Commissioning of the Type A suspensions control: tower part

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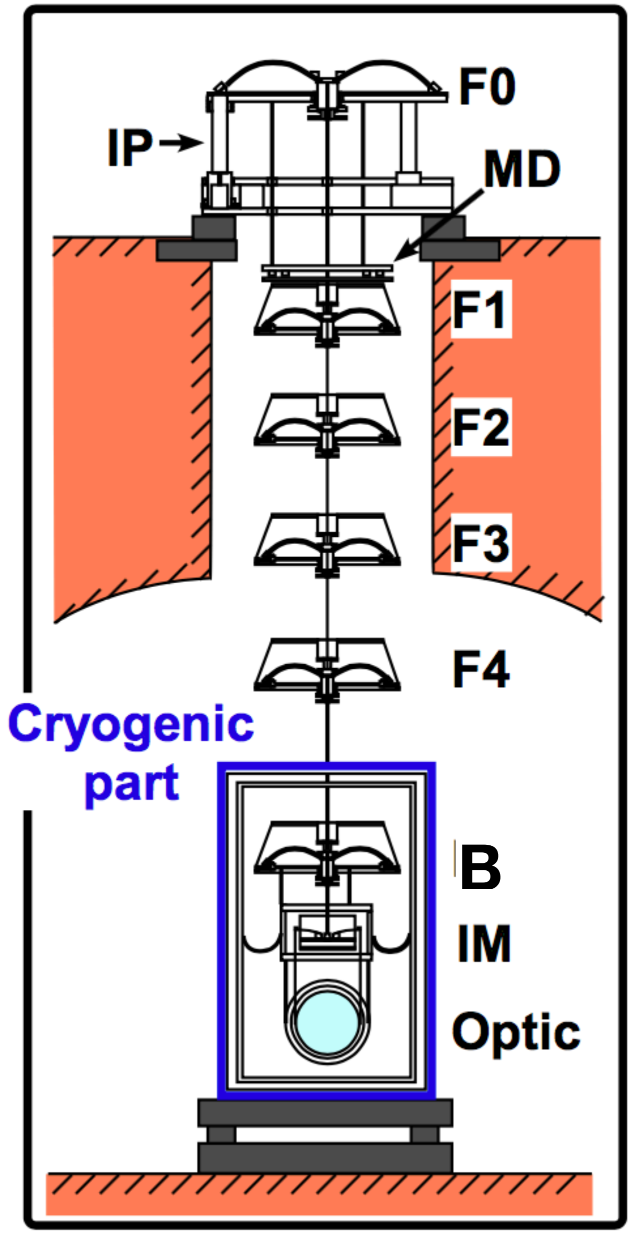
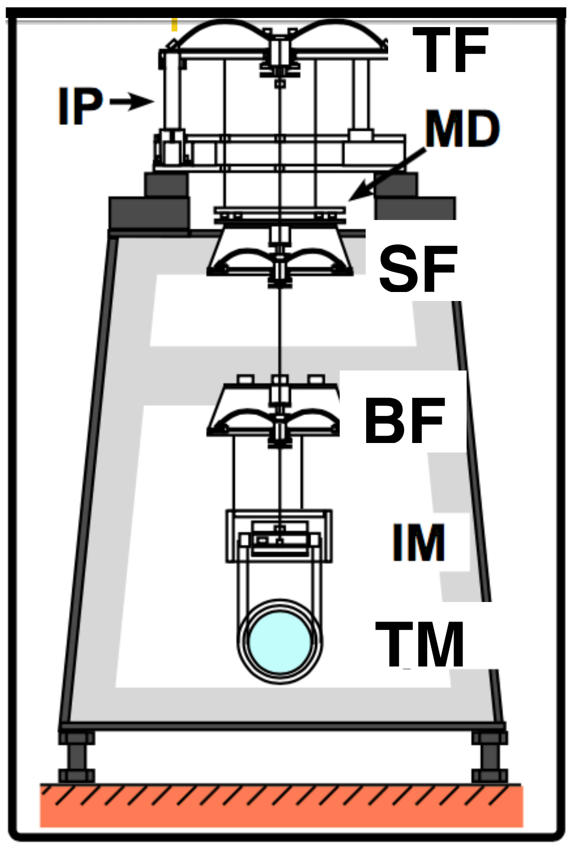
OUTLINE

- Type A
- Noise budget of diagonalized sensors
- Blending technique
- Inertial damping: preliminary results
- GAS filter damping control
- Conclusion

