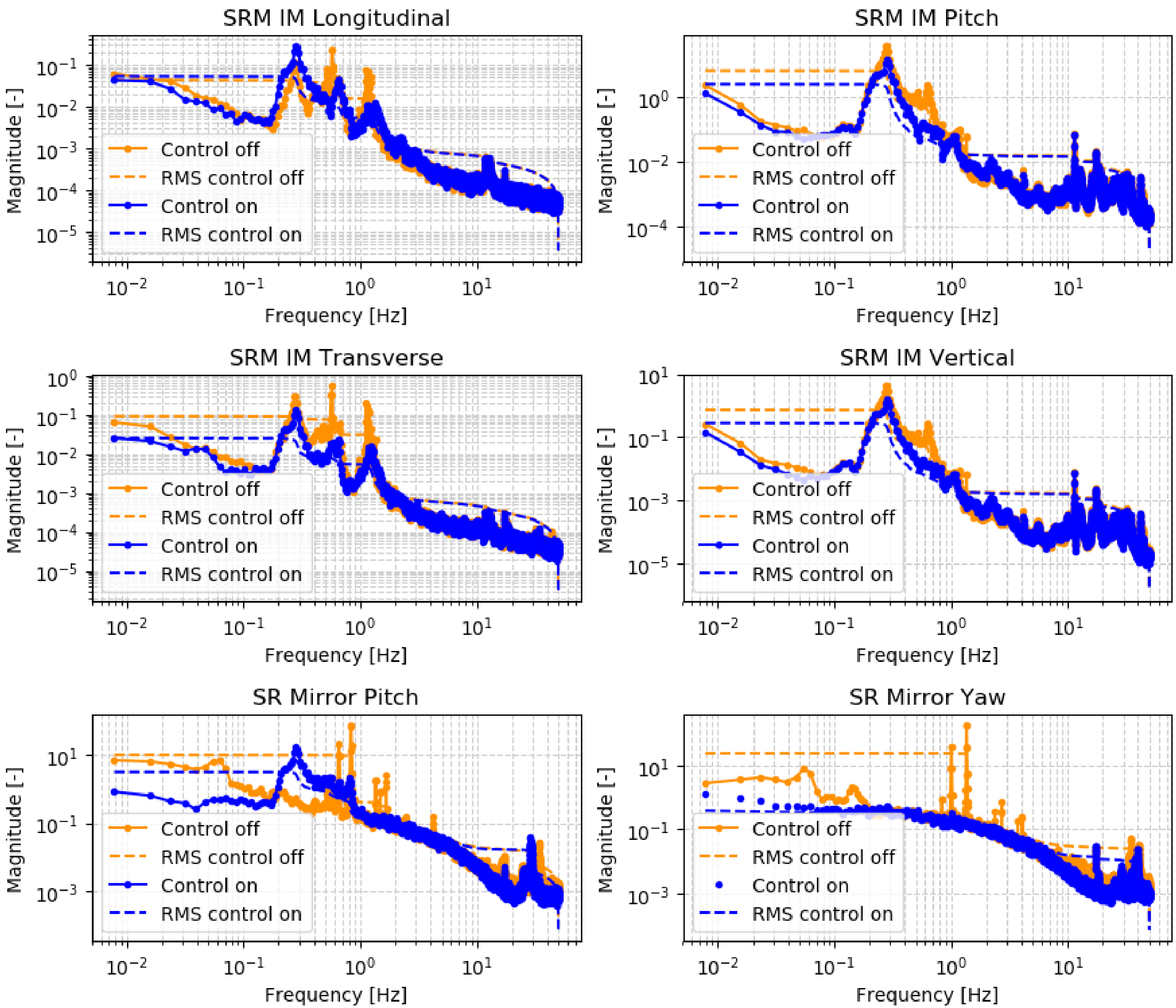




Only IP stage with position control on.

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

Damping of the modes stage by stage

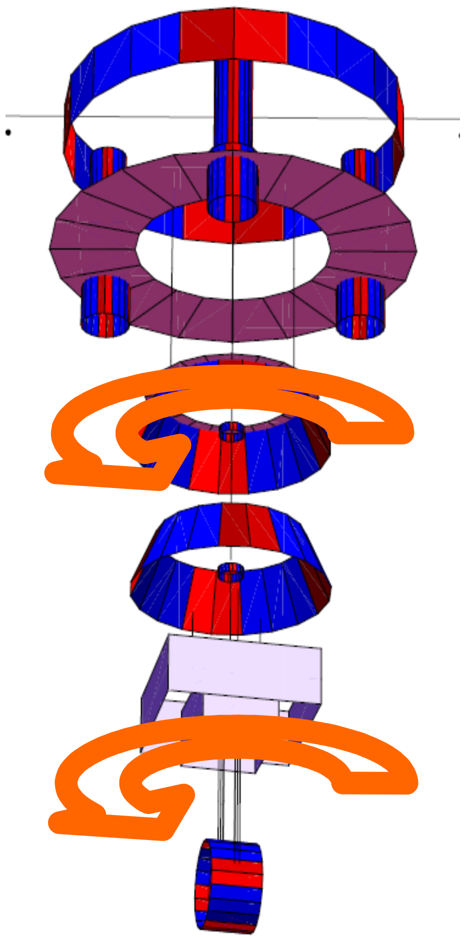


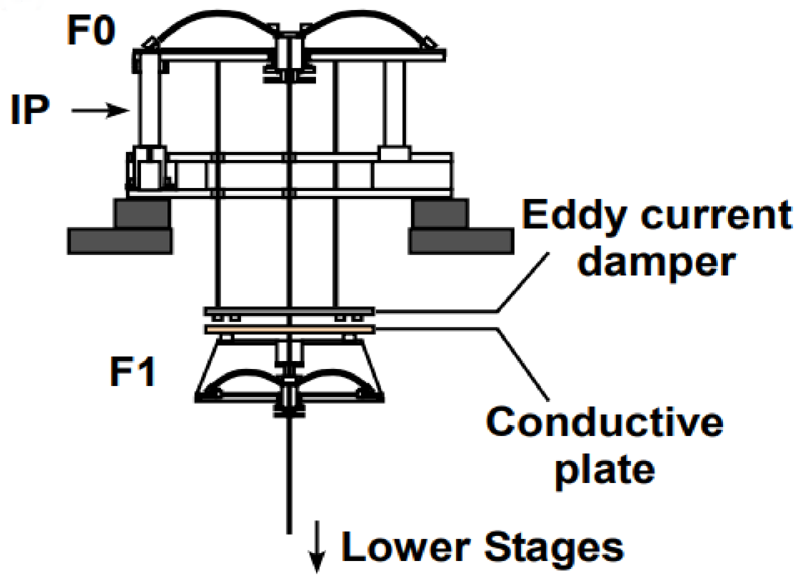
IP and IM stage with controls on.

