E-TEST Einstein Telescope EMR Site & Technology

Status of compact isolation of a large mirror at a low frequency

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On behalf of the E-TEST collaboration

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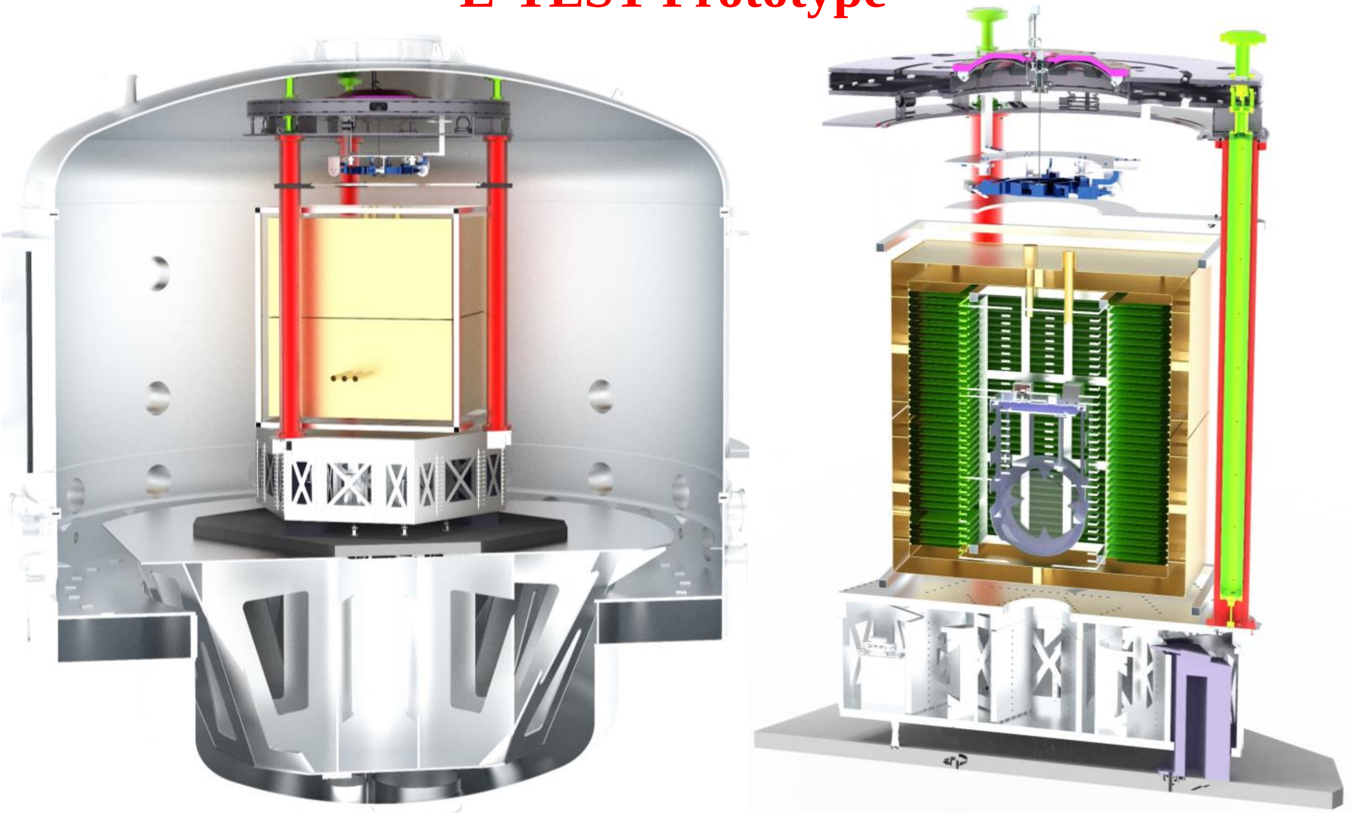
Interreg
Euregio Meuse-Rhine
European Regional Development Fund
EUROPEAN UNION

E-TEST project for proof of concepts

Features of E-TEST Project:

- Suspend large silicon mirror (100 Kg)
- Cryogenic temperature (25 K)
- Developing cryogenic sensors and electronics.
- Laser and optics at 2 microns.
- **Compact suspension (4.5 meters) with isolating at low frequency (0.1-10 Hz).**