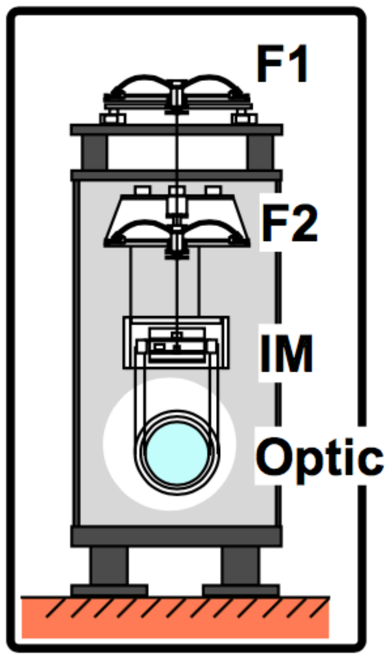
VIS Suspension Systems



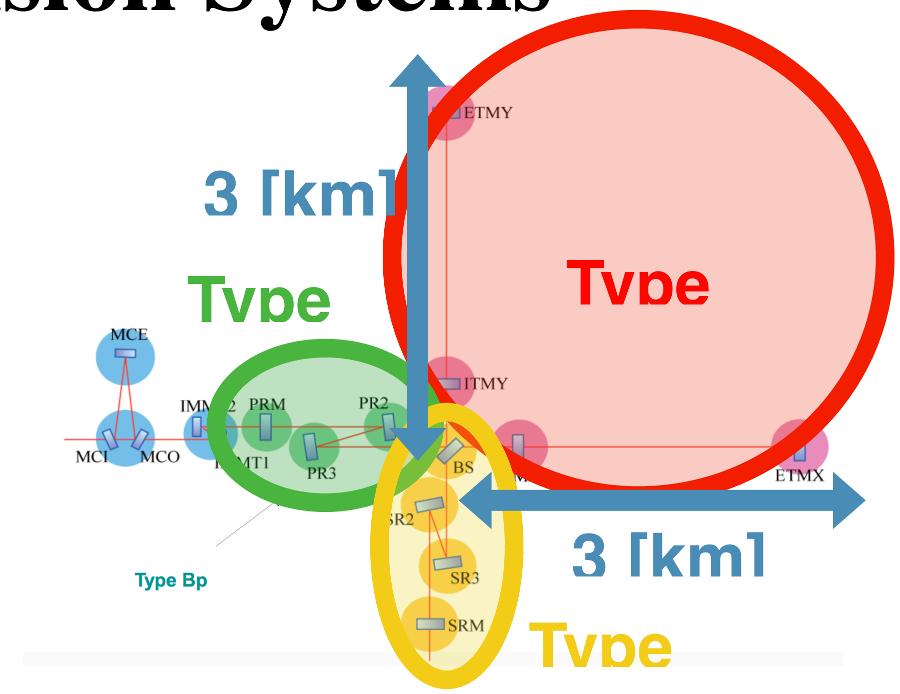
Type-A

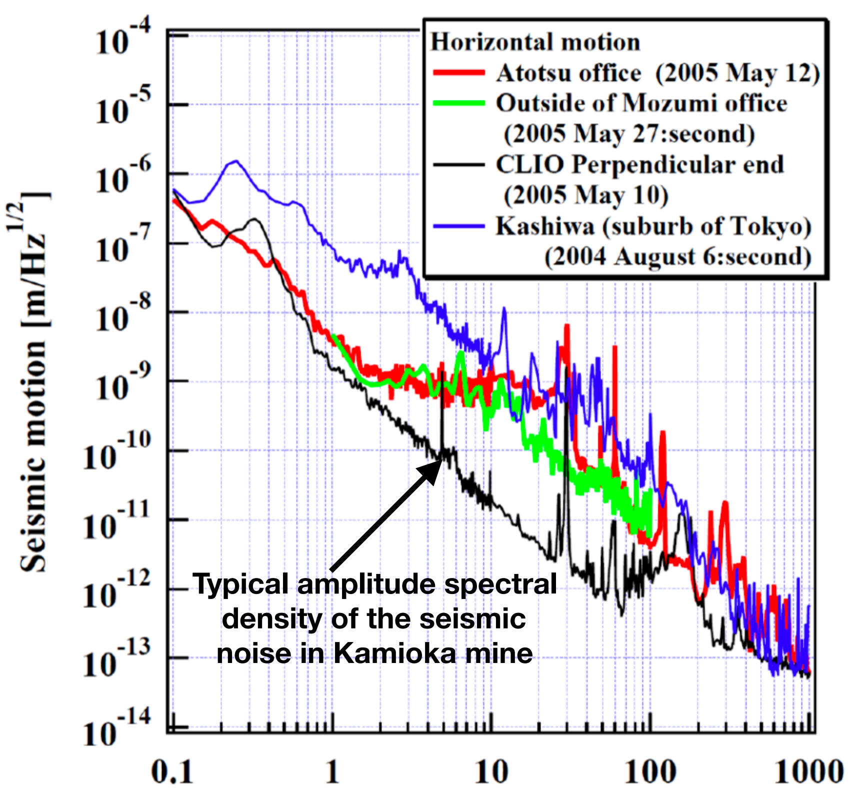


Type-B

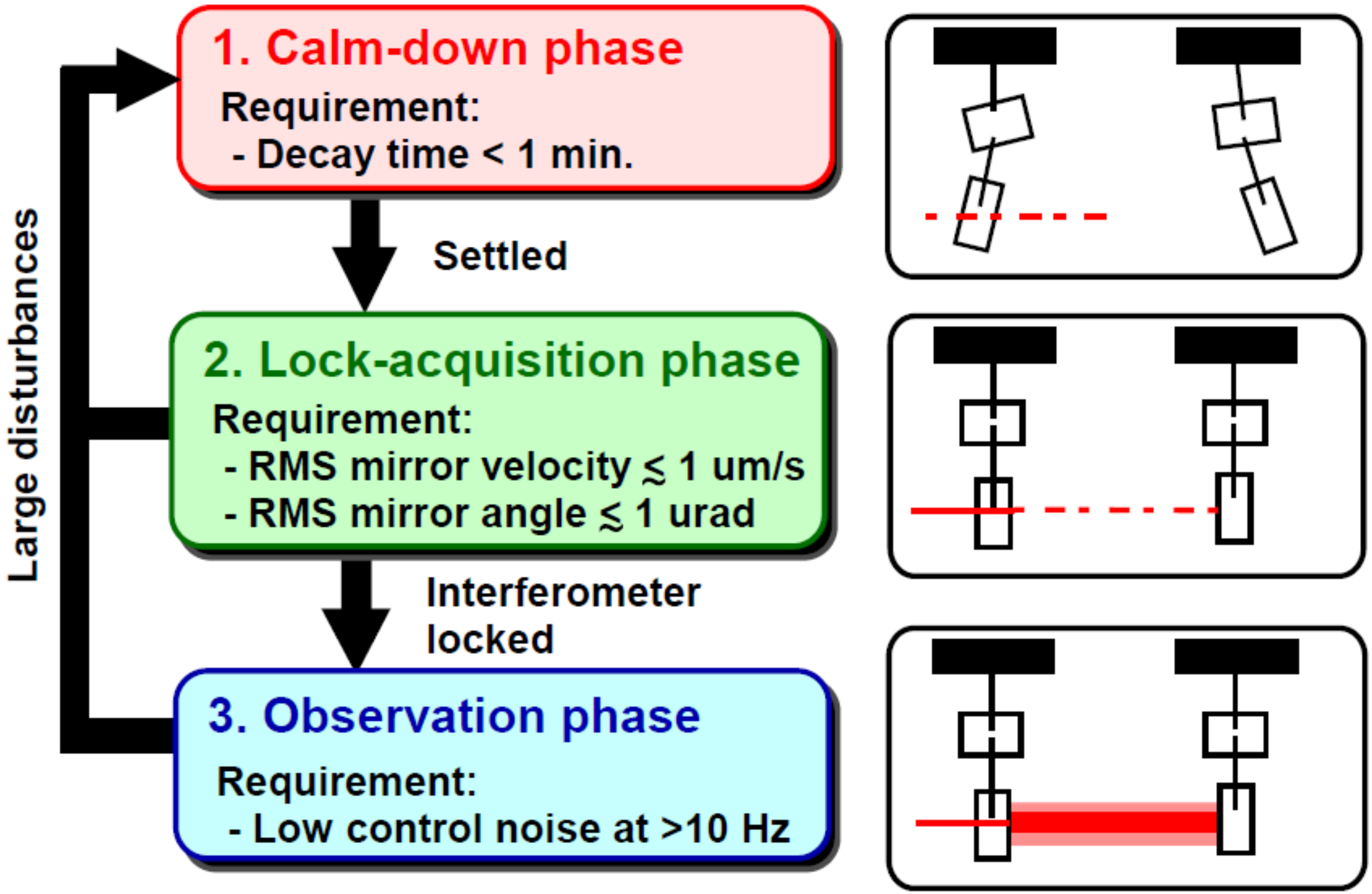


Type-Bp

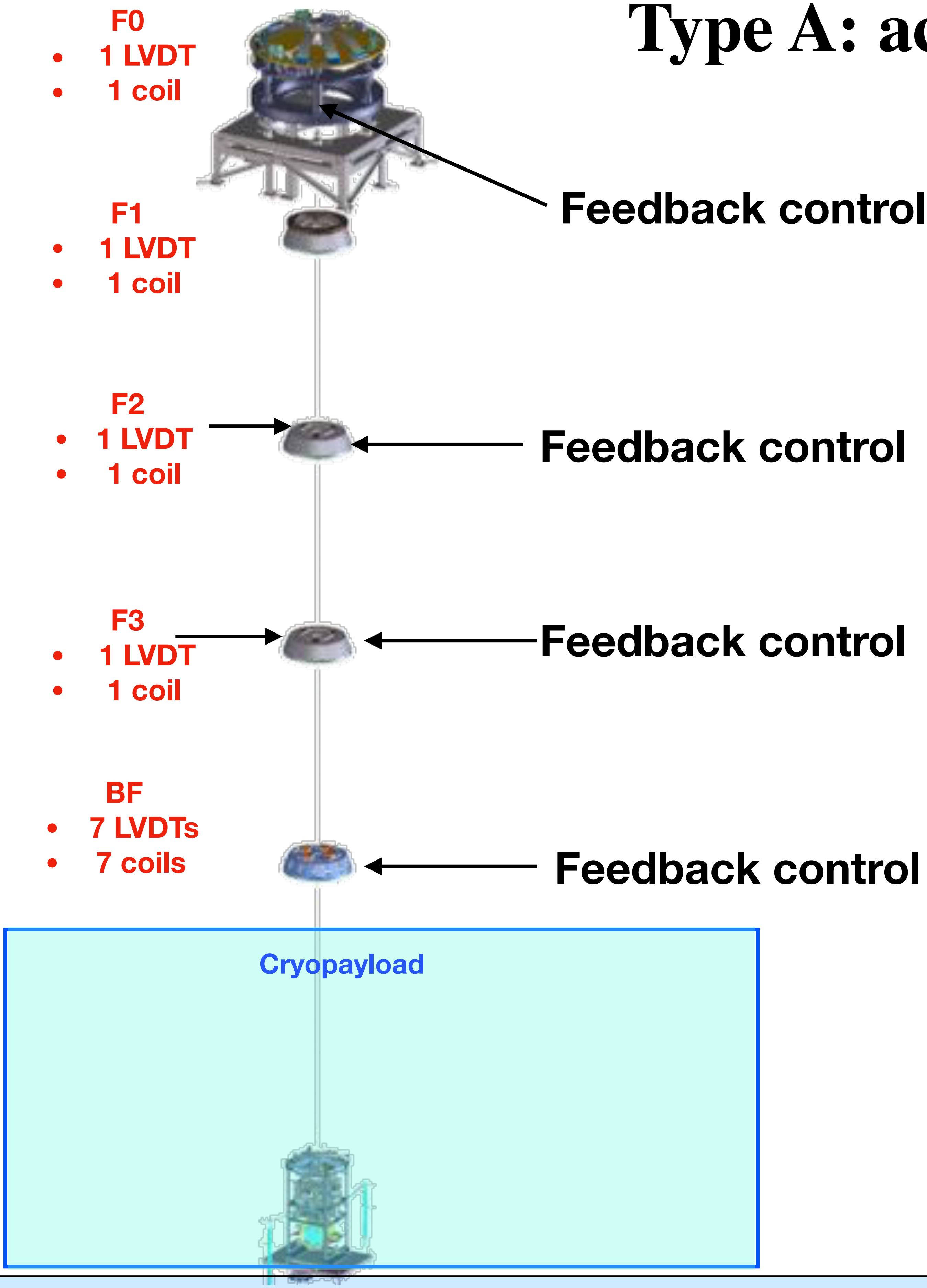




Type A suspension:requirements



Type A: actuation points



Calm down phase:
- **IP control**

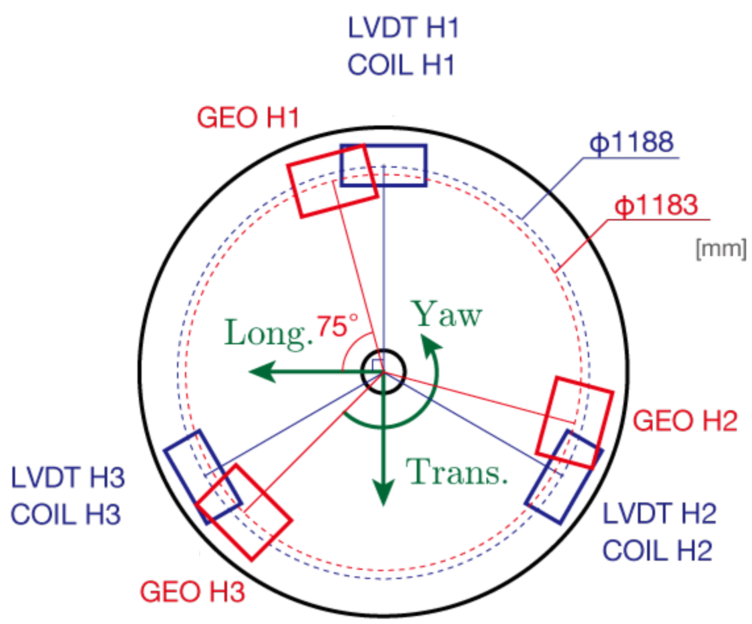
Calm down phase:
- **GAS filters control**

Calm down phase:
- **BF Y control**

Type A suspension: sensors and actuators

To implement the Damping control on the IP and on the BF first we build the diagonalized sensors and actuators in the (L,T,Y) base

IP

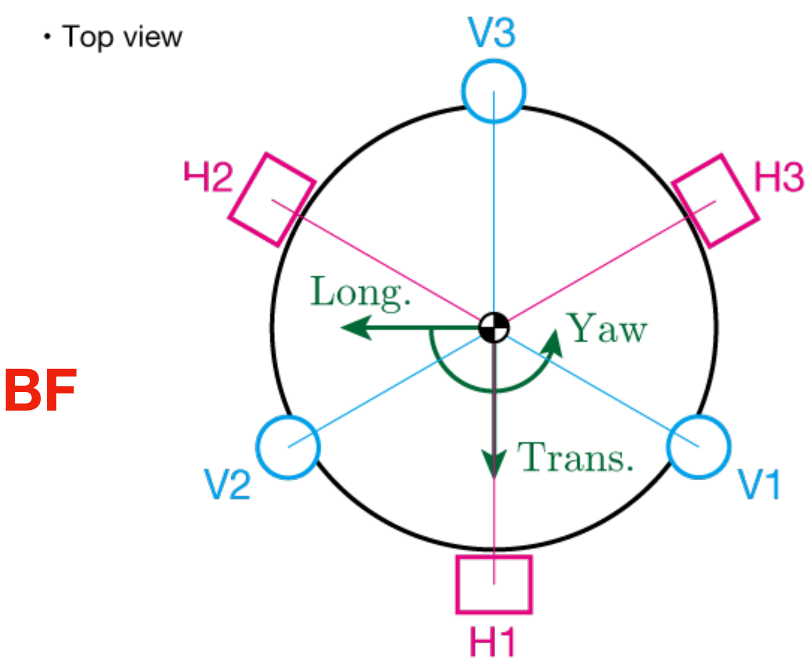


LVDTs sensing matrix

sensor base: (H1, H2,H3) —*Geometrical transformation*→ **Euler base: (L, T,Y)**

Read-out Driving matrix

Actuators base: (H1, H2,H3) —*Noise injection from each actuator (@2 Hz line)*→ **Euler base: (L, T,Y)**



BF

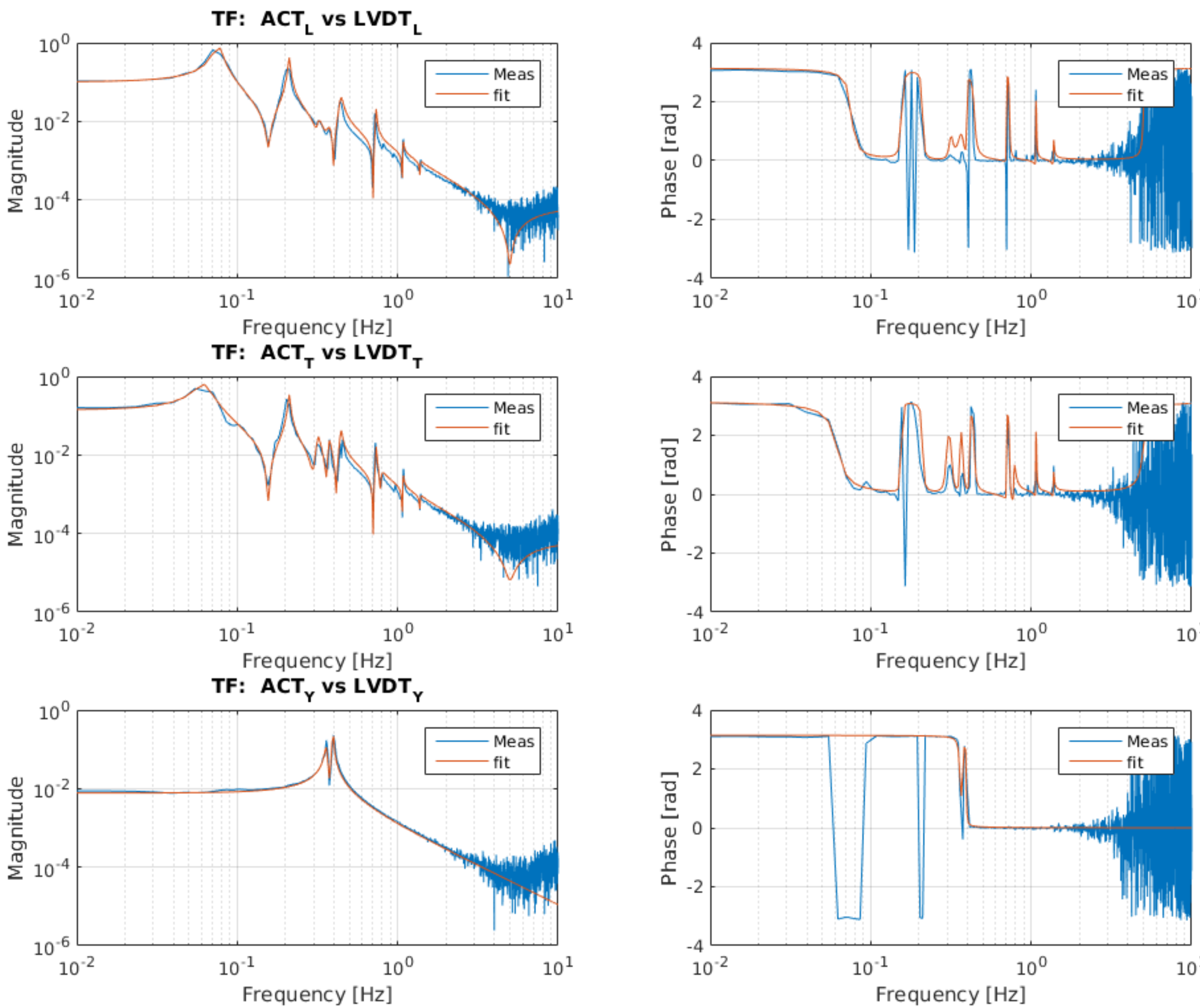
LVDTs sensing matrix

sensor base: (H1, H2,H3) (V1, V2,V3) —*Geometrical transformation*→ **Euler base: (L, T,Y) (P, R,V)**

Driving matrix

Actuators base: (H1, H2,H3) (V1, V2,V3) —*Geometrical transformation*→ **Euler base: (L, T,Y) (P, R,V)**