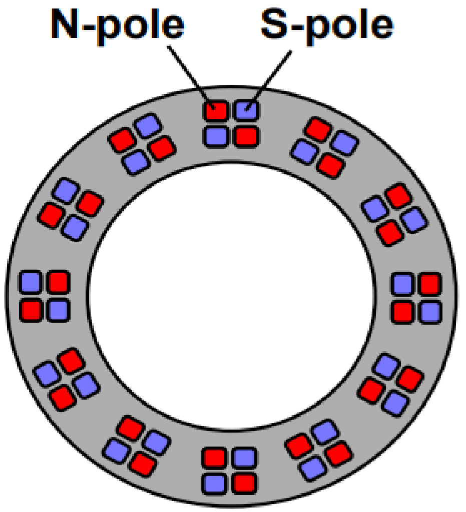
Angular fluctation of SRM.
Pitch: 10.3μrad --> 3.3μrad.
Yaw: 24.4μrad --> 0.4μrad.

Damping of the torsion mode (#1)

#1 Wire torsion (0.054 Hz)



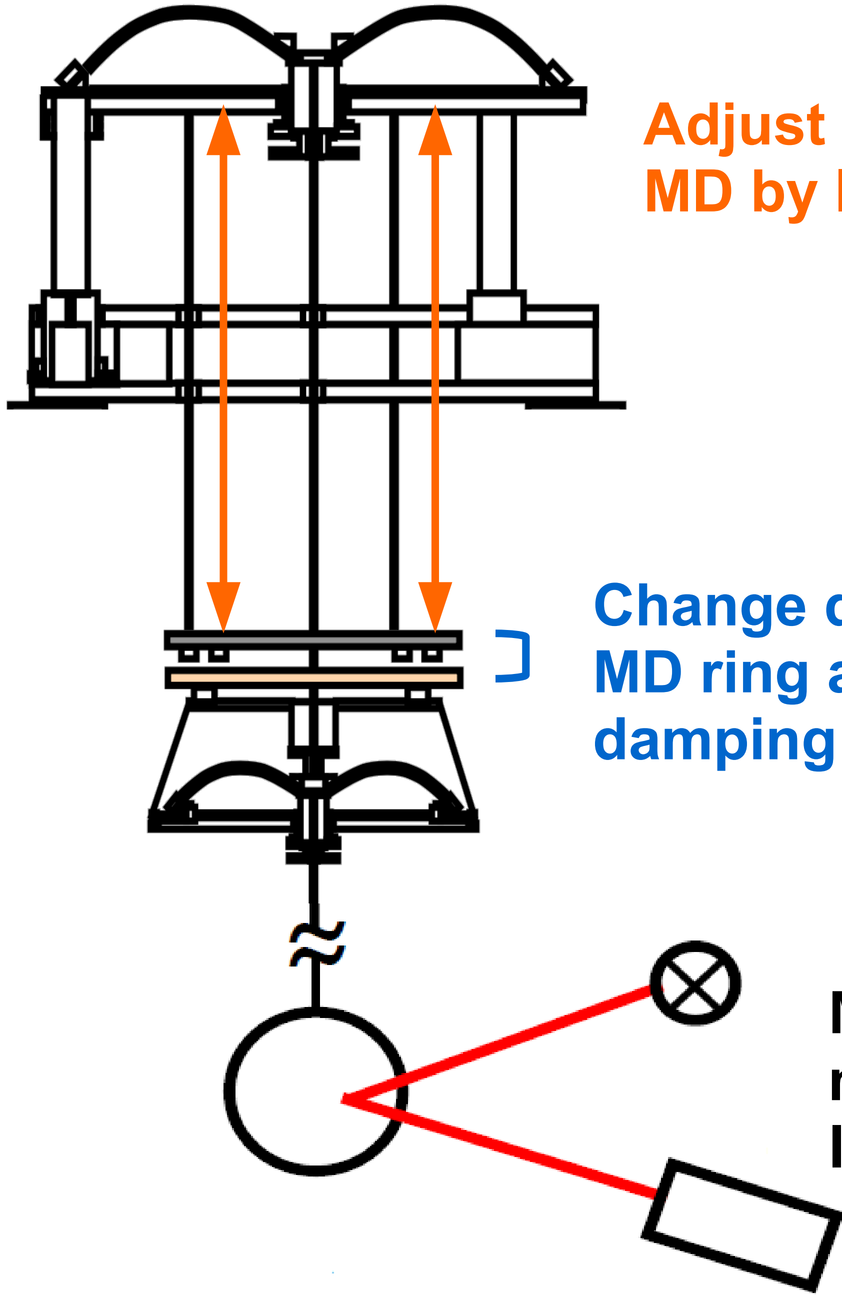




High quality factor. Long decay time.

Torsion mode is passively damped by the eddy current damper.