E-TEST Prototype

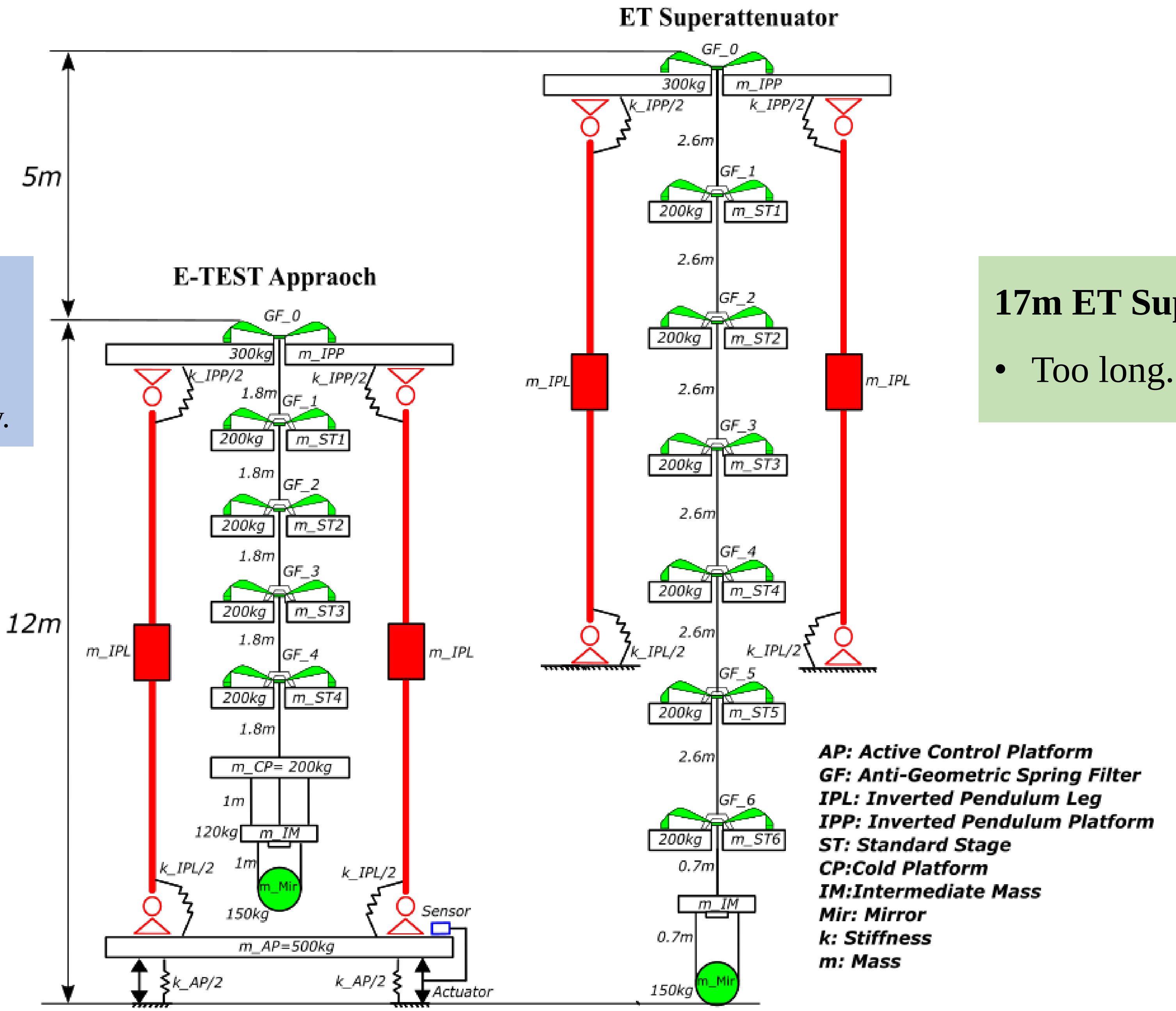


E-TEST is a project funded by the Interreg Euregio Meuse-Rhine and ET2SME consortium.

E-TEST isolator & 17m ET Superattenuator (ET CDR, 2011)

E-TEST (new isolation system):

- Compact isolator
- Extra isolation in low frequency.