Inverted Pendulum (IP) mechanical transfer functions

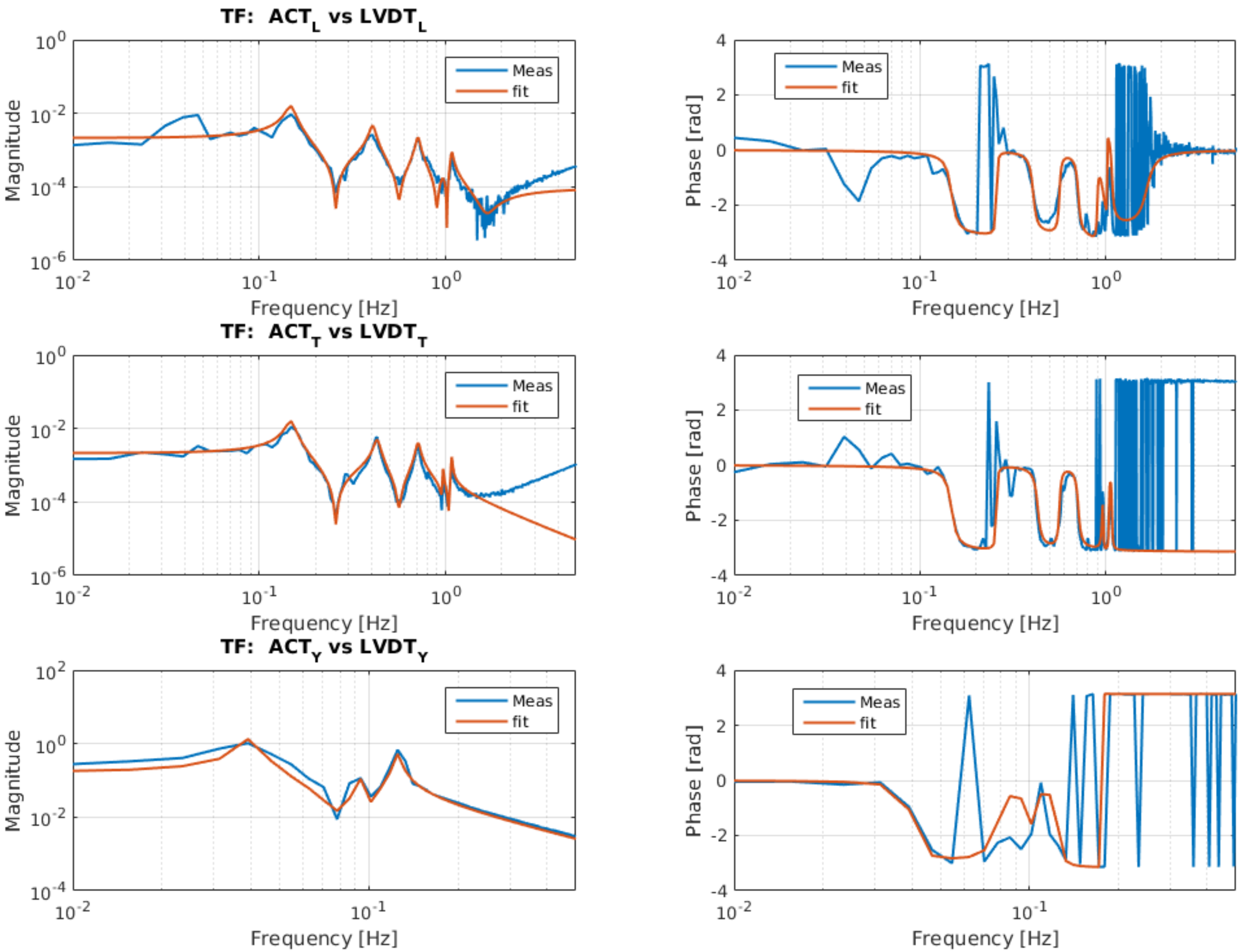


IP: L mode 0.067 Hz

IP:T mode 0.067 Hz

IP:Y mode 0.4 Hz

Bottom Filter (BF) mechanical transfer functions



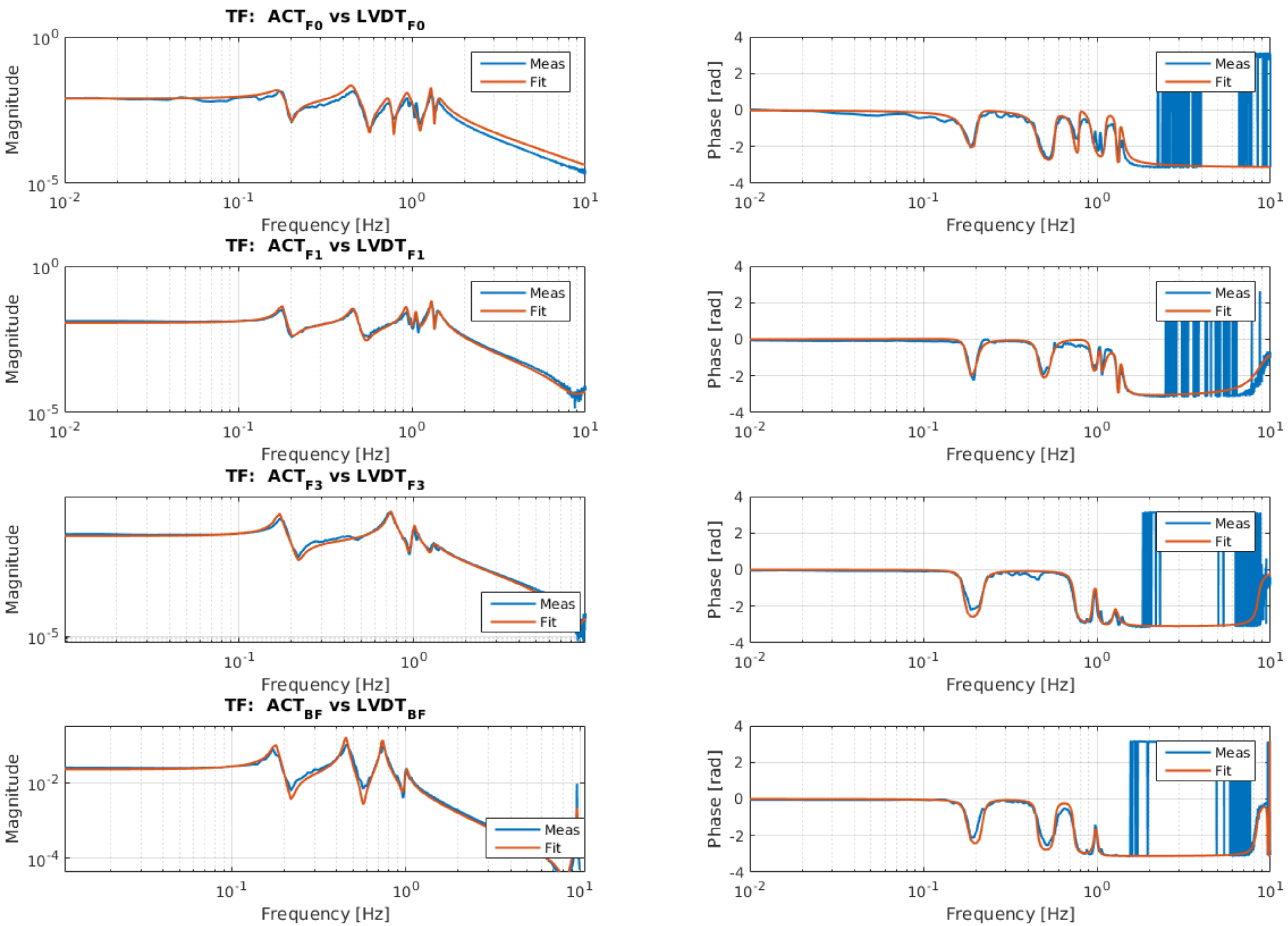
BF: L mode 0.148 Hz

BF:T mode 0.148 Hz

BF:Y mode 0.04 Hz

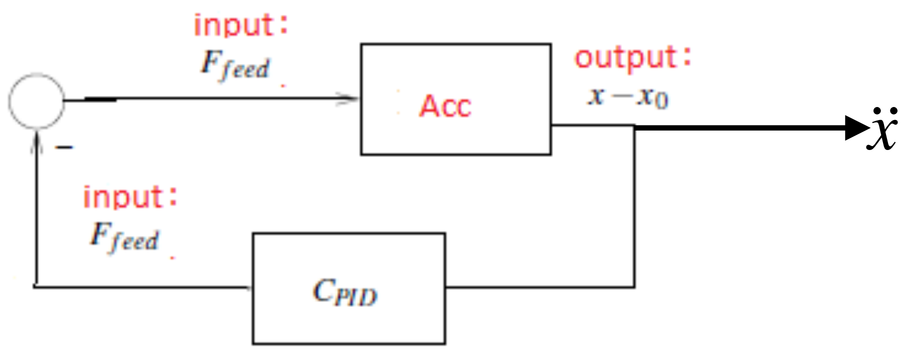
GAS filter mechanical transfer functions

ETMX Gas Filter: F0 mode 0.179 Hz



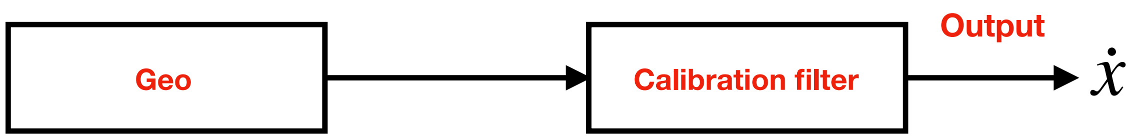
Type A: inertial sensor (I)

Input suspensions (ITMX,~~ITMY~~): 3 accelerometers



Output signal : acceleration

End suspensions (ETMX,ETMY): 3 Geophones



Output signal : speed

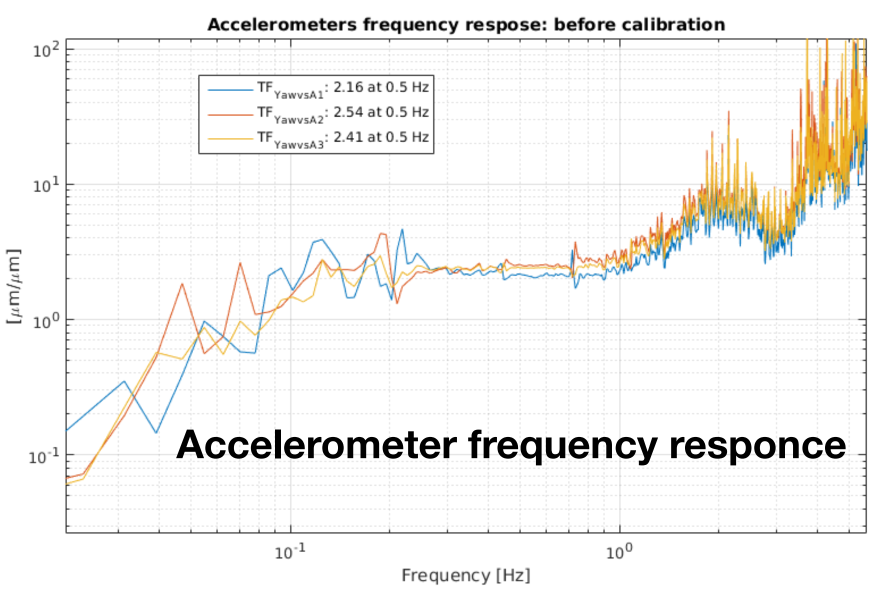
In both cases we need of the inter-calibration with the LVDT signals!

Injecting white noise along the IP Yaw degree of freedom and to measure the transfer function:

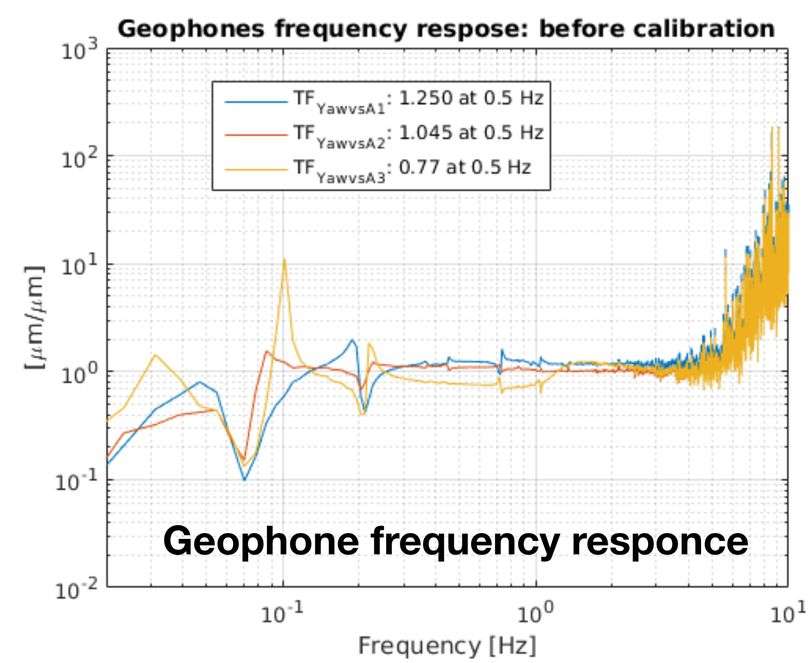
$$TF_{yaw_{acc_i}} = \frac{Yaw_{lvdt} \cdot r}{\frac{acc_i}{\omega^2}}$$

where i=1,2,3 and r is the linear distance of each inertial sensor from the center of IP

$$TF_{yaw_{geo_i}} = \frac{Yaw_{lvdt} \cdot r}{geo_i}$$

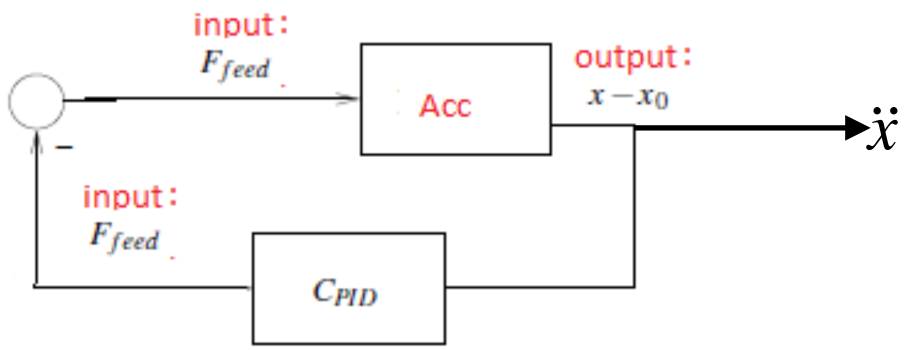


Yaw is an isotropic motion: these TFs should be equals.



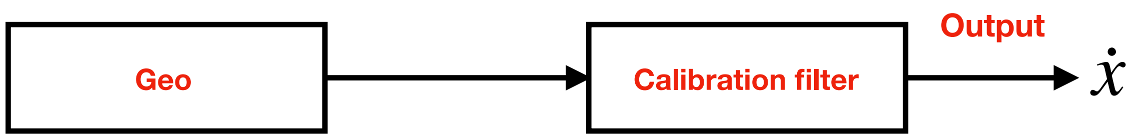
Type A: inertial sensor (I)

Input suspensions (ITMX,~~ITMY~~):
3 accelerometers

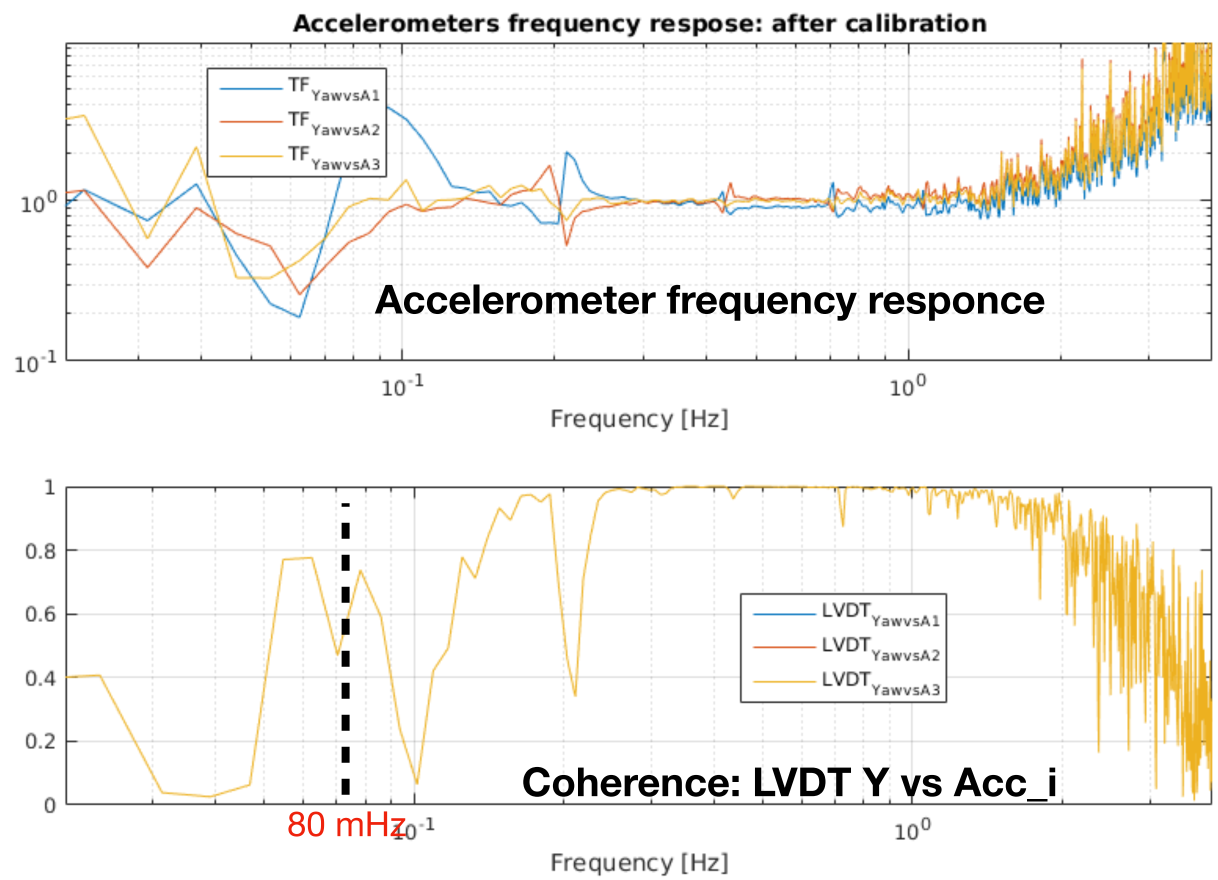


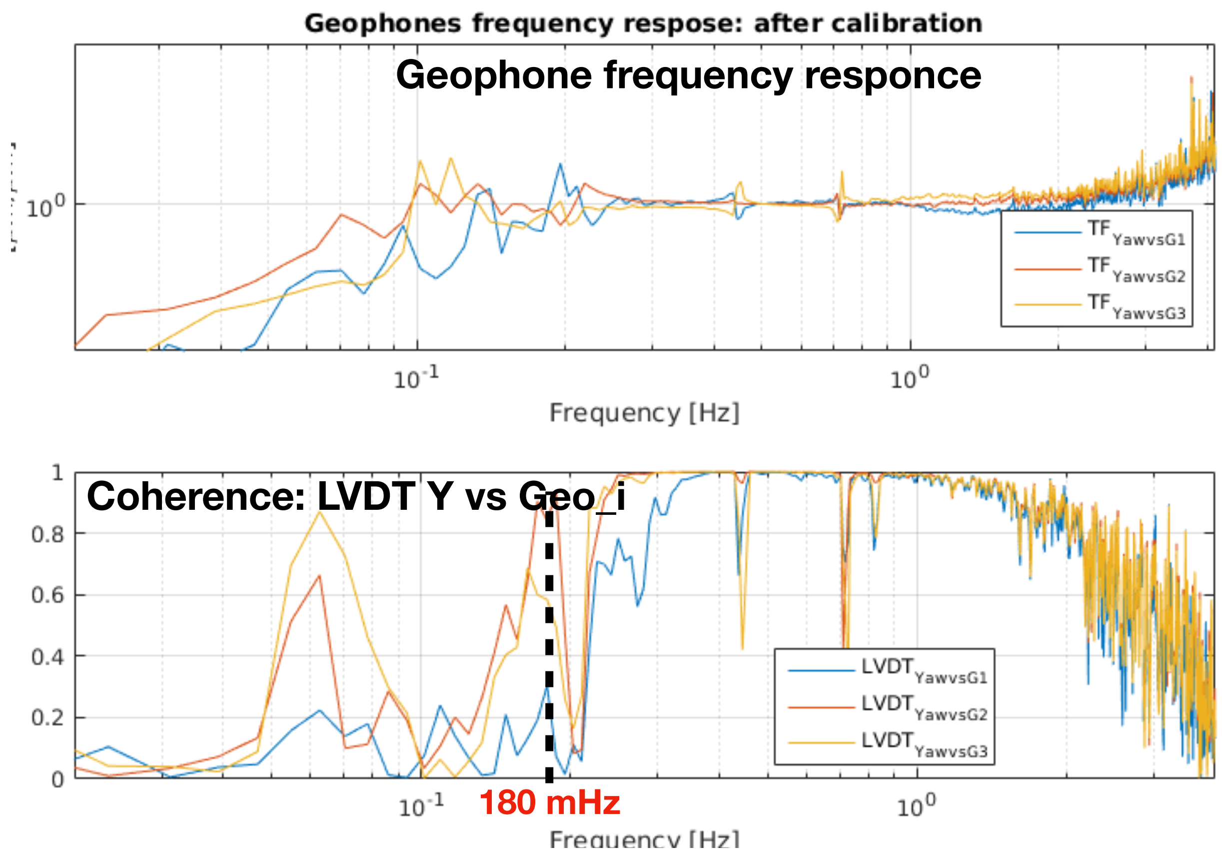
Output signal : acceleration

End suspensions (ETMX,ETMY):
3 Geophones



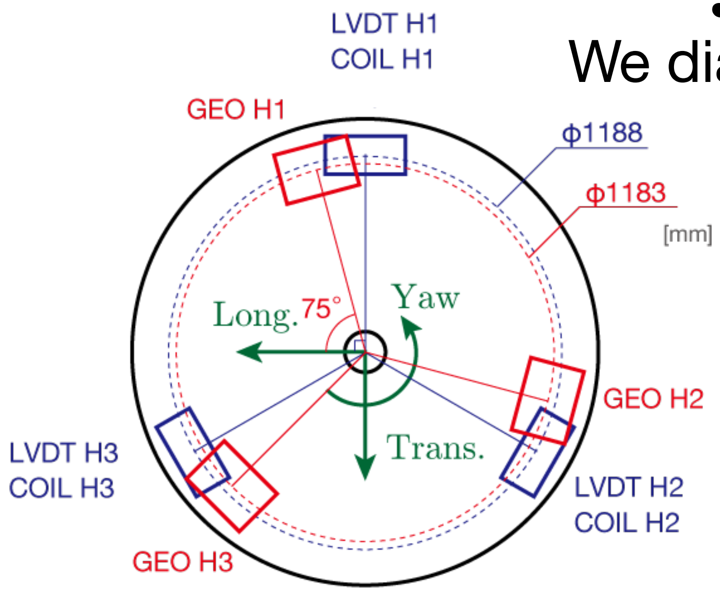
Output signal : speed





Type A: inertial sensor (II)

We diagonalize the inertial sensors in the (L,T,Y) base.