Damping of the torsion mode (#1)

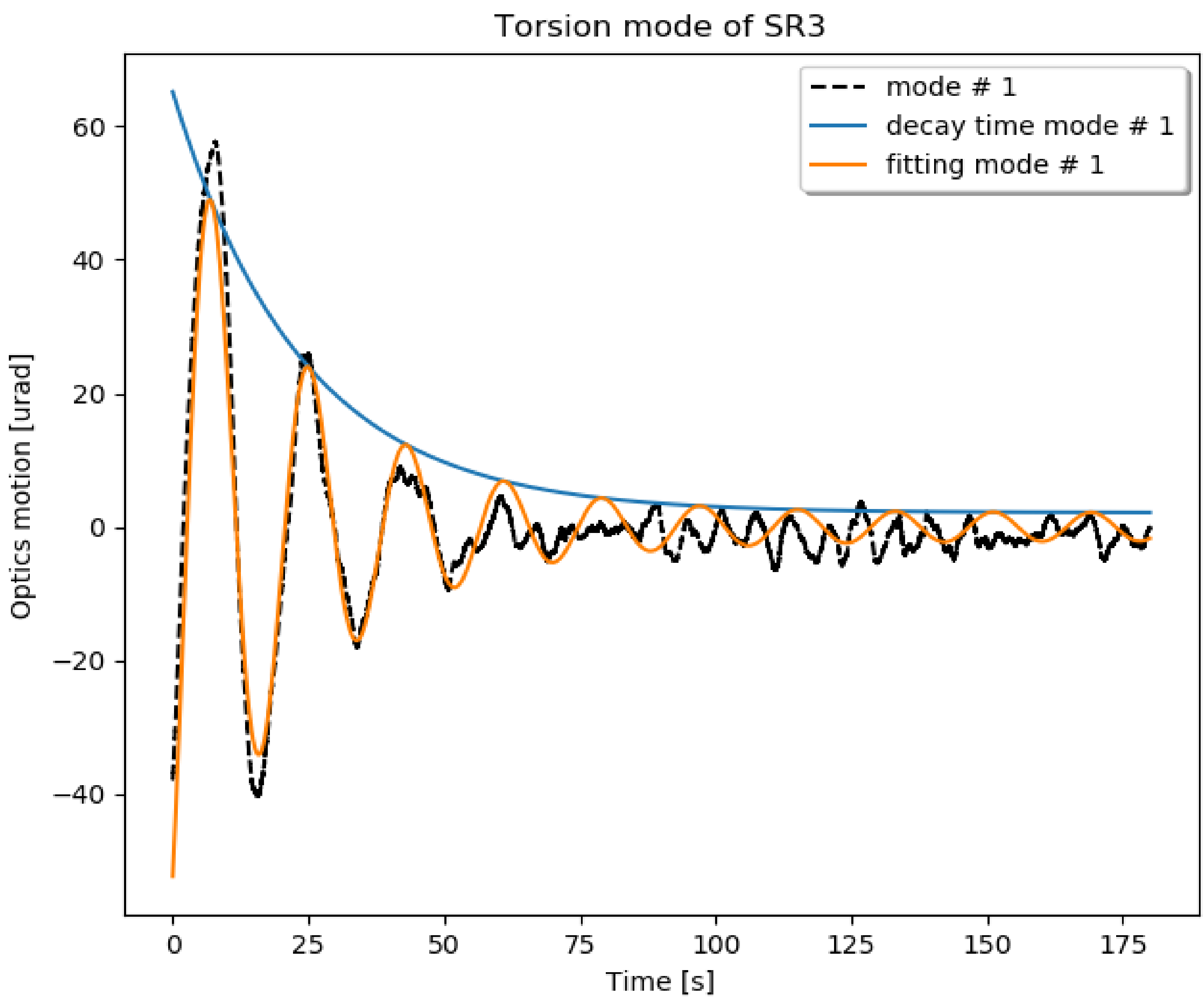


Adjust the height of the MD by lifting the rods.

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)

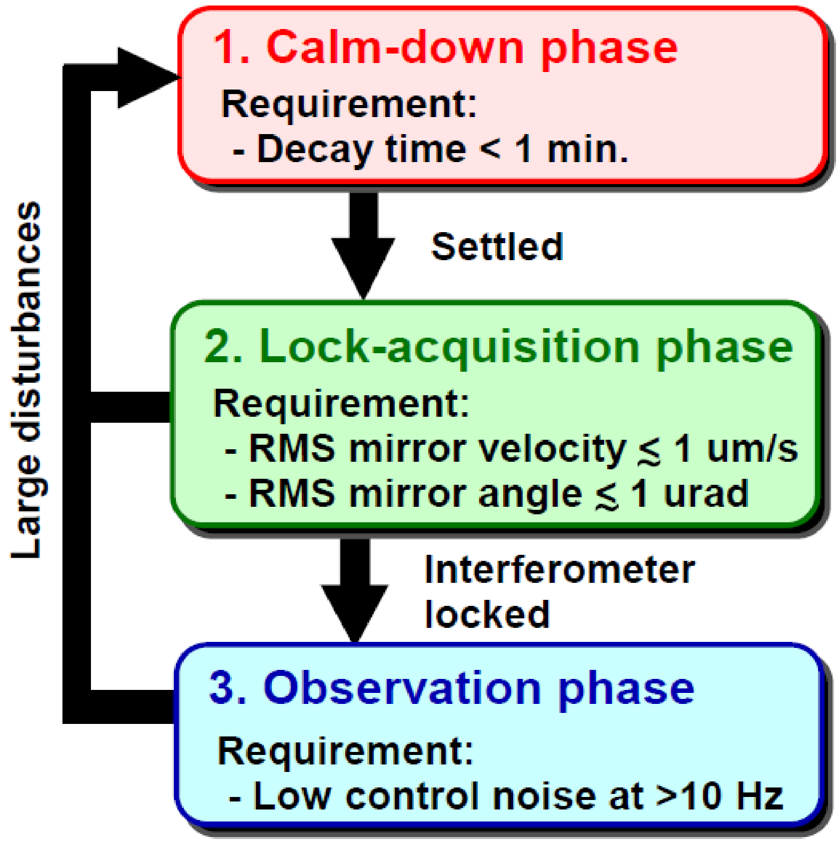


Decay time <60[s]

Freq. Simulation:
0.054 [Hz]

Freq. Measured:
0.055 [Hz]