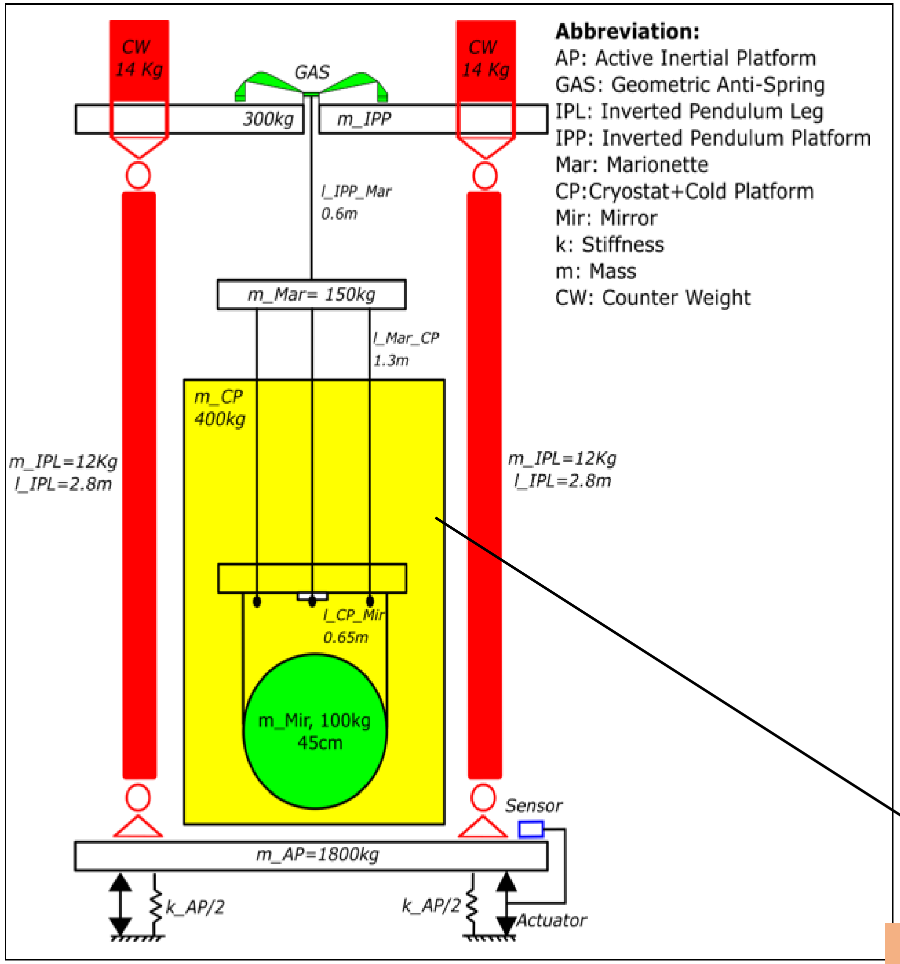


17m ET Superattenuator:

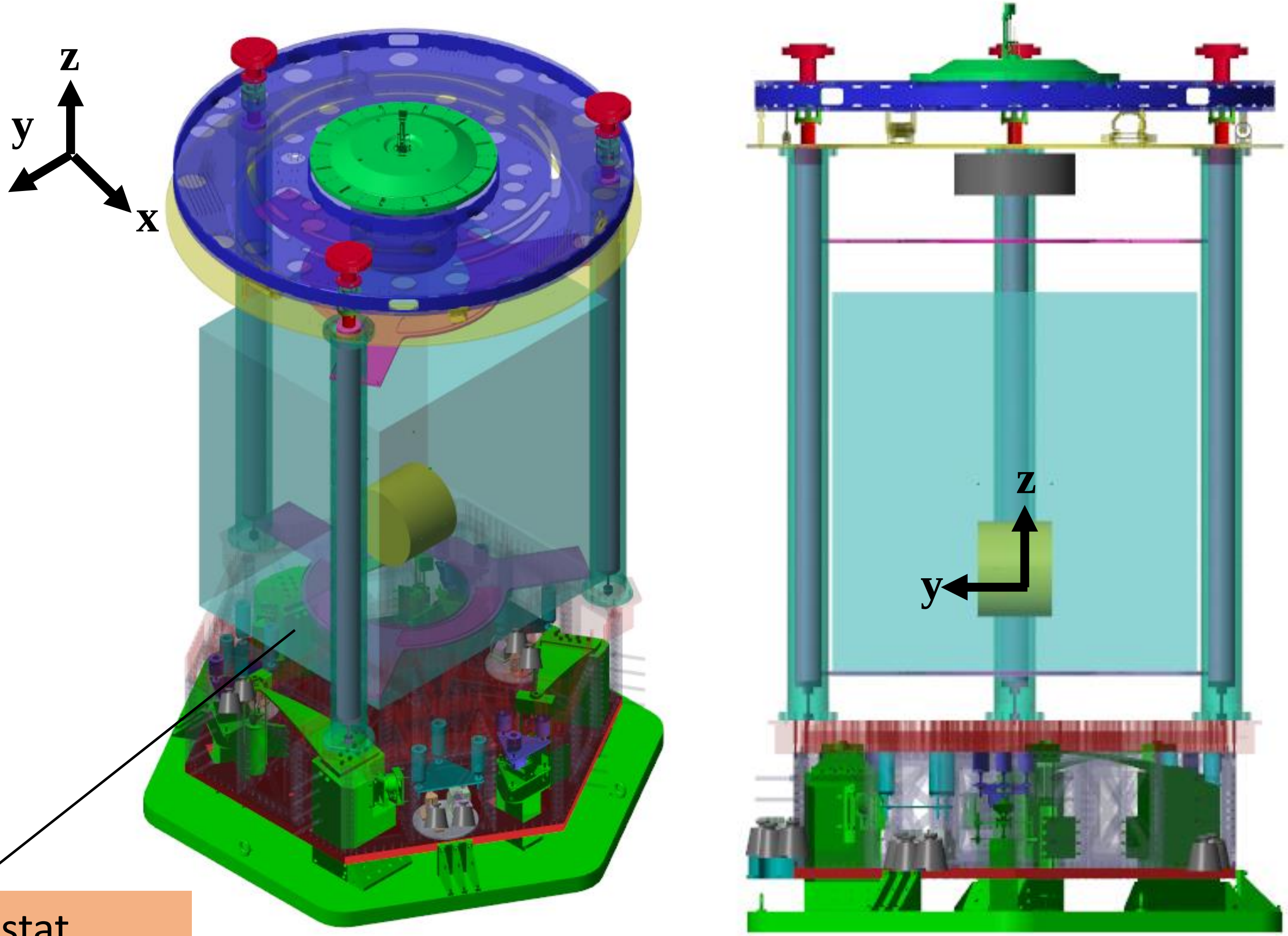
- Too long.