Read-out Sensing matrix

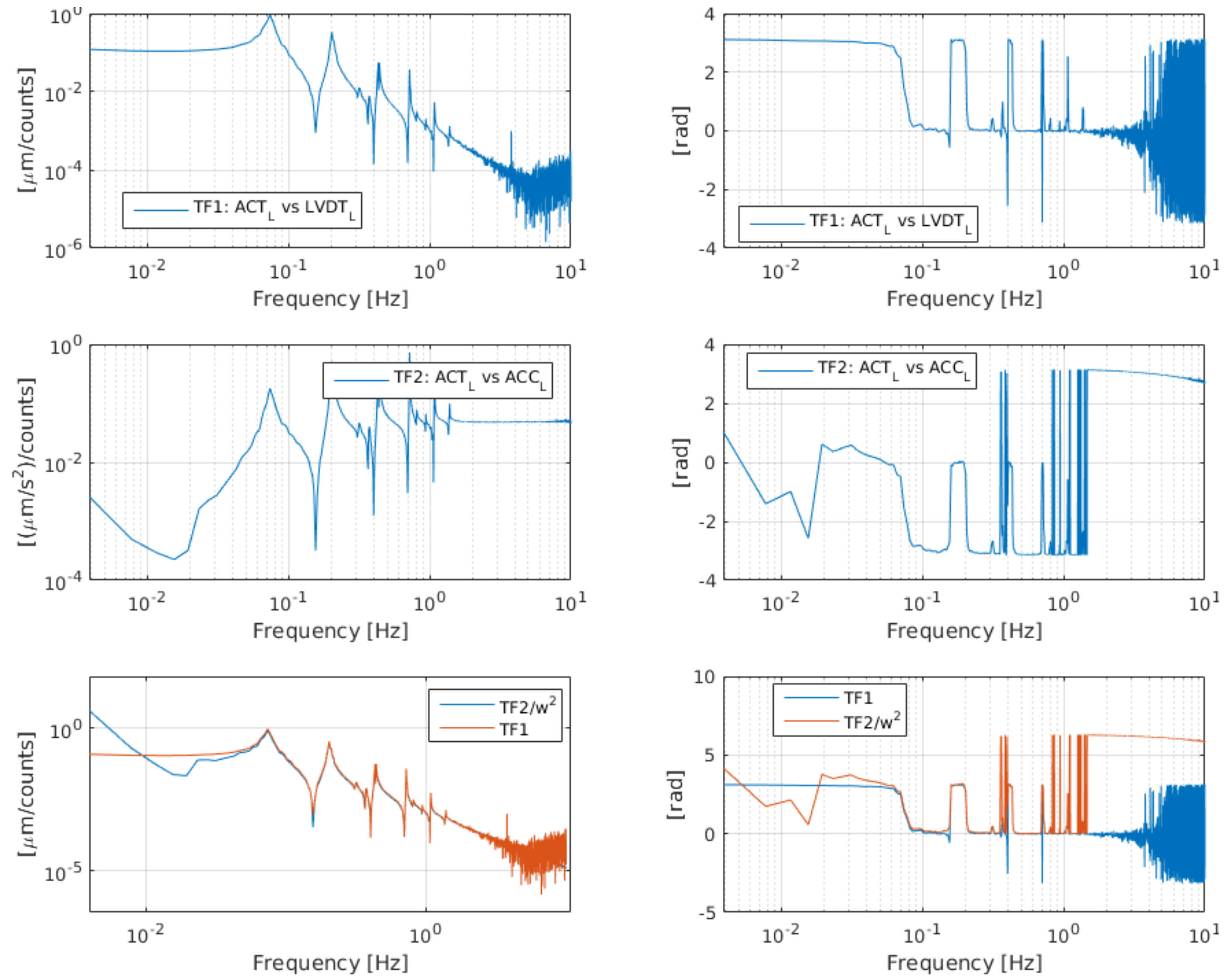
Sensors base: (H1, H2,H3) → ***Noise injection from each diagonalized actuator (@2 Hz line)*** → **Euler base: (L, T,Y)**

The sensor response is equalized.

LVDT: L

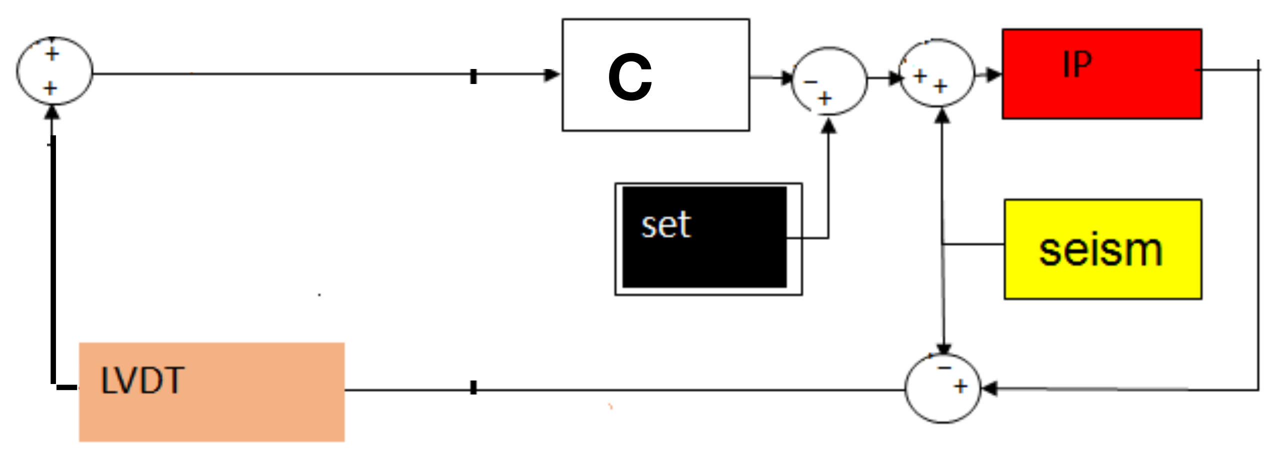
ACC: L

ACC & LVDT: L



Type A: Damping control

Feedback control scheme



C= is the damping filter

IP= mechanical system

LVDT= is the sensor monitoring the displacement

$$x_{lvdt} = x_{IP} - x_0$$

x_0 **is the ground motion**

set= is the set point

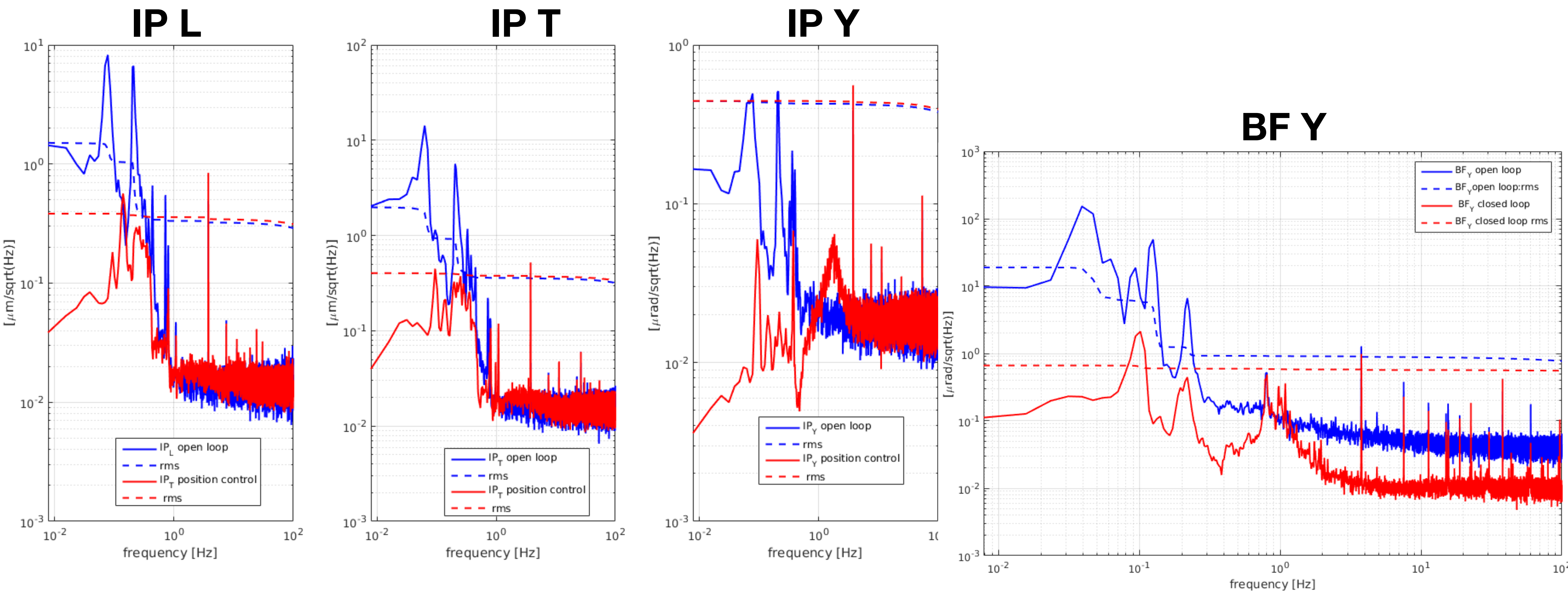
The closed loop signal is defined as

$$\tilde{S}_{iv}^{CL}(\omega) = \frac{\tilde{S}_{iv}(\omega)}{1 - \tilde{M}_i(\omega) \cdot \tilde{C}_i(\omega)}$$

In this configuration:

IP LVDT signal =
Error signal in L, T ,Y

Type A: Damping control



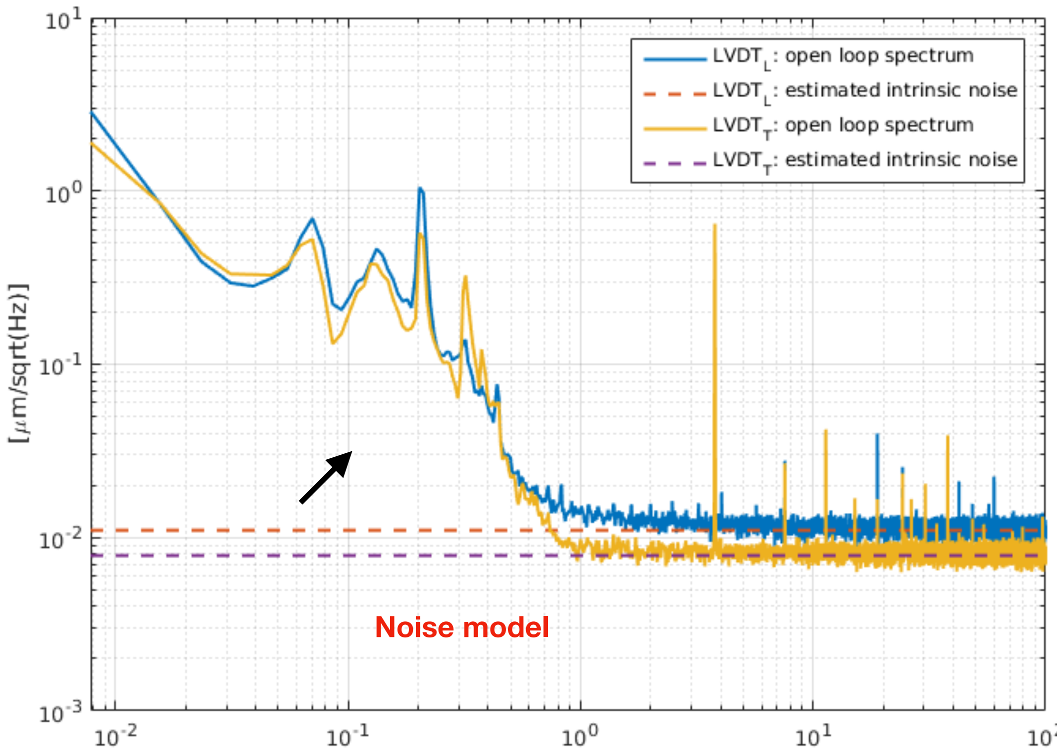
	L RMS [µm]	T RMS [µm]	Y RMS [µrad]
IP(OL)	**1.5**	**2**	**0.5**
IP (CL)	**0.4**	**0.4**	**0.5**
BF (OL)			**30**
BF (CL)			**0.7**

In this configuration we are limited by seismic noise

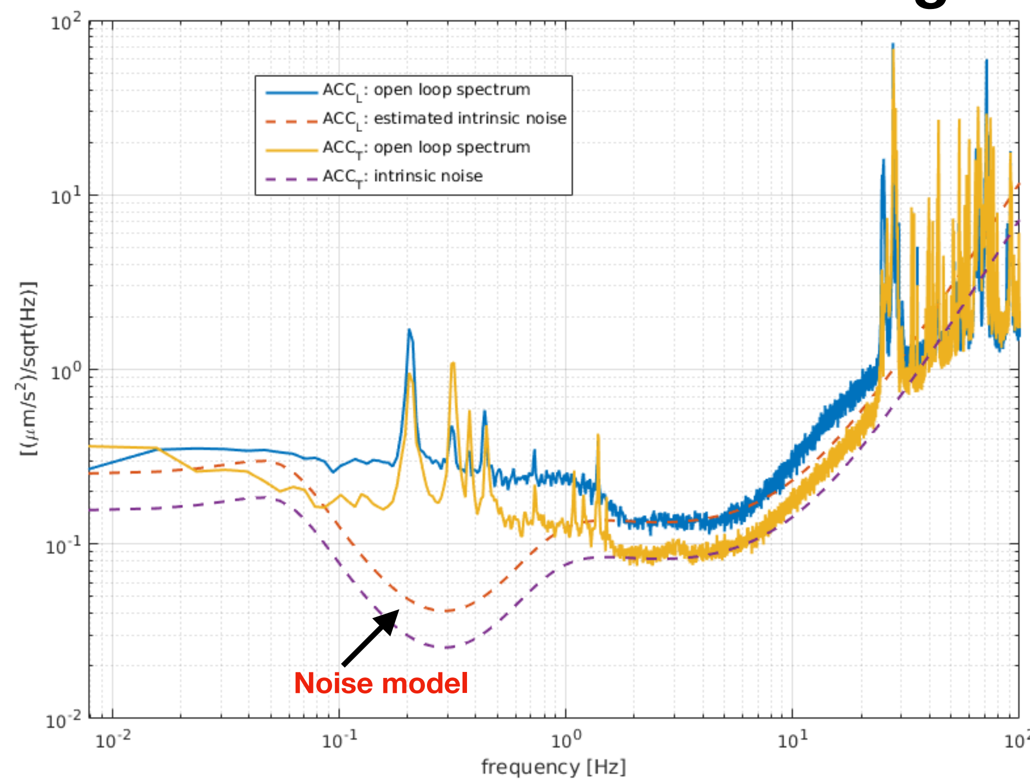
Type A: seismic noise reduction and Inertial control