Meeting the requirements



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

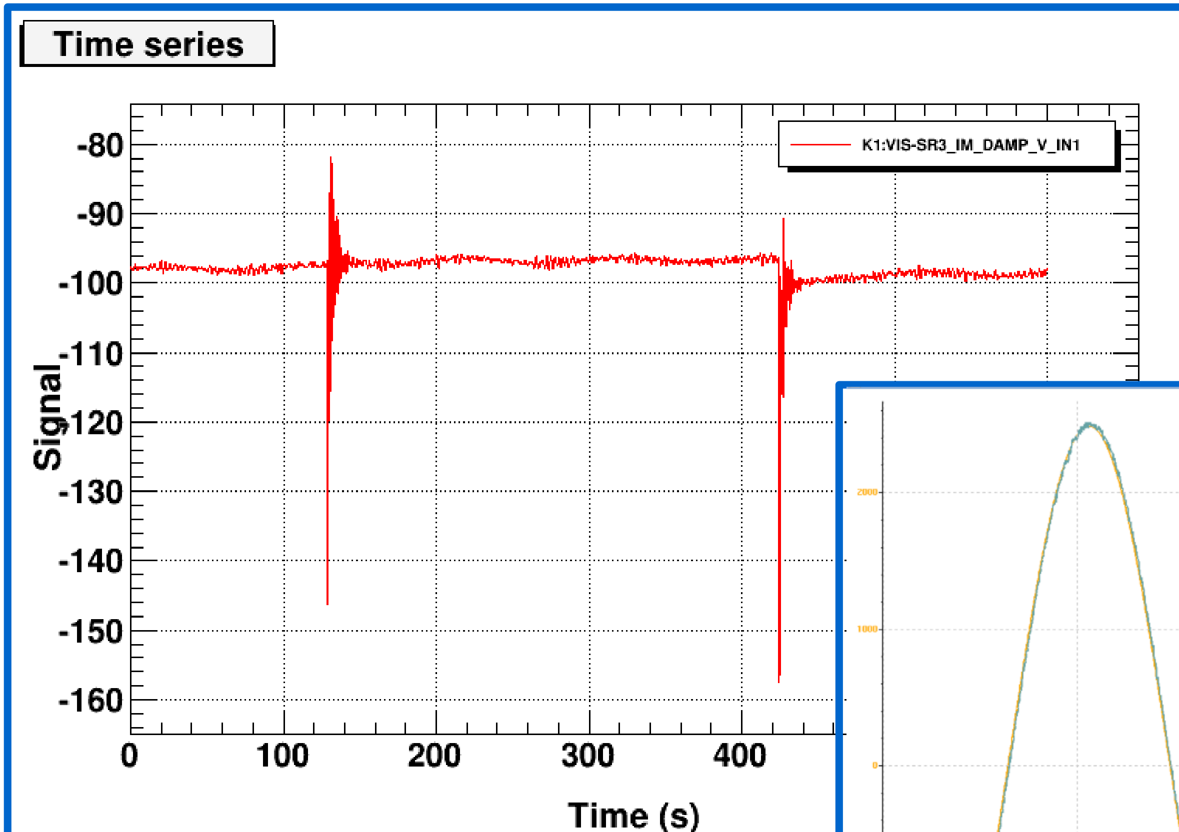
Angular fluctation of SRM.
Pitch: 10.3μrad --> 3.3μrad.
Yaw: 24.4μrad --> 0.4μrad.

We need to work in the tuning of the controls.

But we have also other urgent problems...

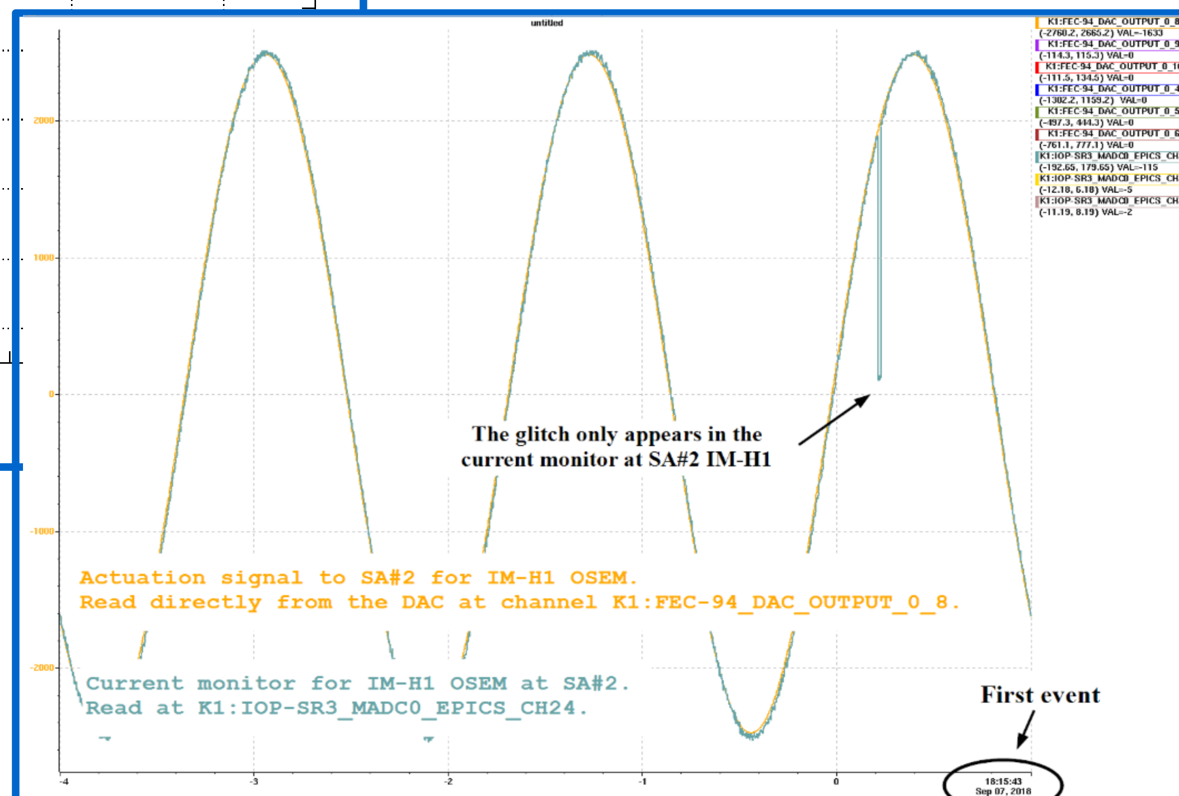
Problems: Glitches

Glitches found at ETMY, BS and, later on, SR3.