E-TEST Prototype

Schematic Diagram

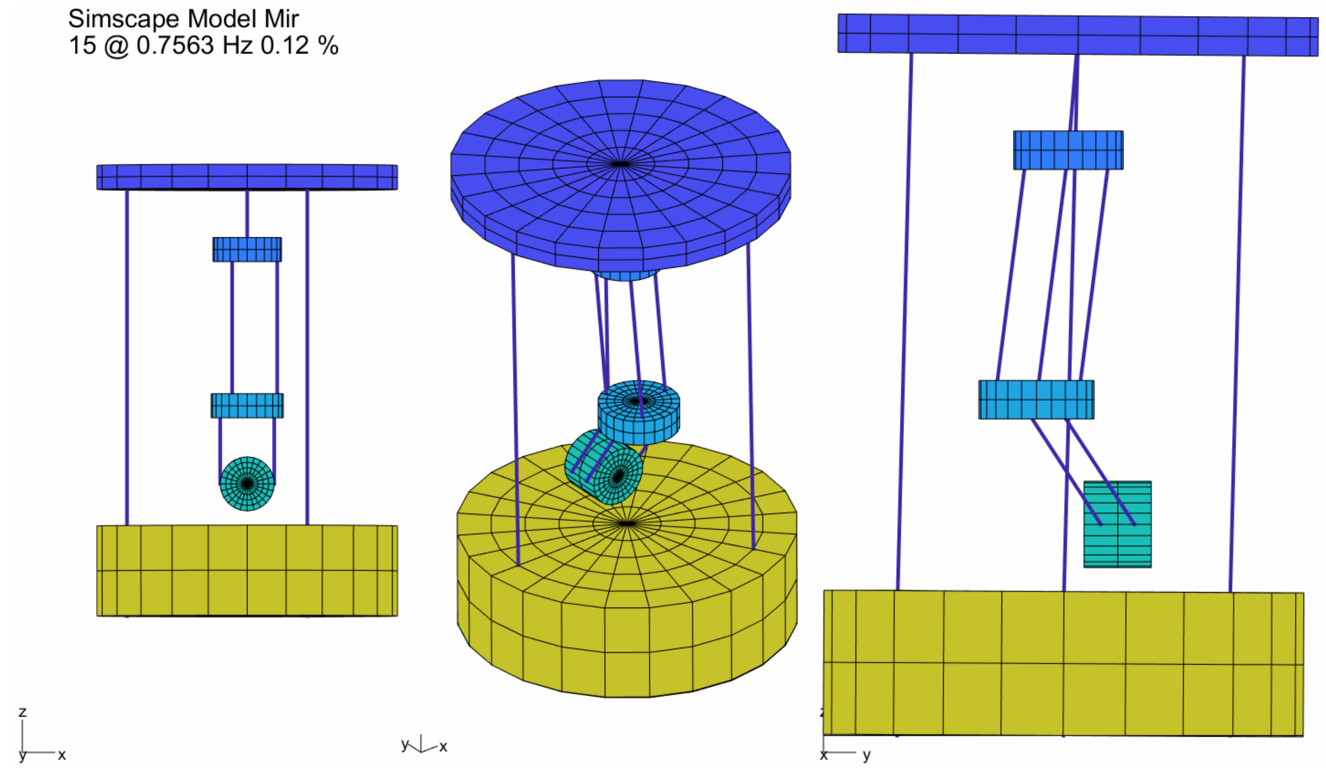


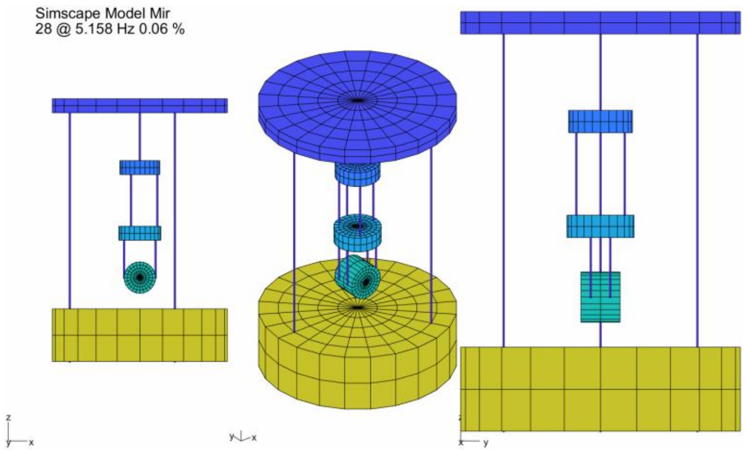
Simscape Model to obtain system dynamics