Let's consider the sensors in the L,T,Y base

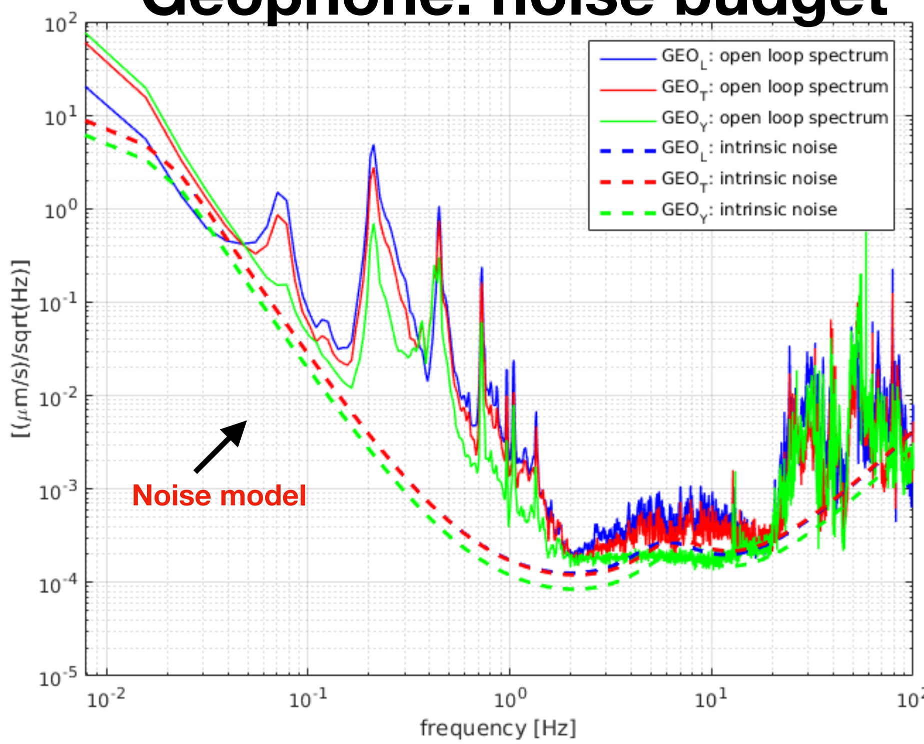
LVDT: noise budget



Accelerometer: noise budget

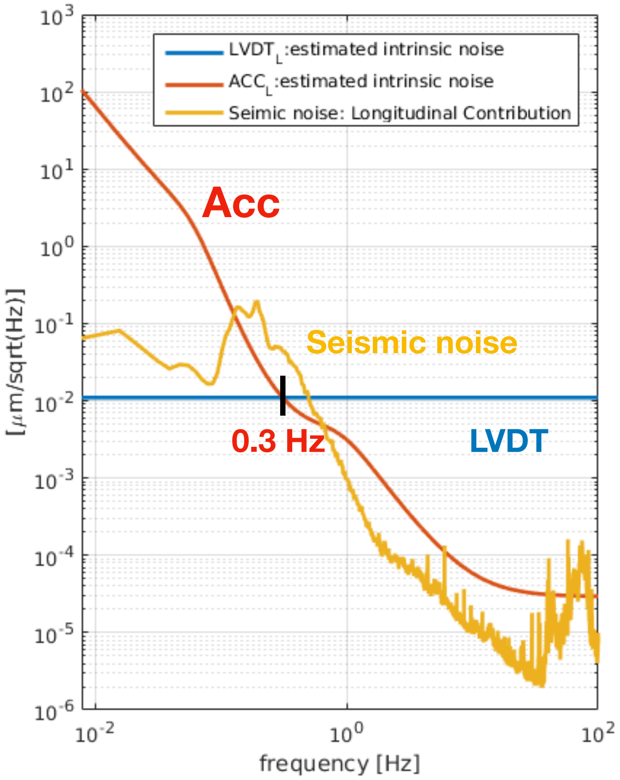


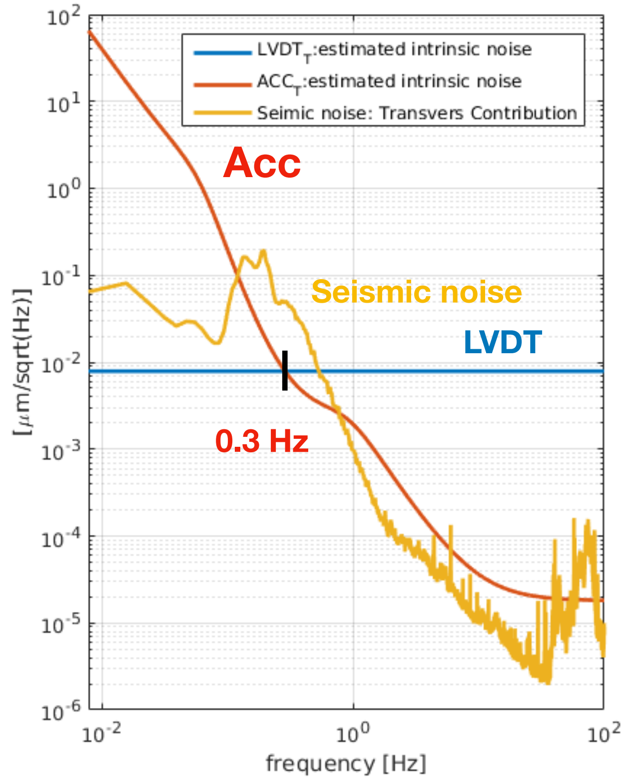
Geophone: noise budget



Sensors spectrum signal (LVDT, accelerometer, geophone) versus intrinsic noise (model)

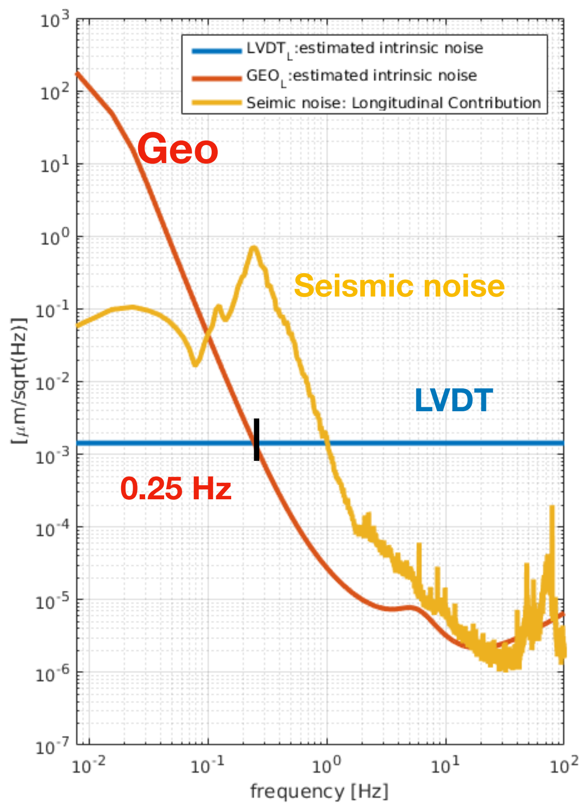
Inertial control: noise budget (II)

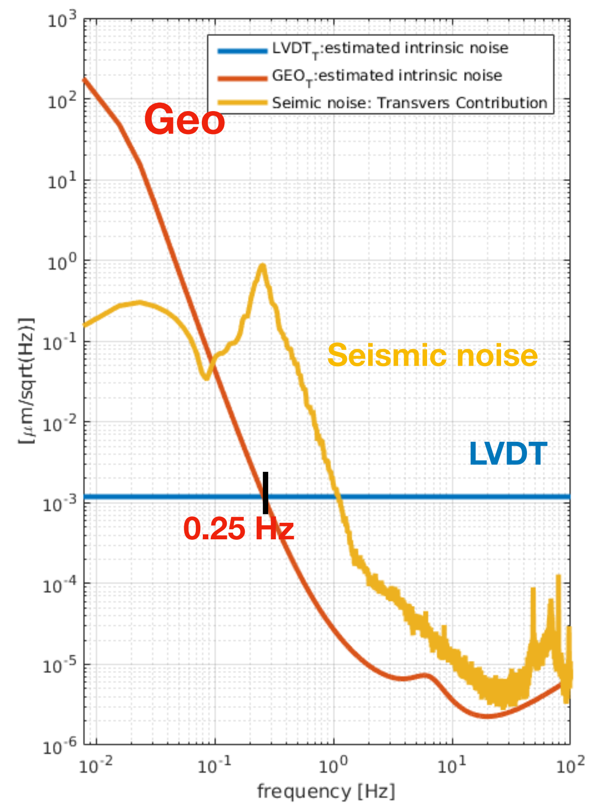




In the range [0.1,0. 5] Hz, the LVDT signal is spoiled by seismic noise

Below 0.3 mHz, the accelerometer noise is dominant





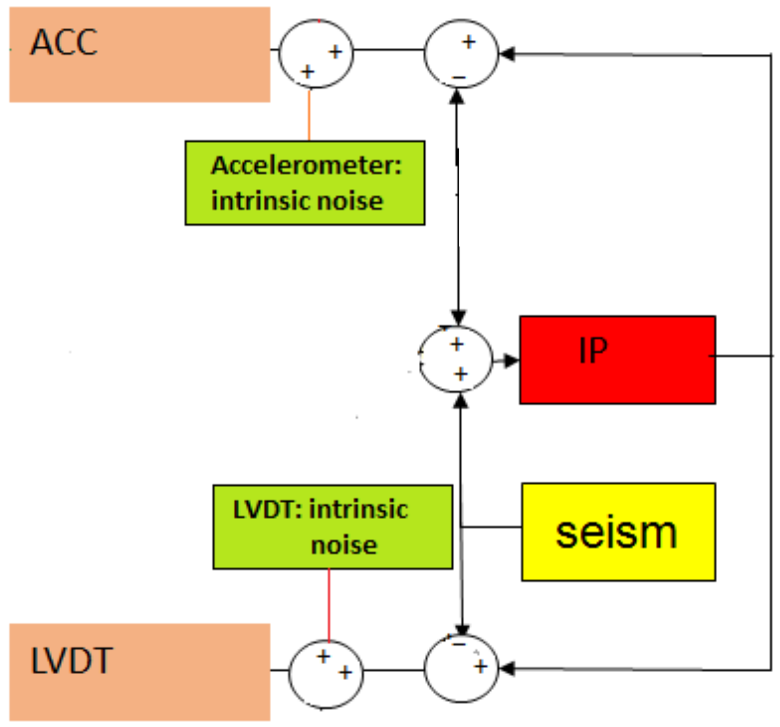
Below 0.250 mHz, the geophone noise is dominant

We want reduce the contribution of the seismic noise

Blending technique

Blending technique (I)

To take the better part of both signals, the *blended virtual sensing signals*, is attained through neutral pre-filtering.



ACC or GEO — High Pass filter (HP)

LVDT — Low Pass filter (LP)

HP+LP=1

- **LP filter must be shaped taking into account the background disturbance (seismic noise)**
- **For LP filter tipical cutoff is below 100 mHz, to reduce the seismic contribution.**
- **For HP filter we should be careful not to reintroduce accelerometer noise.**

Blended Sensor is defined as :

Accelerometer

$$S(\omega) = LP(\omega) \cdot S_{LVDT}(\omega) - \omega^{-2} HP(\omega) \cdot S_{Acc}(\omega)$$