klog6012

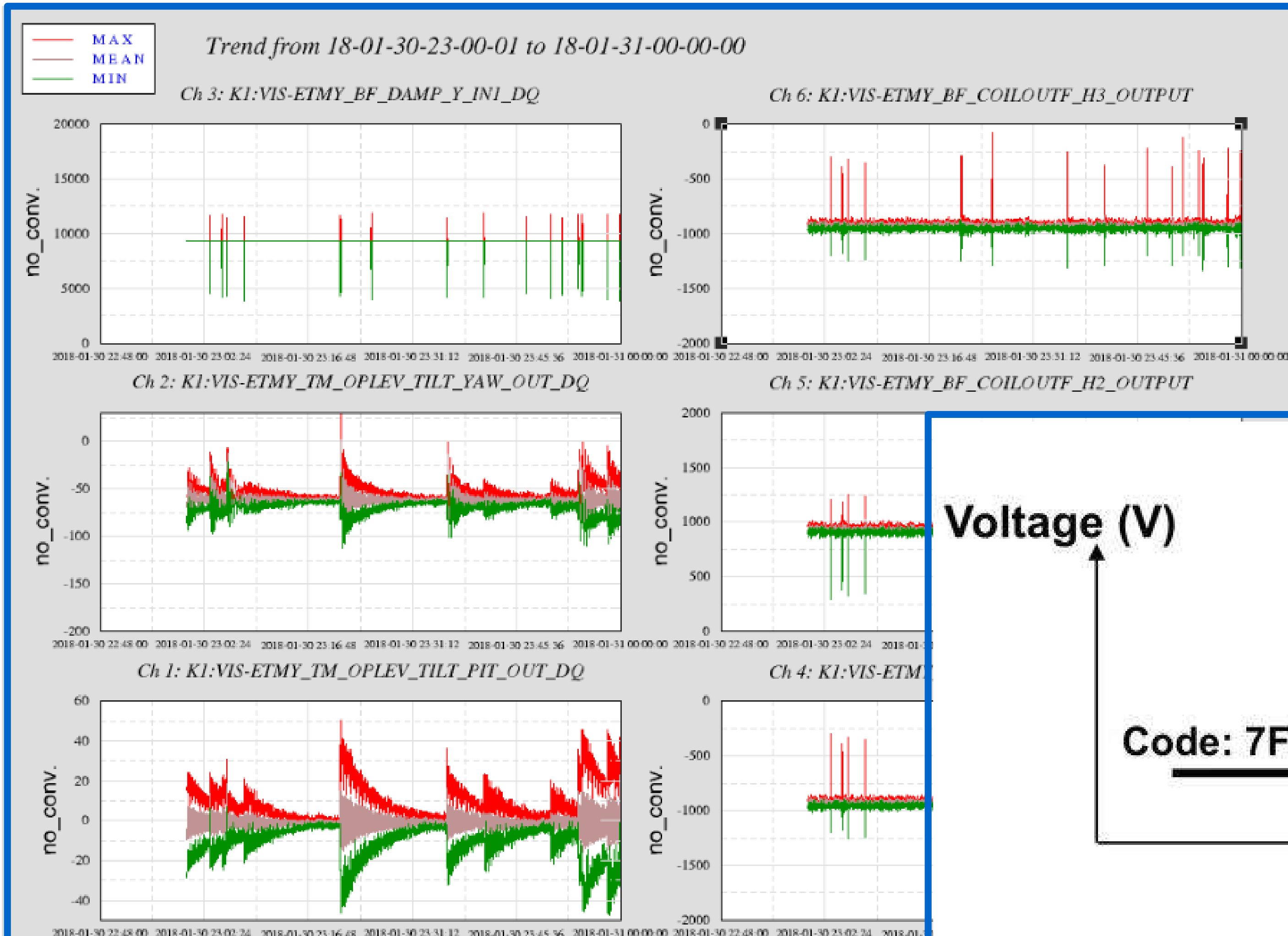
klog6062



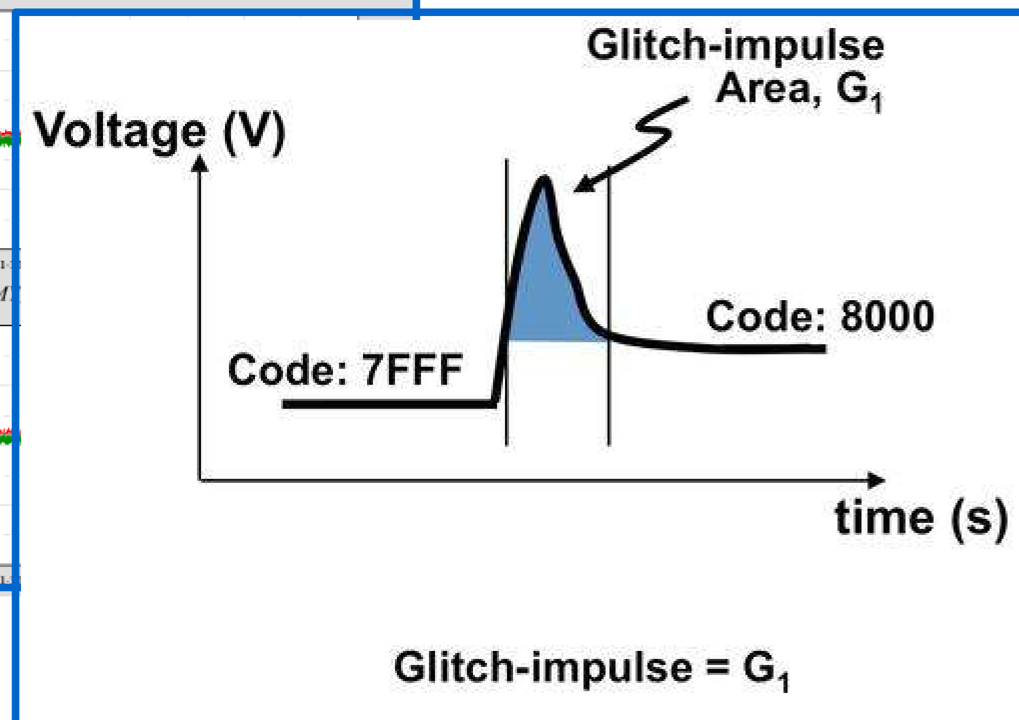
Different sources:
HP Coil Drivers, Satellite amplifiers, DAC...