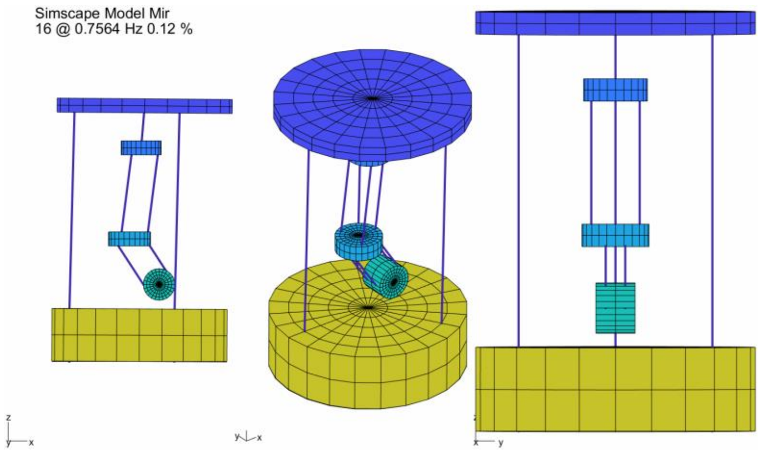


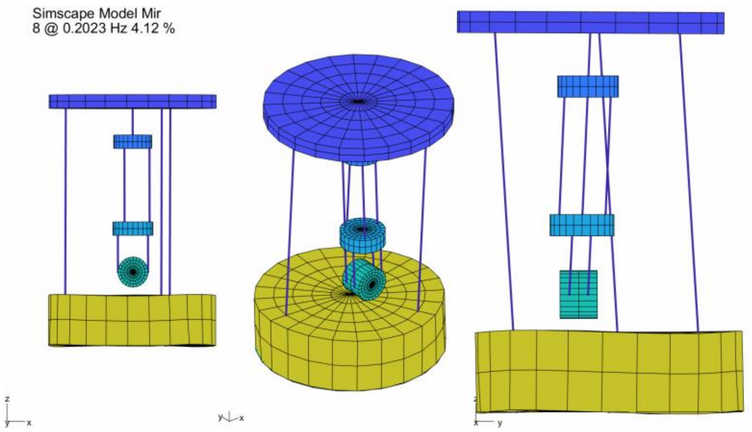
Cryostat
(Cooling system)

Extracting mode shape
(deeper understanding of the dynamics)





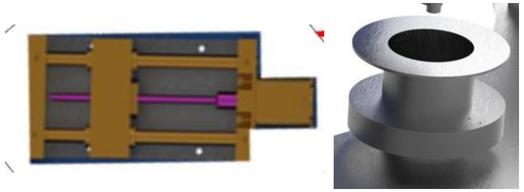




Sensors & Actuators (vacuum compatible)

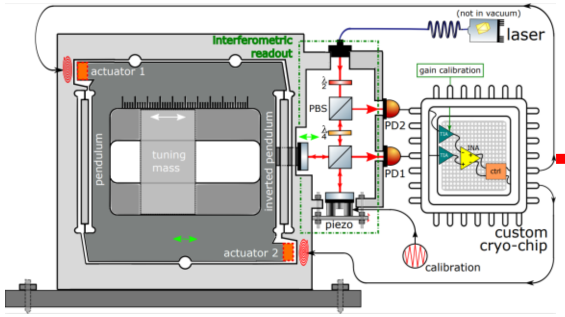
4 Interferometric sensors,
4 Voice coil actuators
4 stepper motors

2 stepper motor
8 coil-magnet actuators



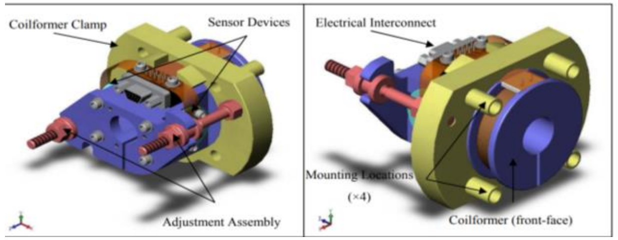
Temperature sensors

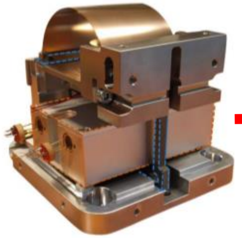
6 Cryogenic inertial sensors (3 horizontal & 3 vertical)