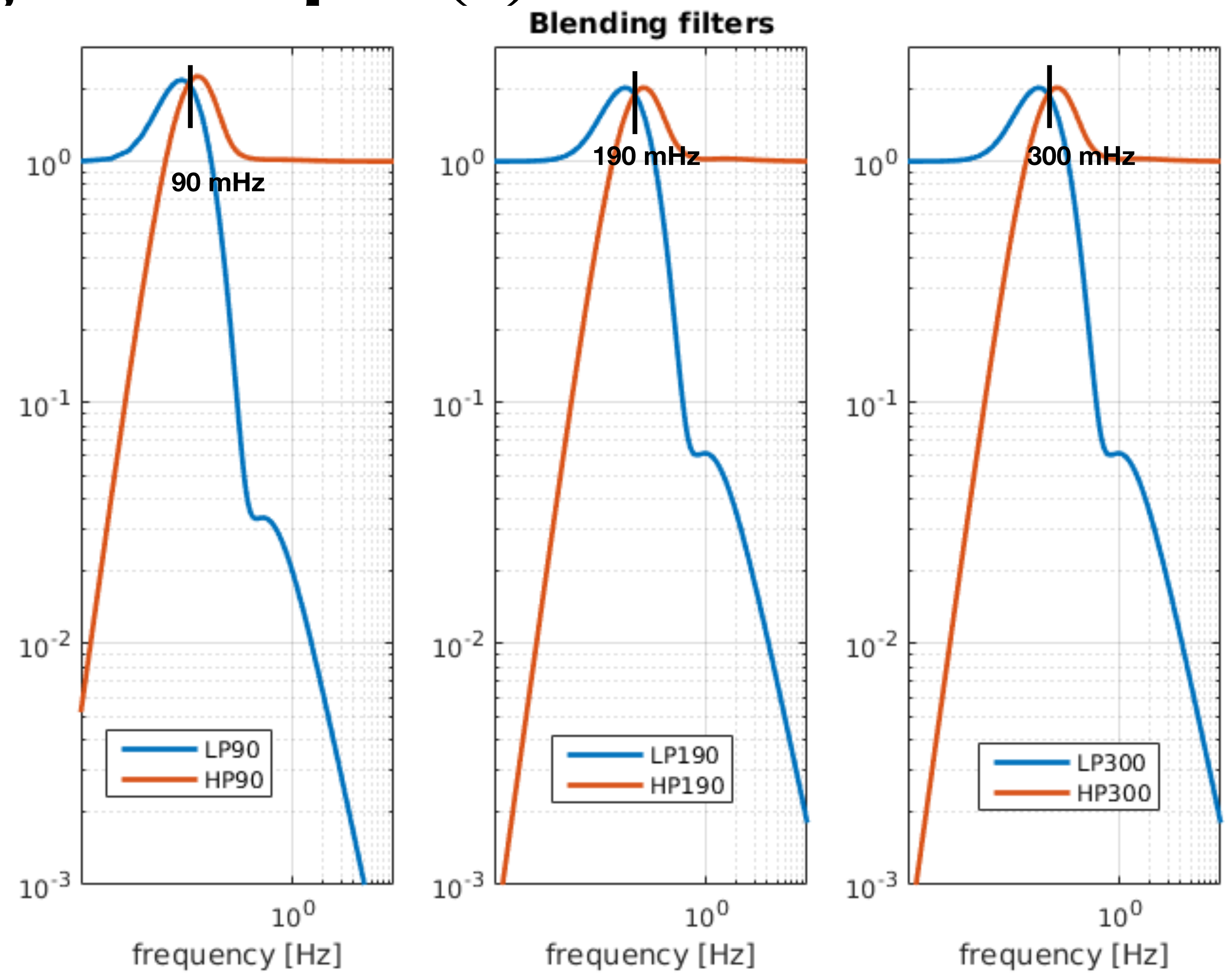
Geophone

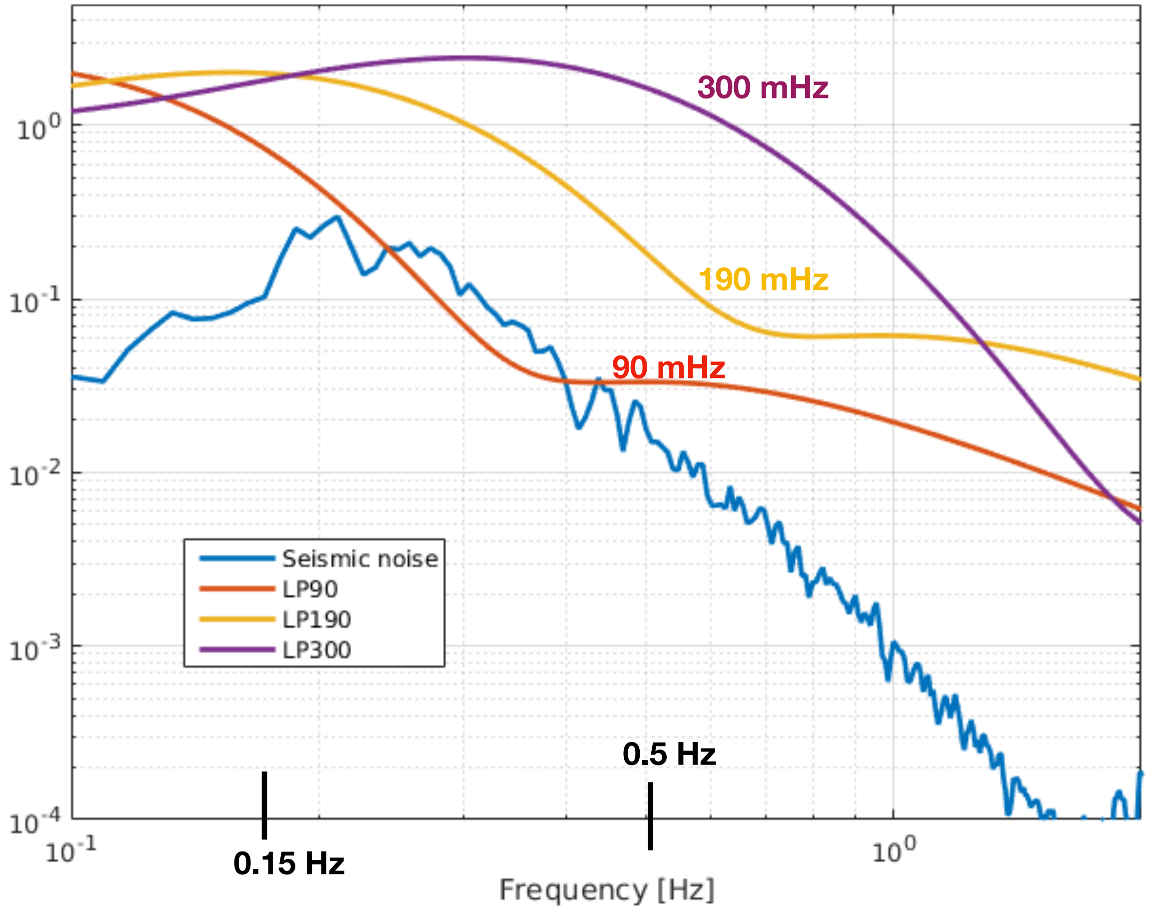
$$S(\omega) = LP(\omega) \cdot S_{LVDT}(\omega) - \omega \cdot HP(\omega) \cdot S_{Geo}(\omega)$$

Blending technique (I)

Example of blending filters:

- ✦**Blending frequency: 90 mHz**
- ✦**Blending frequency: 190 mHz**
- ✦**Blending frequency: 300 mHz**

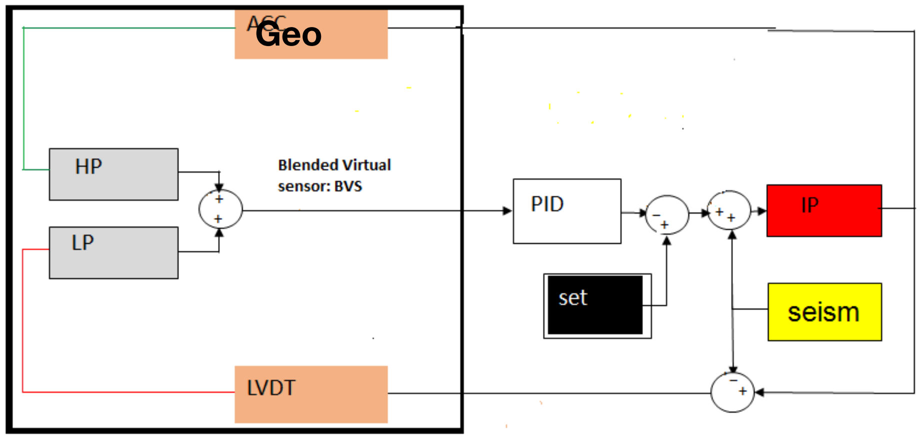




Impact of each one of these strategies on the seismic noise:
The 90 mHz is shaped to reduce the re-injection of seismic noise in the range [0.2 -0.5] Hz

Inertial damping: IP residual motion(II)

ITMX

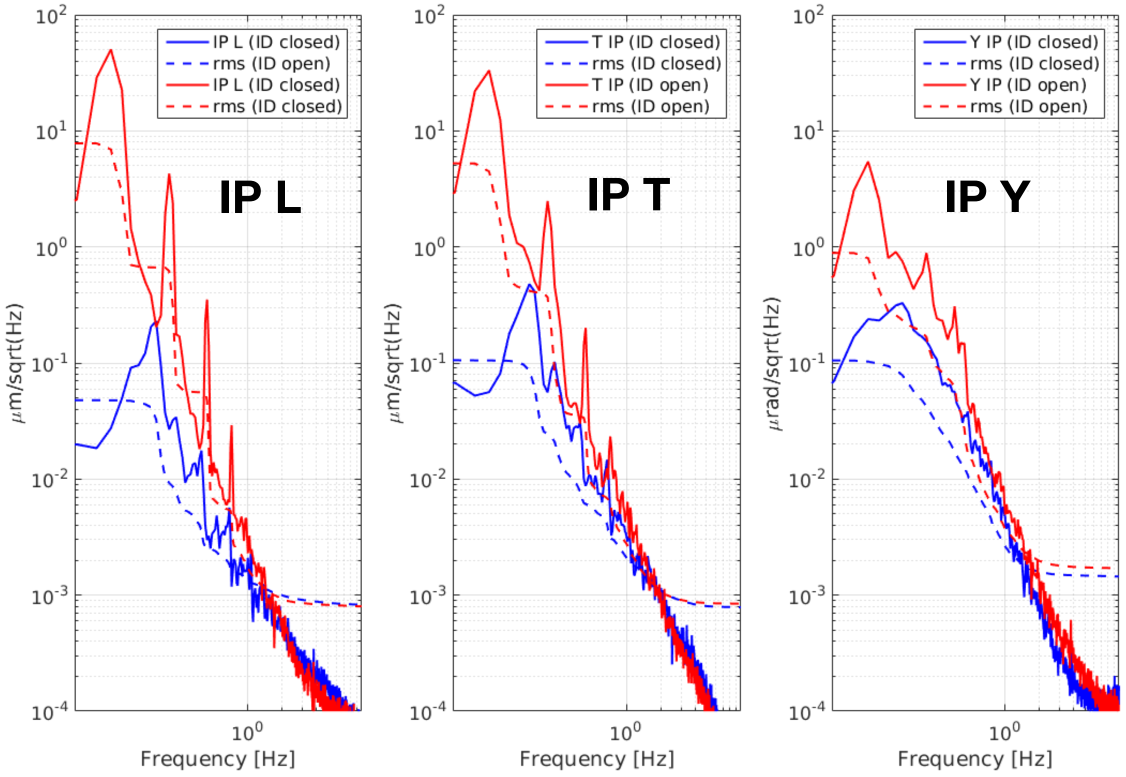


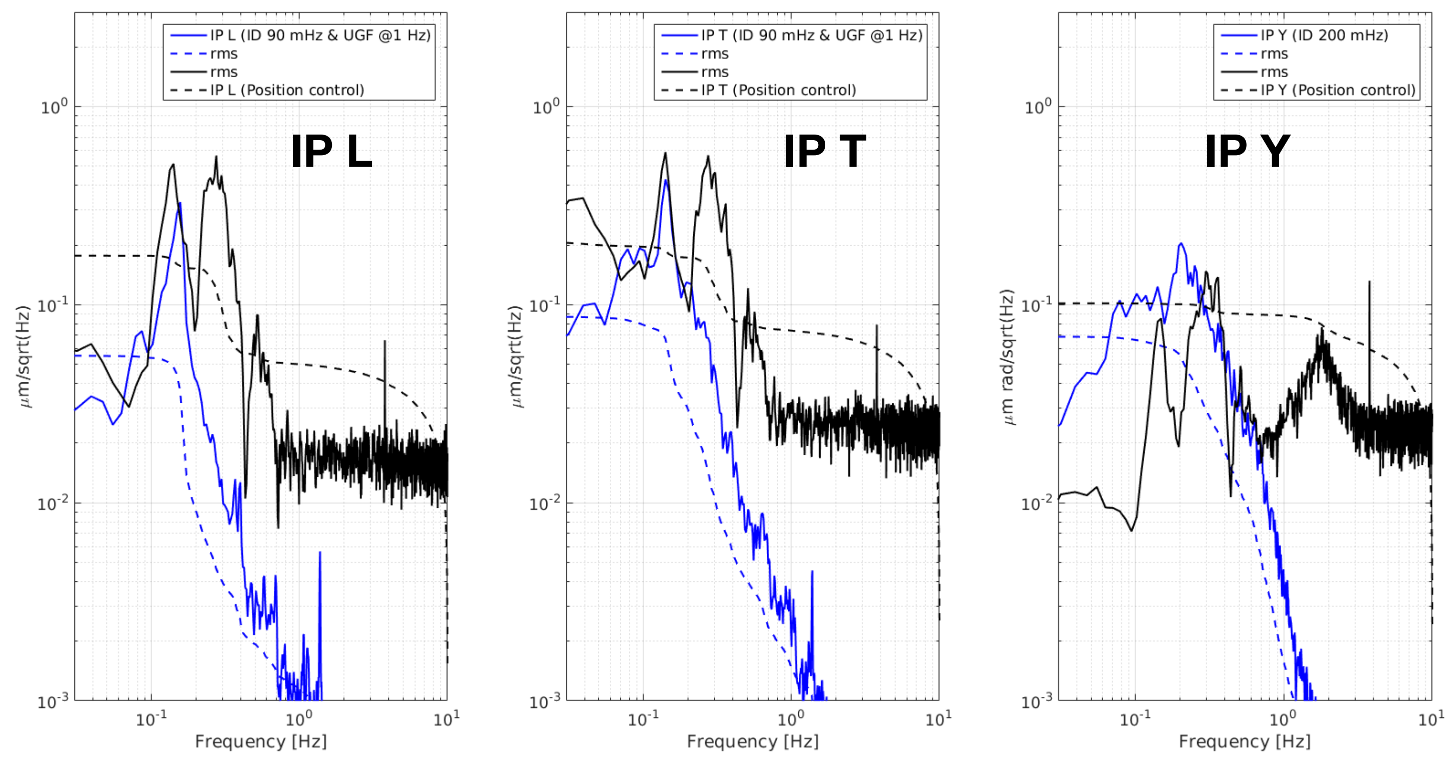
Blended sensor= Error signal in L ,T & Y

$$S(\omega) = LP(\omega) \cdot S_{LVDT}(\omega) - \omega \cdot HP(\omega) \cdot S_{Geo}(\omega)$$

- L and T blending frequency: 190 mHz
- Yaw blending frequency: 300 mHz

In this configuration the residual motion of the IP is



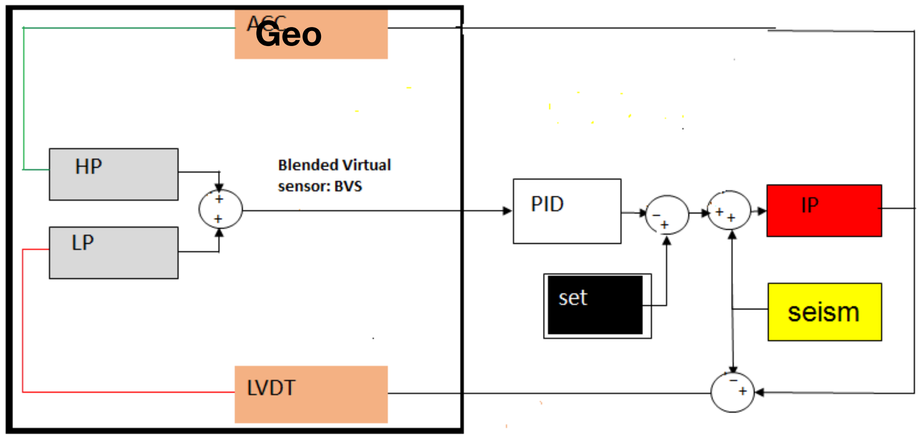


Open loop versus closed loop with Inertial Damping

Closed loop: LVDT is the error signal
Closed loop: blended signal is the error signal

Inertial damping: IP residual motion(II)