DAC Glitches

Glitches found at ETMY.



klog4072

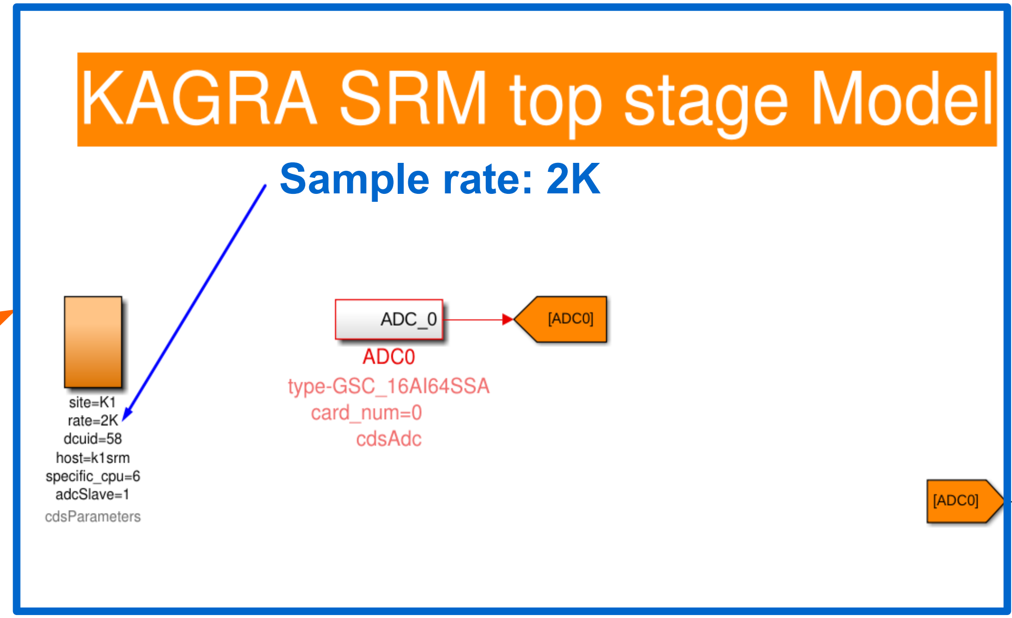


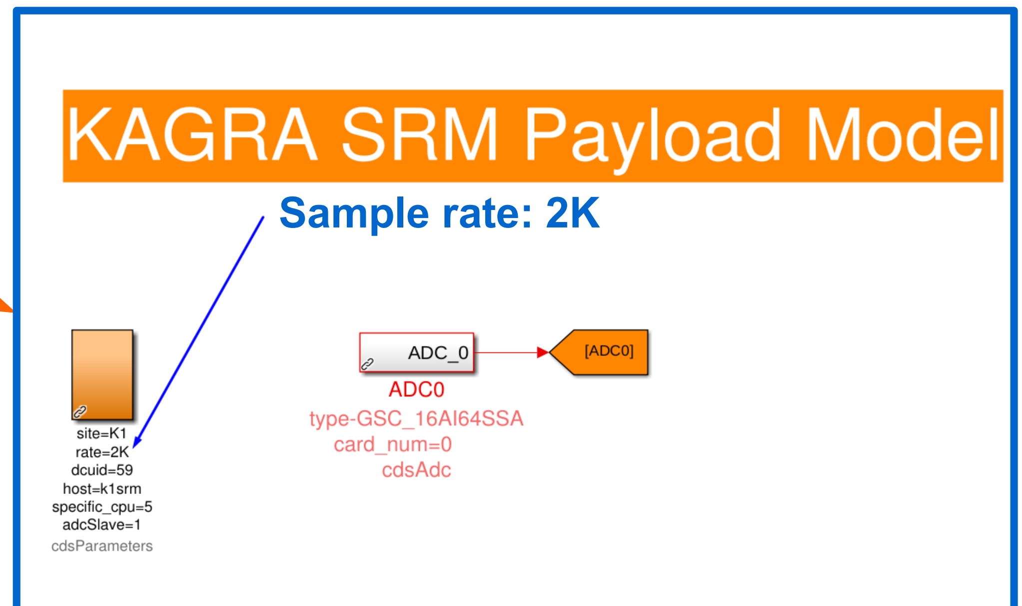
Splitting real-time model of BS and SRM

Preventive measures:

SRM RTM rate: 16K

- IP stage
- GAS filter chain
- IM stage
- TM stage
- BIO





Study other solutions if necessary.

Future Work

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.