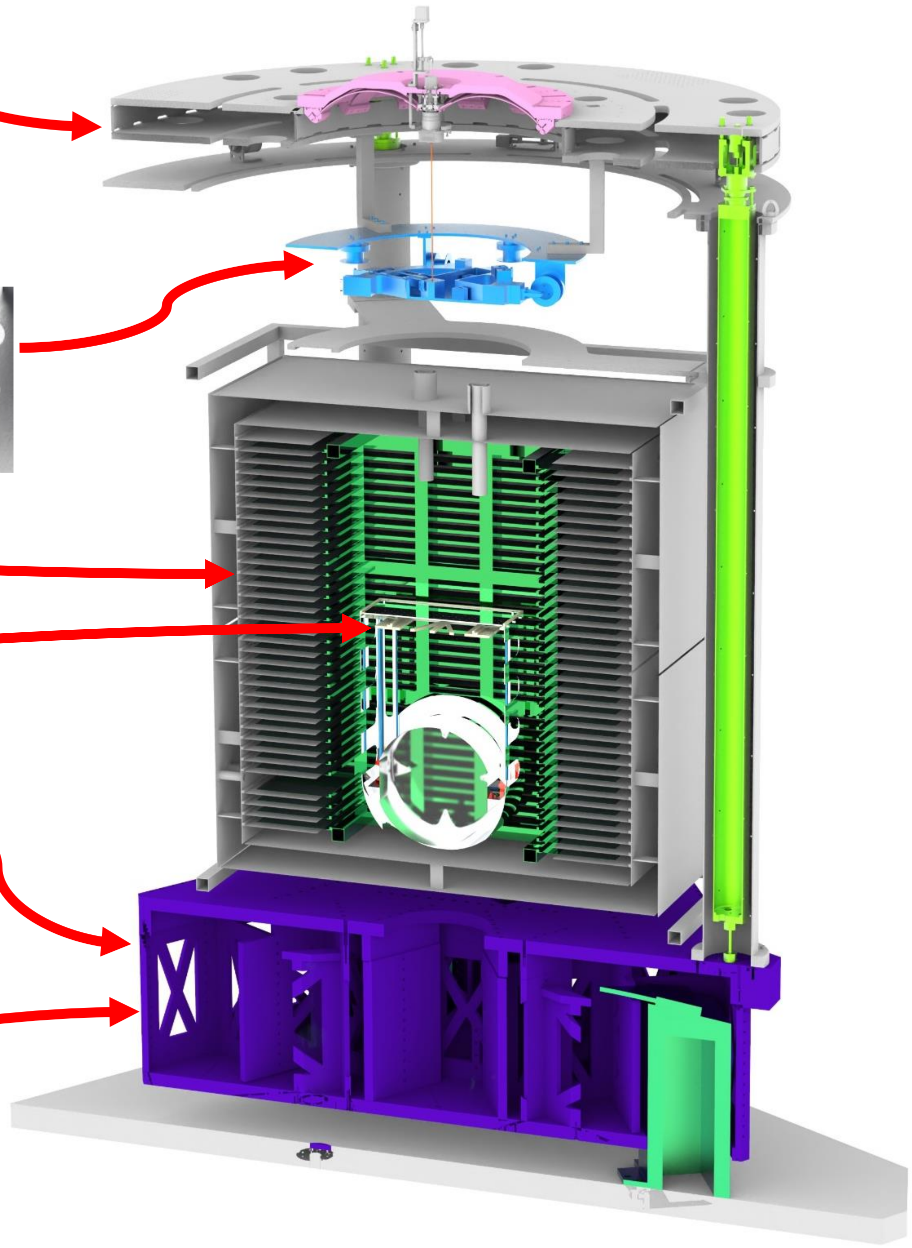


6 voice coil Actuators

6 Inertial sensors (3 horizontal & 3 vertical)
6 BOSEMs (3 horizontal & 3 vertical)