ETMX



Blended sensor= Error signal in L ,T & Y

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- L and T blending frequency: 190 mHz
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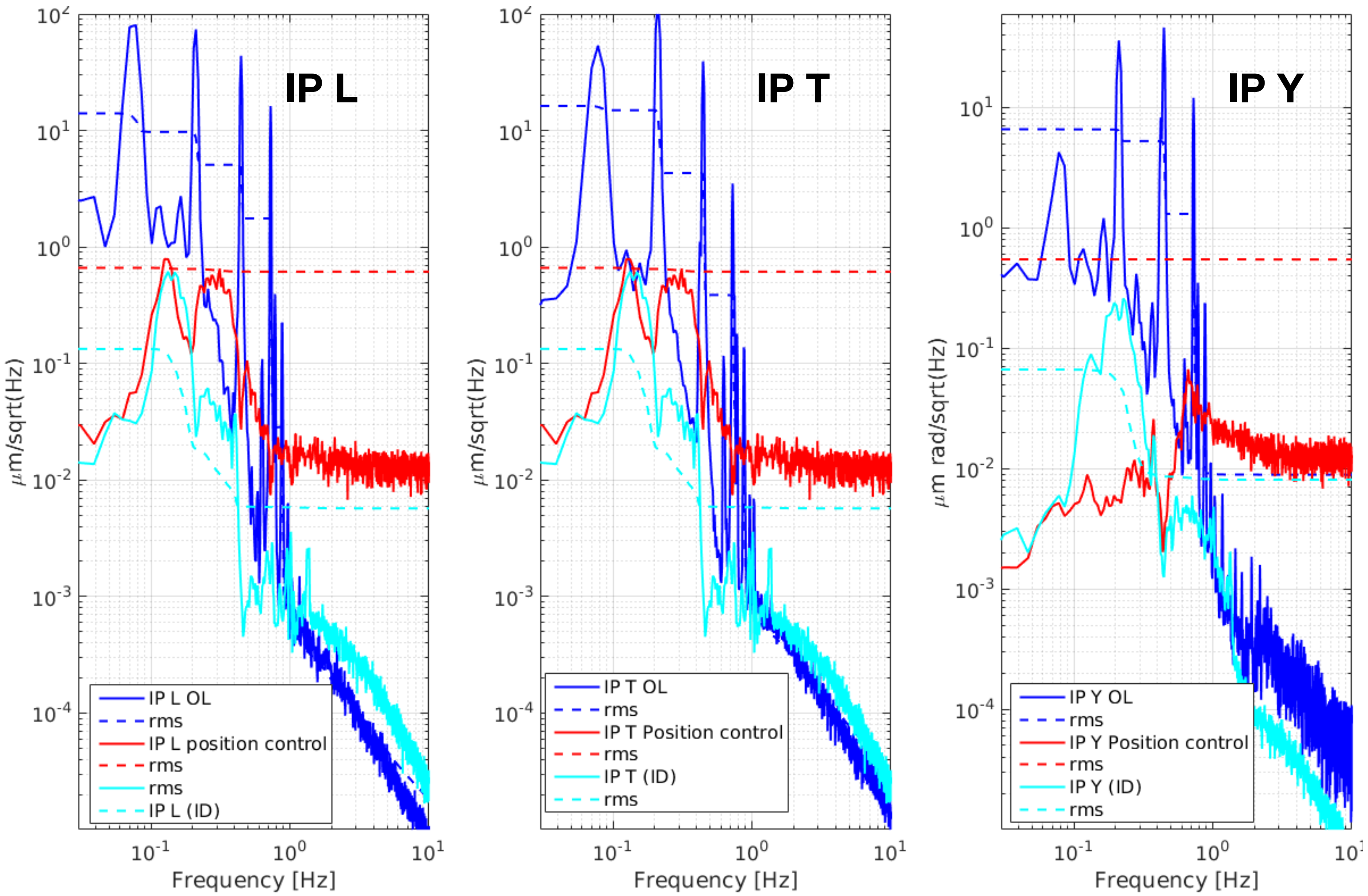
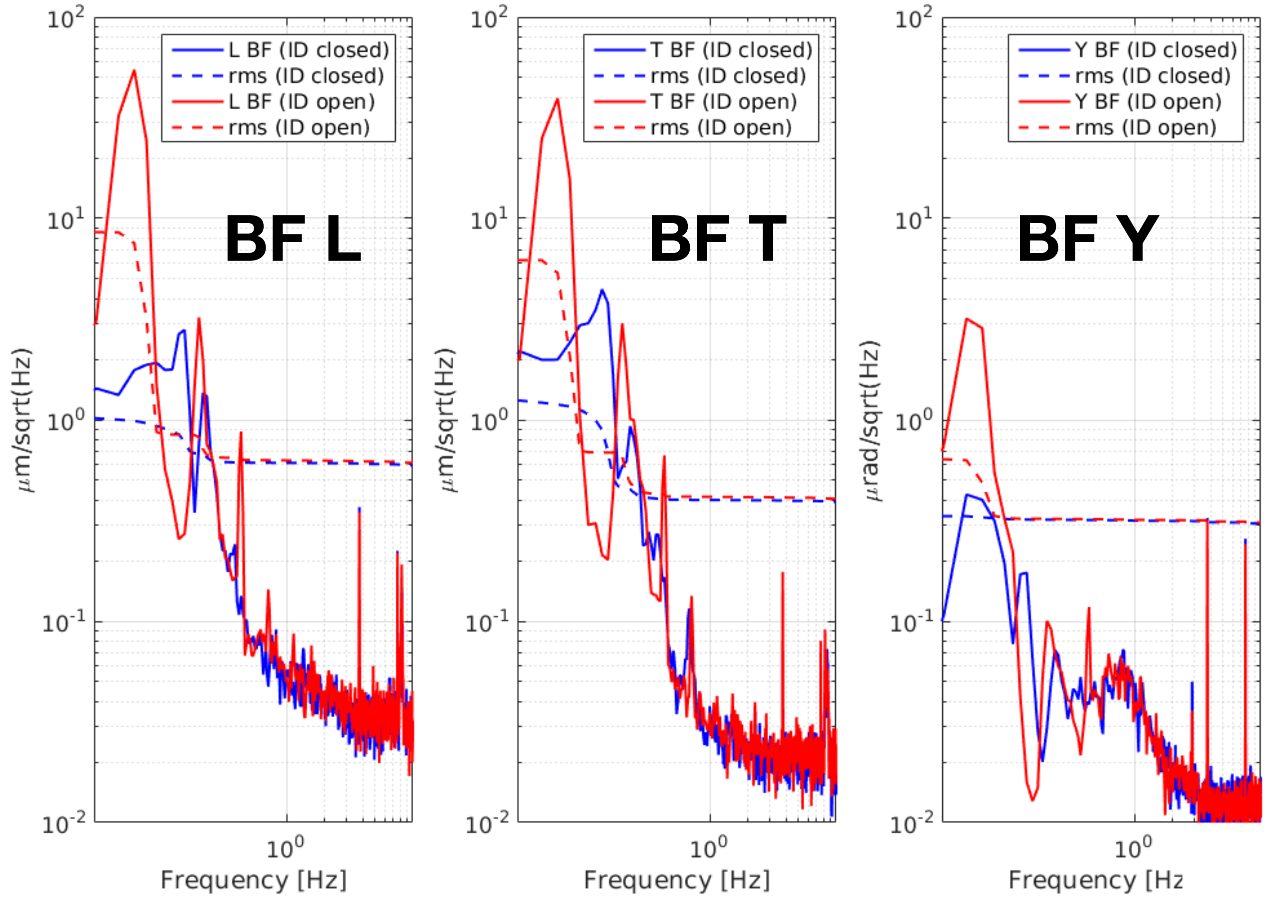
In this configuration the residual motion of the IP is



Open loop versus closed loop:

Closed loop:
LVDT is the error signal
Closed loop:
blended signal is the error signal

Inertial damping: BF & Test Mass (TM) residual motion (I)



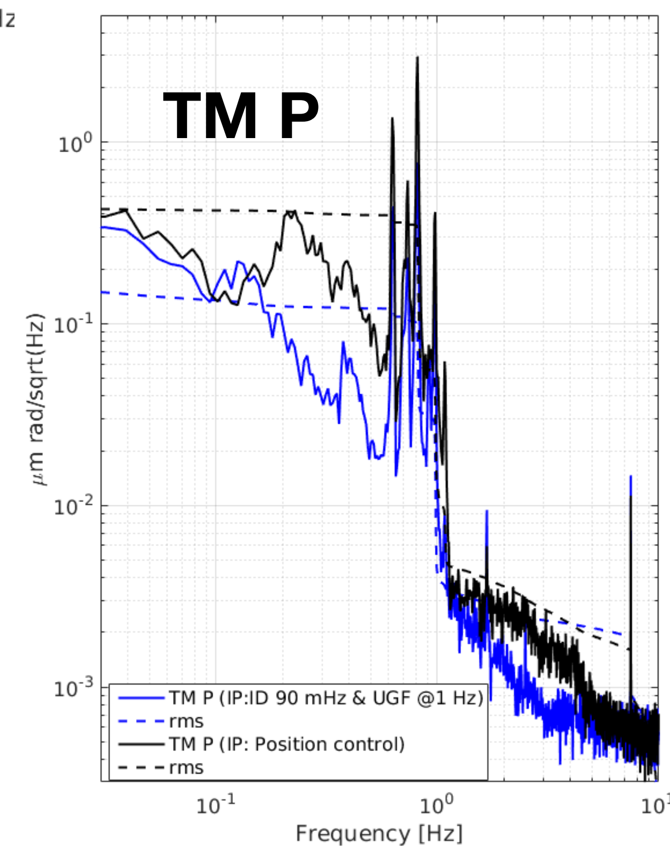
ITMX

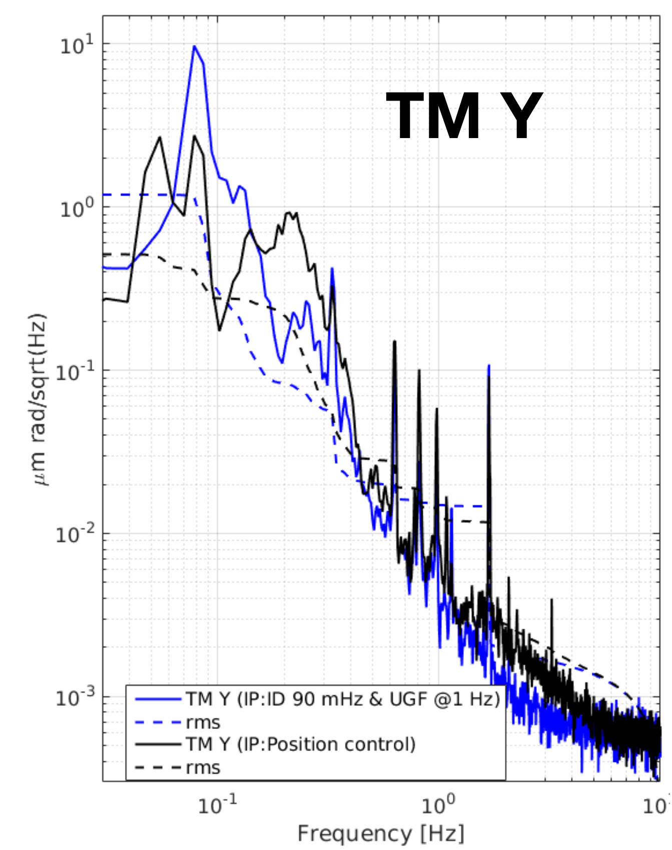
In this configuration:

- ✦ **BF L: damp off**
- ✦ **BF T: damp off**
- ✦ **BF Y: damp on**

In this configuration:

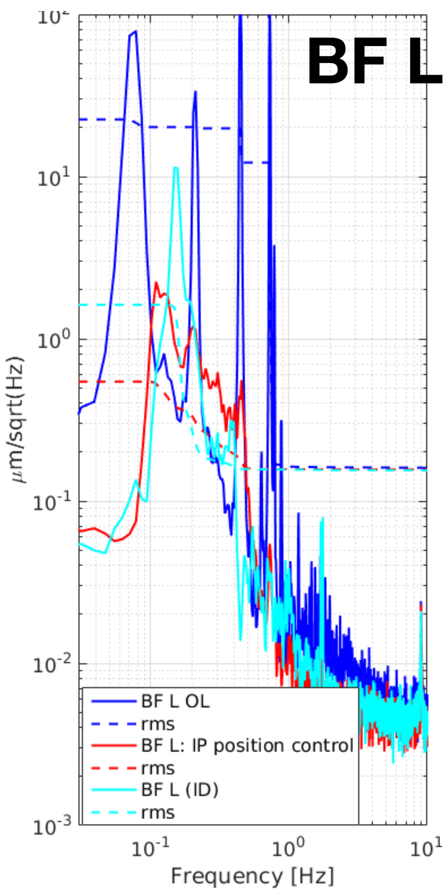
- ✦ **MN & TM P: damp off**
- ✦ **MN & TM Y: damp off**

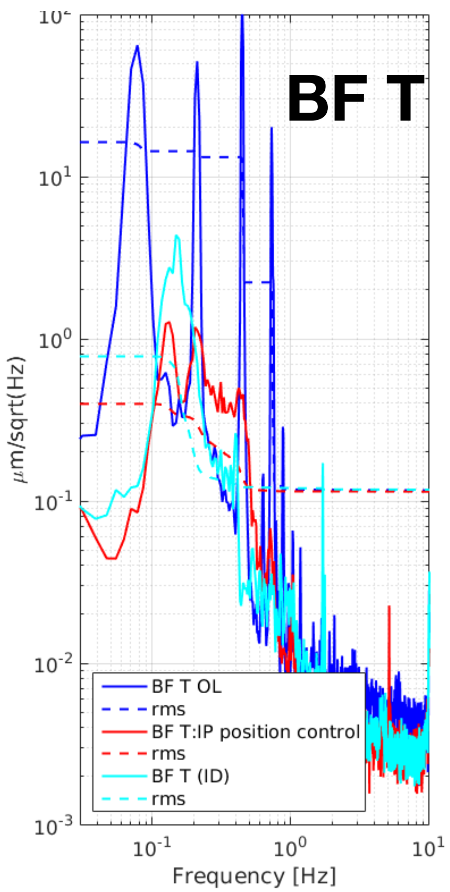


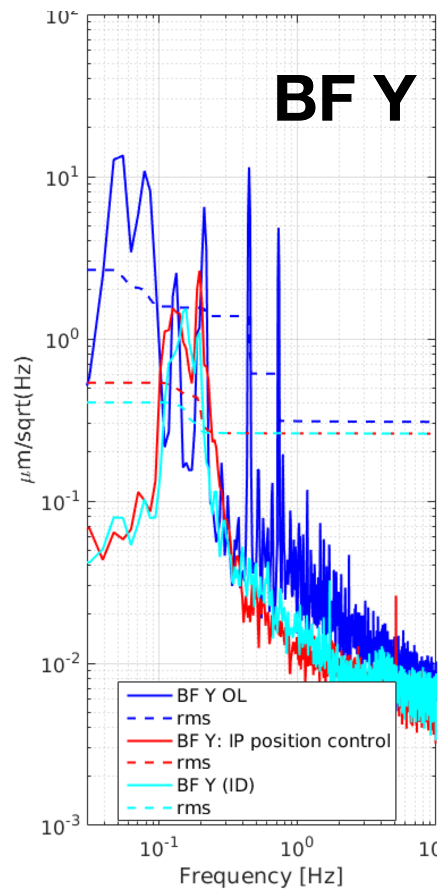


Inertial damping: BF & Test Mass (TM) residual motion (II)

ETMX





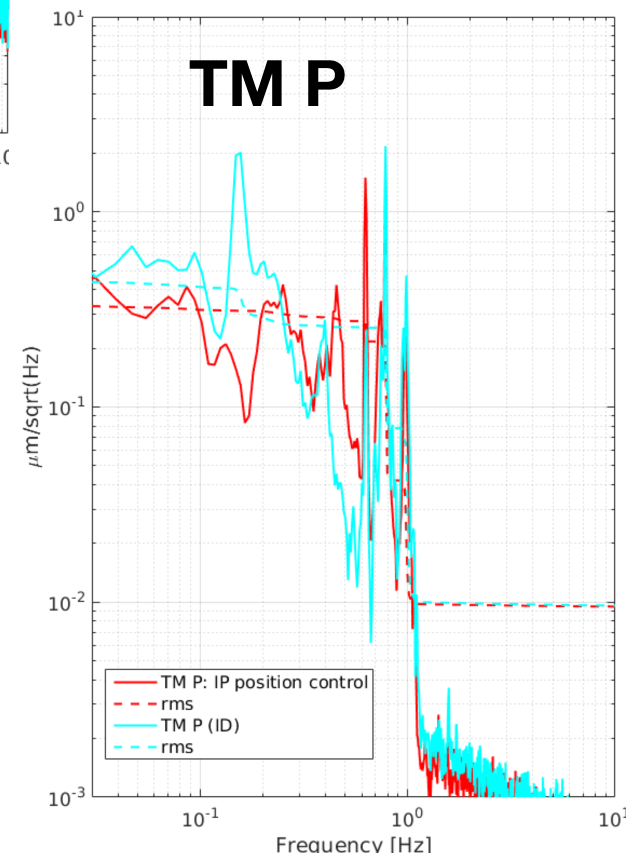


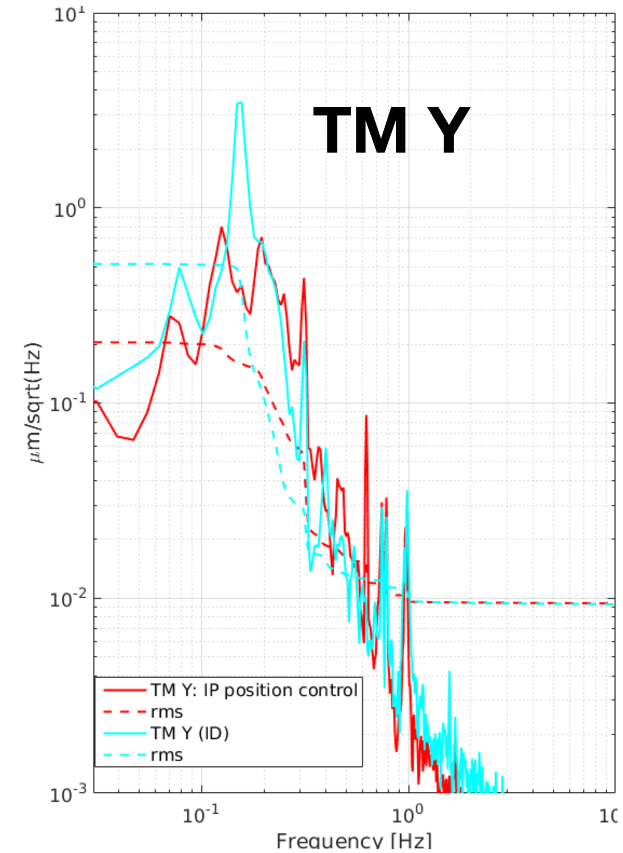
In this configuration:

- ✦ **BF L: damp off**
- ✦ **BF T: damp off**
- ✦ **BF Y: damp on**

In this configuration:

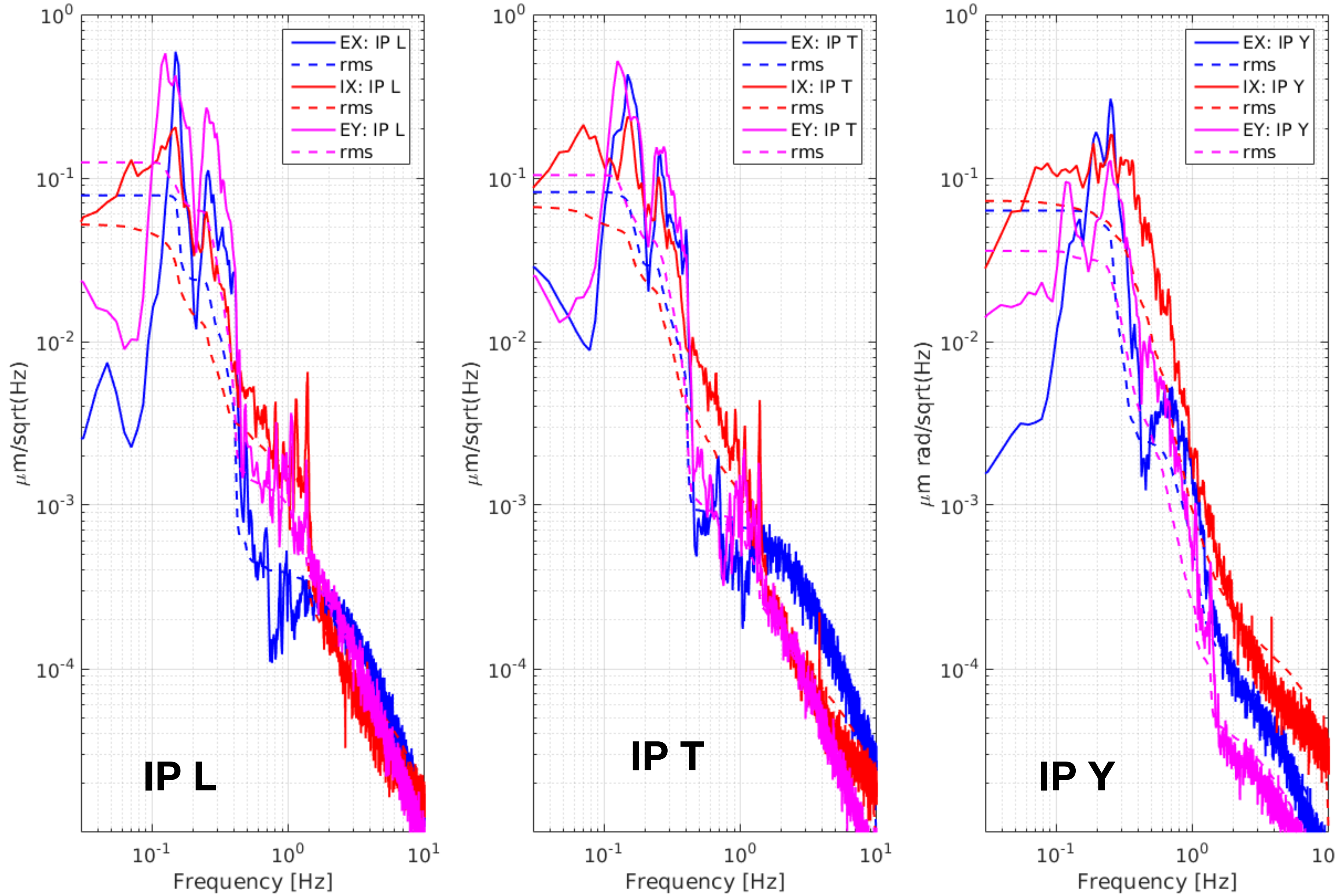
- ✦ **MN & TM P: damp off**
- ✦ **MN & TM Y: damp off**



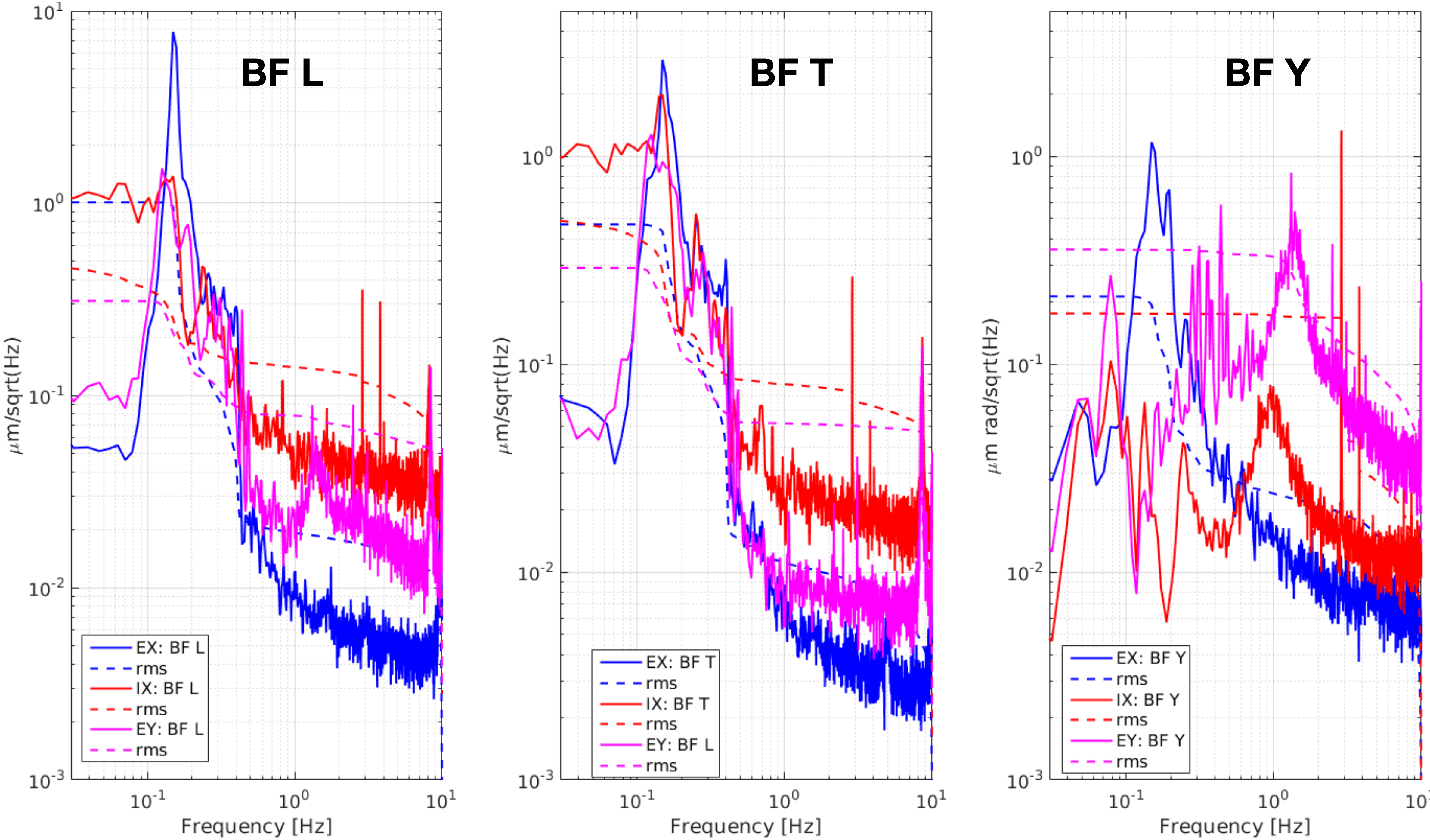


Inertial Damping On

The Inertial Damping is implemented on ITMX, ETMX and ETMY.



Inertial Damping On: bottom stage residual motion

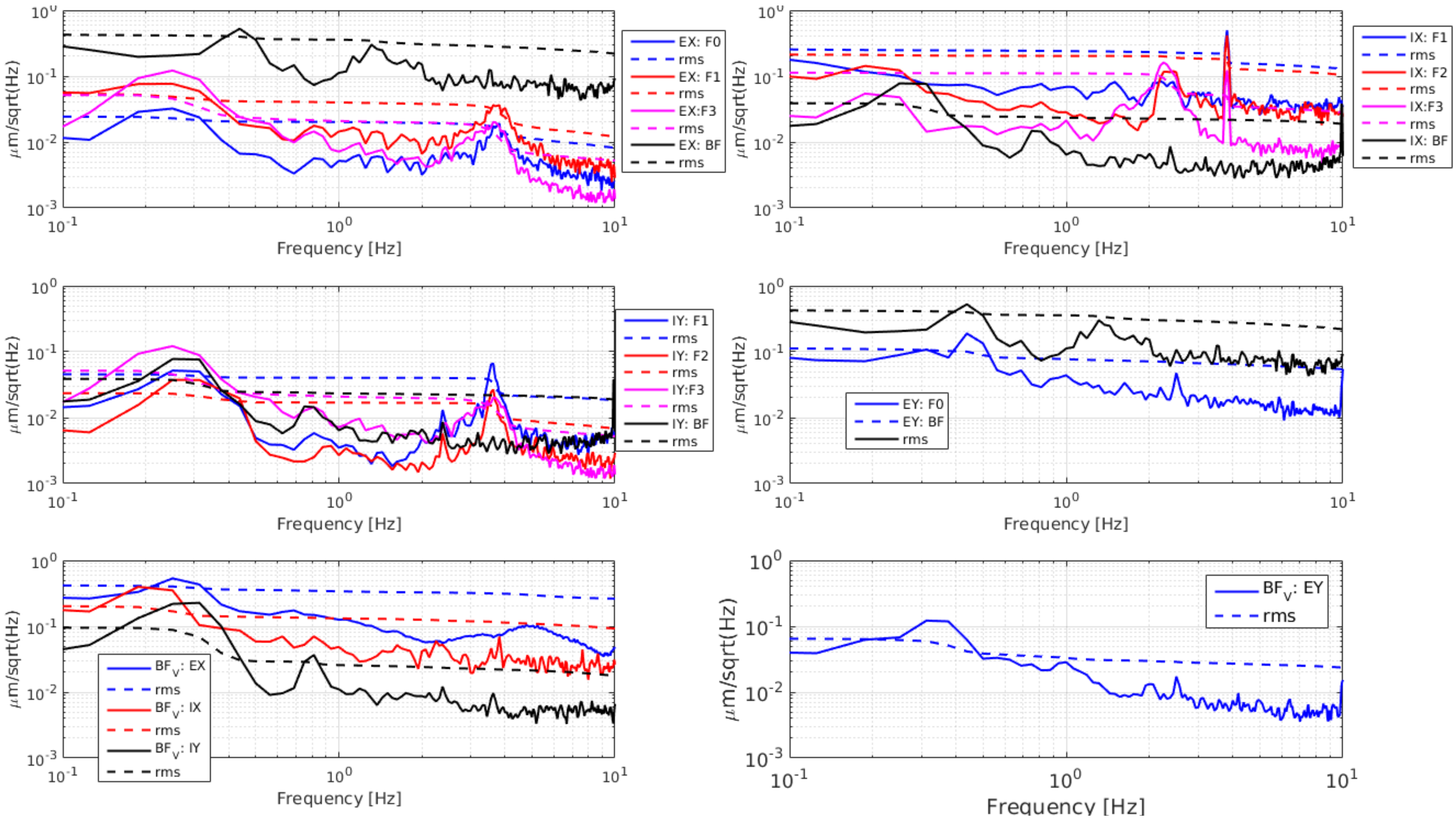


GAS Filter: damping + DC control on

To compensate the vertical drift of the GAS filter and reduce the vertical motion of the TM DC+ damping control has been implemented on each GAS filter.

GAS Filter	ITMX	ITMY	ETMX	ETMY
F0	Mechanically locked	Mechanically locked	Damp on	Damp on
F1	Damp on	Damp on	Damp on	Mechanically locked
F2	Damp on	Damp on	Mechanically locked	Mechanically locked
F3	Damp on	Damp on	Damp on	Mechanically locked
BF	Damp on	Damp on	Damp on	Damp on

GAS Filter: damping + DC control on



Conclusion and next steps

- We have diagonalized sensors and actuators
- We applied the bending technique to ITMX
  - L and T blending frequency: 90 mHz
  - Yaw blending frequency: 300 mHz
- ETMX, ETMY
  - L and T blending frequency: 190 mHz
  - Yaw blending frequency: 300 mHz
- Thanks to the implementation of the inertial damping we observed a reduced motion of IP, BF and TM

- **IP inertial damping ON**
- **YAW BF damping ON**
- **All other d.o.f NOT DAMPED**

ITMX: ACC	L RMS [µm]	T RMS [µm]	Y RMS [µrad]	P RMS [µrad]
IP	0,05	0,08	0,08	
BF	1	1	0,3	
TM			0.5	0,4

Conclusion and next steps

- ETMX, ETMY
  - L and T blending frequency: 190 mHz
  - Yaw blending frequency: 300 mHz

- **IP inertial damping ON**
- **YAW BF damping ON**
- **All other d.o.f NOT DAMPED**

ETMX :GEO	L RMS [µm]	T RMS [µm]	Y RMS [µrad]	P RMS [µrad]
IP	0,07	0,08	0,08	
BF	0.8	0.4	0,3	
TM			0.5	0,4

ETMY :GEO	L RMS [µm]	T RMS [µm]	Y RMS [µrad]	P RMS [µrad]
IP	0.1	0,1	0,03	
BF	0.3	0.3	0,3	
TM			Not measured	Not measured

Conclusion and next steps

- The inertial damping (ID) reduces the test mass motion more than the position control with only LVDTs
- To evaluate its impact on the lock performances would be interesting
  - On ITMY is not possible to implement the ID because of accelerometers noise: the accelerometers are not working.
- Some work to further optimize the ID on ITMX (e.g move the blending frequency to 70 mHz) is going on.
  - Carefully evaluate the accelerometers noise re-injection below 0.1 Hz
- Carefully evaluate the geophones noise performance:
  - ✦ now we use them with high blending frequency: this means that the seismic motion is not filtered (e.g the peak at 200 mHz)
  - ✦ It is not possible to reduce the blending frequency because below 190 mHz the geophone has not coherence with LVDT.
  - ✦ However, the ID reduce the motion of the suspension.
- To align the reference frame of BF with respect to the IP.
- Fine tuning: to align the Longitudinal (L) direction of the FP IPs by using the cavity length.
- Modal control implementation on Gas Filters.

Thanks for your attention!