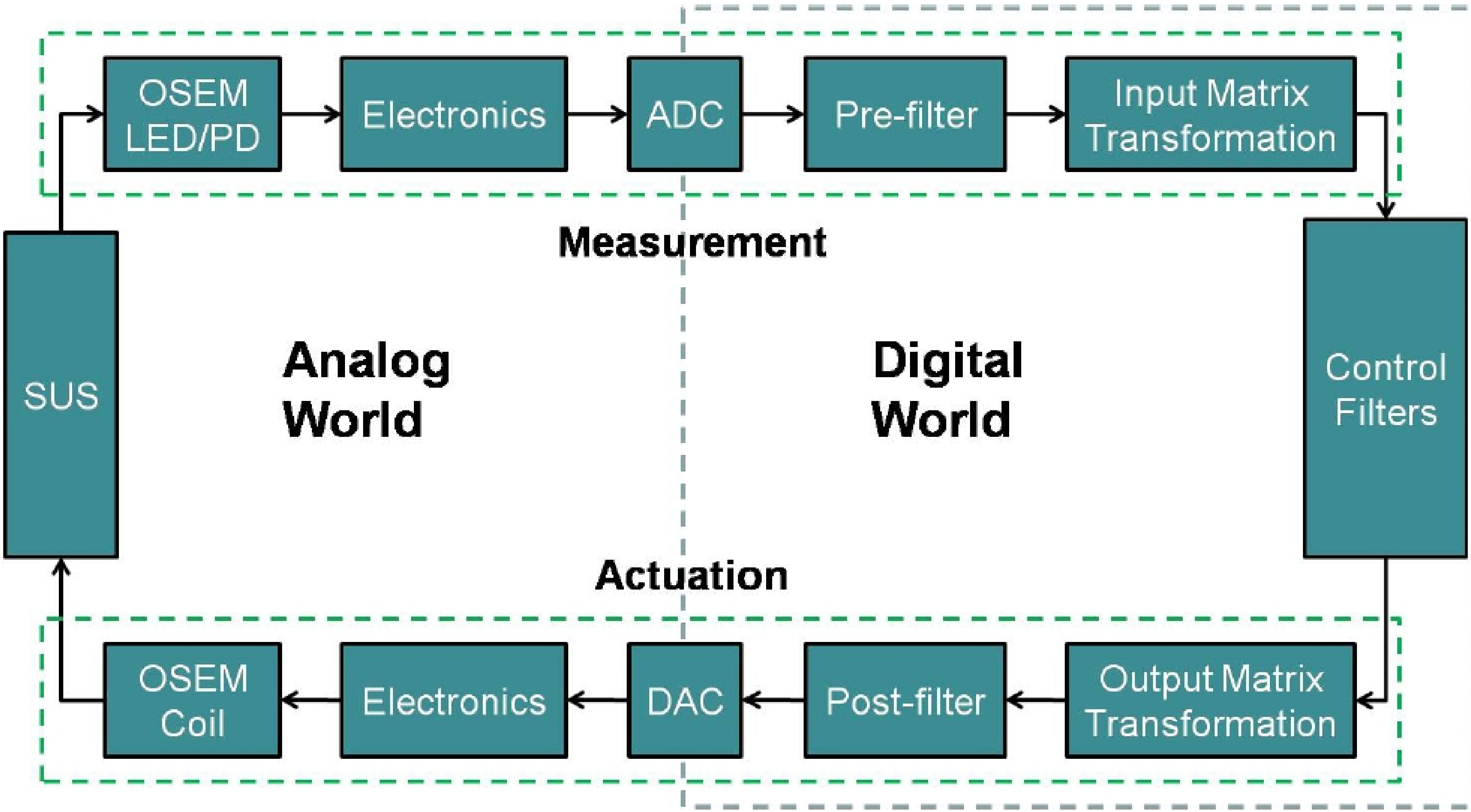
Real time model

- Split the models of SR2 and SR3 suspensions.

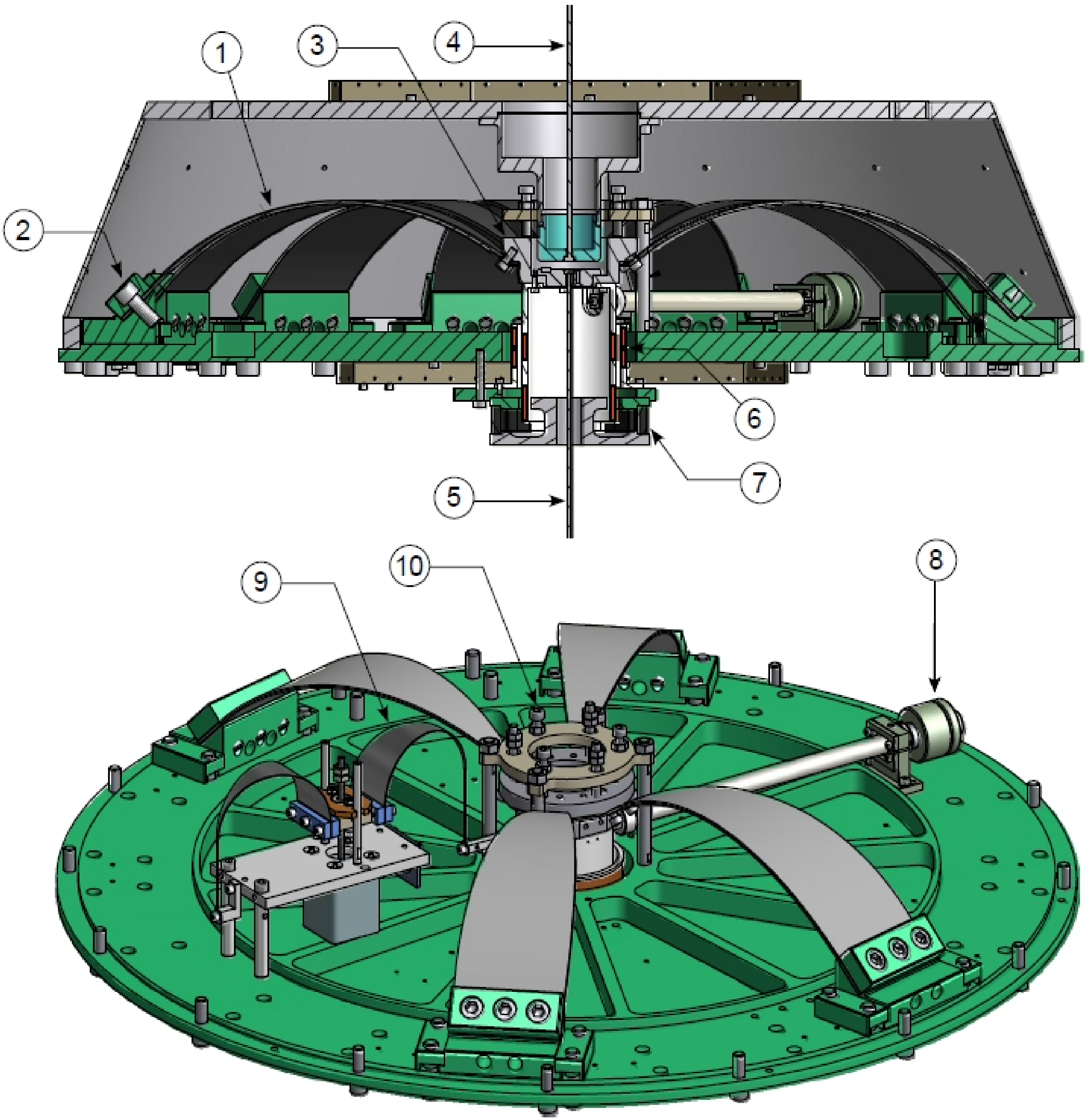
Thank you!

Extras

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).