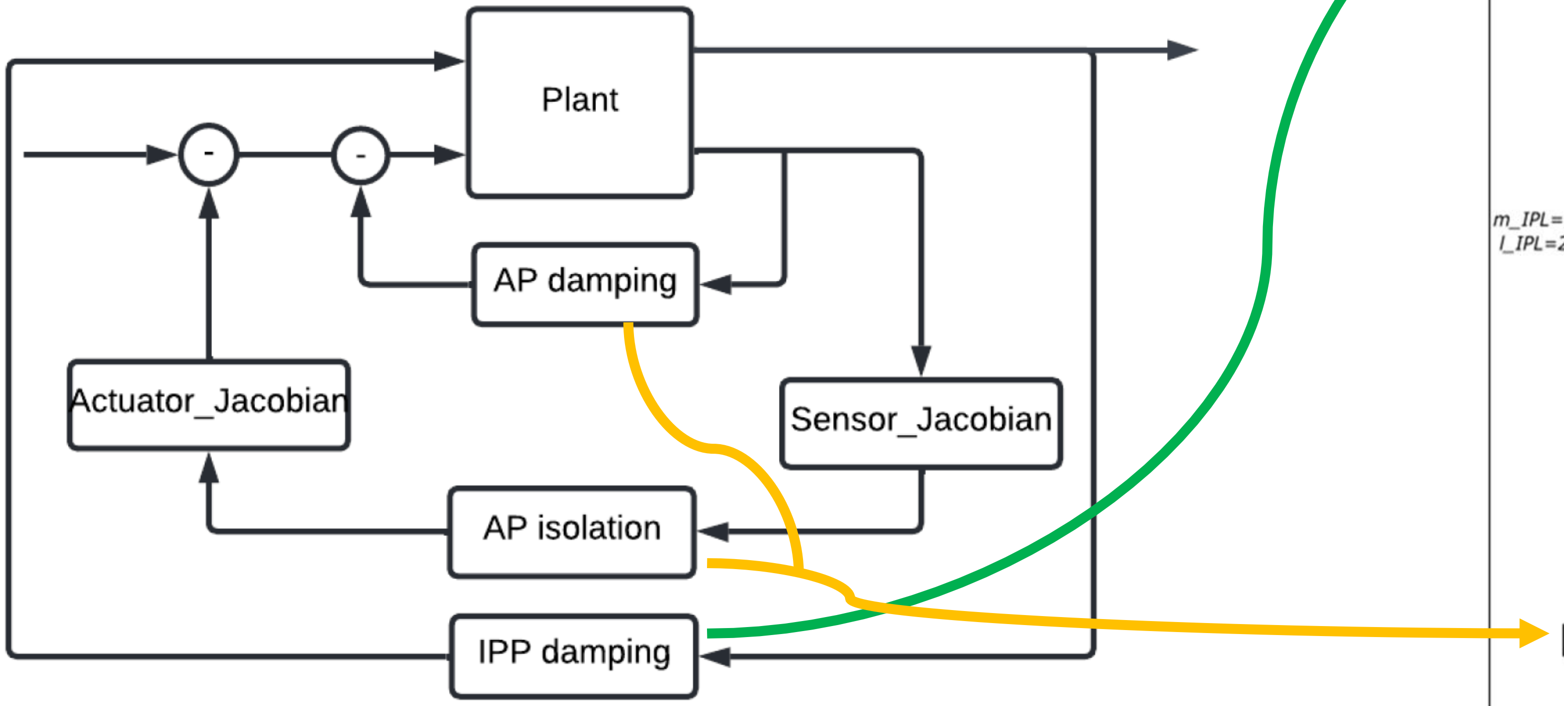


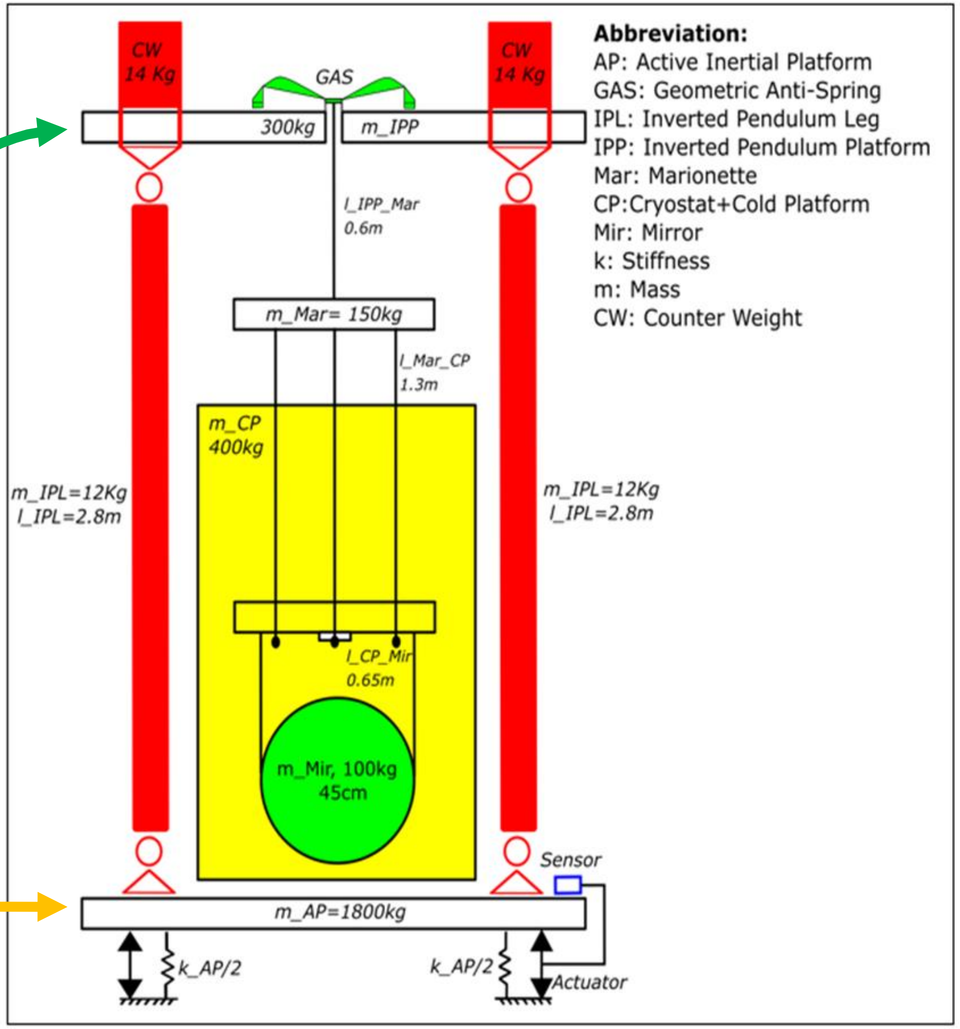




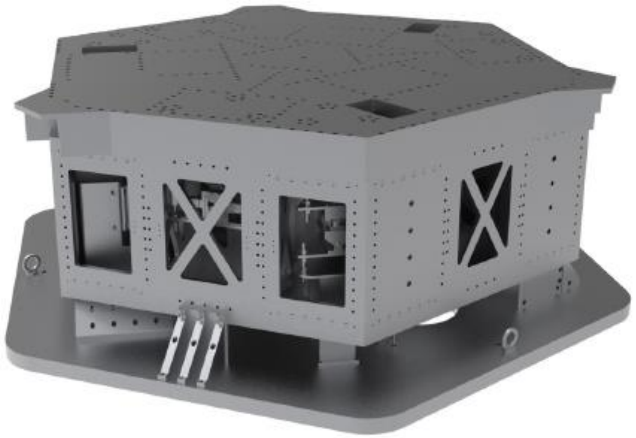
Control strategy