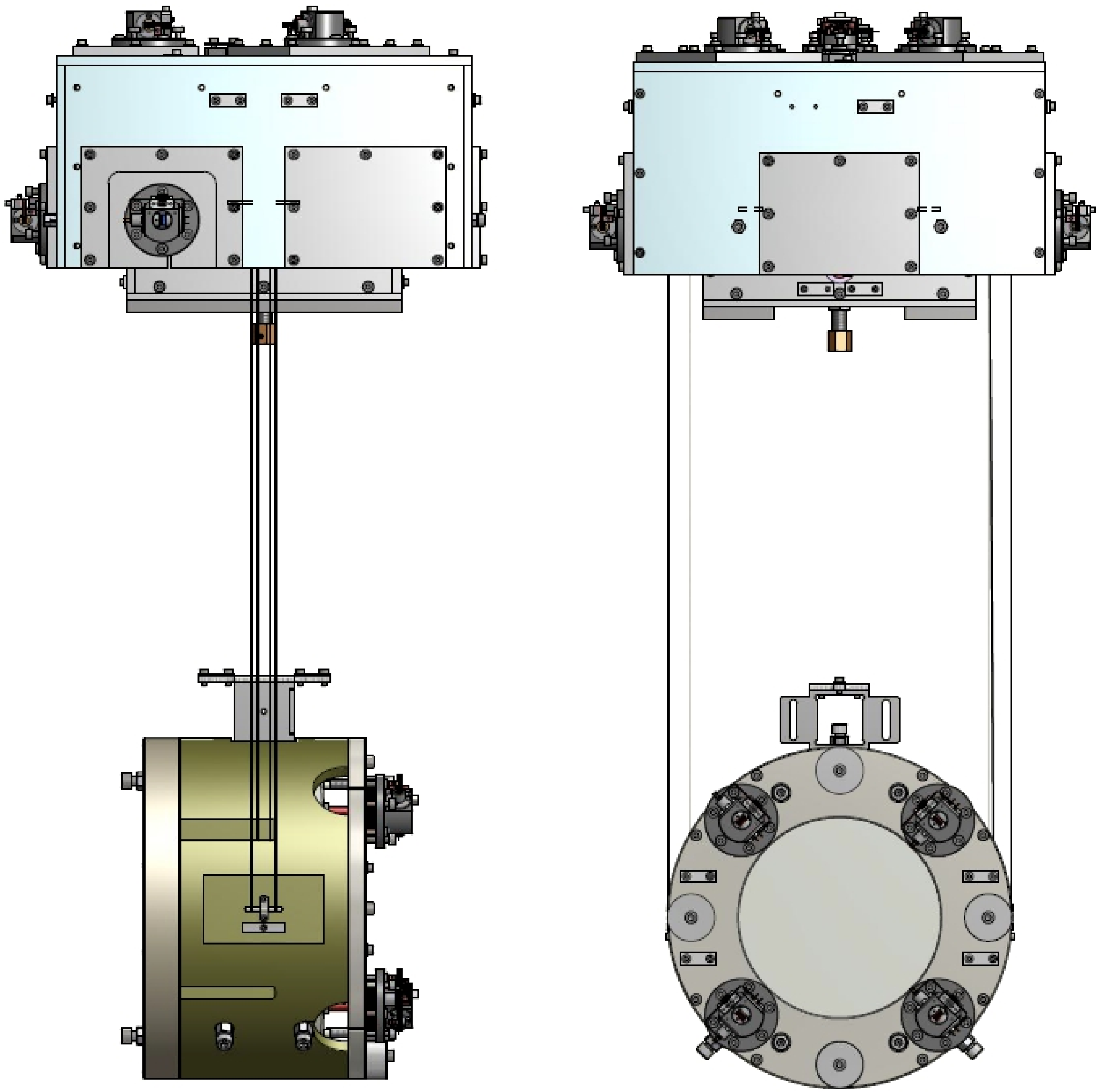
(7) Coil magnet actuator.

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

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

(10) Locking system screws.

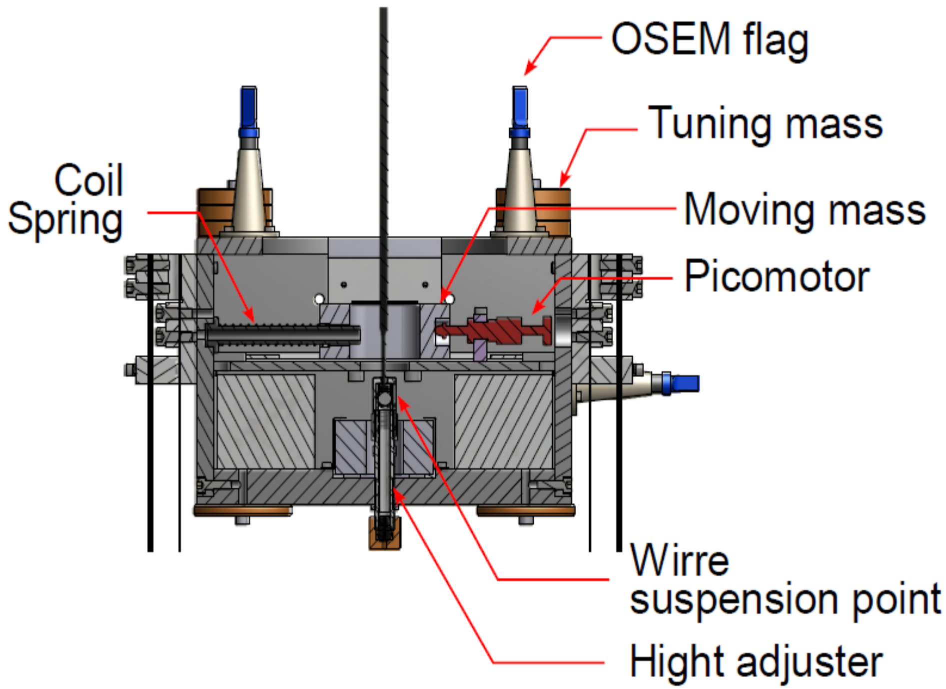
IM OSEMs and TM coil actuators



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

4 Coil actuators
at the Optics stage.

IM stage and OSEMs



OSEM: Optical Sensor and Electro Magnetic actuator.