Controllers are designed based on loop shaping; lead-lag compensator

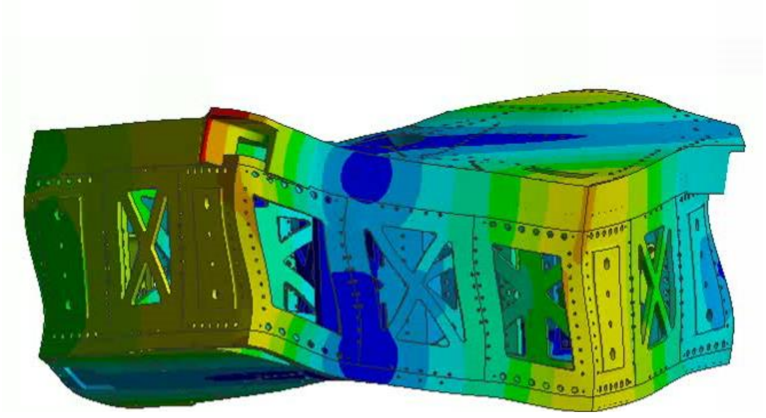


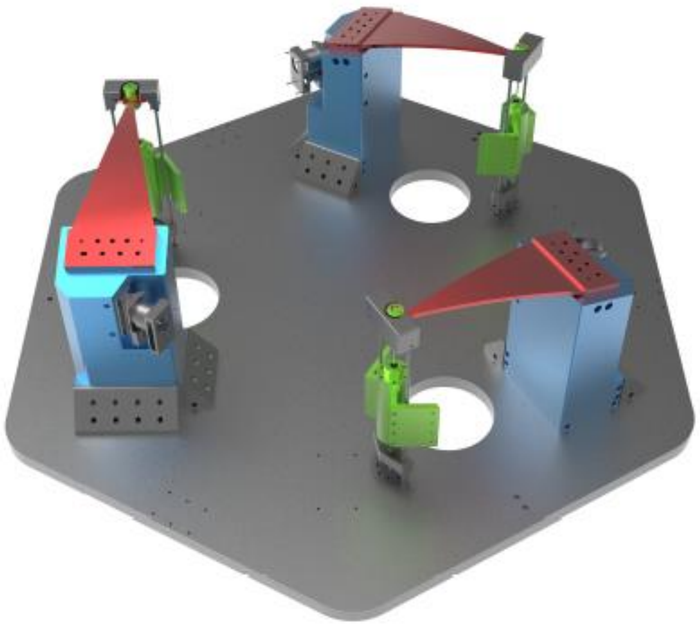


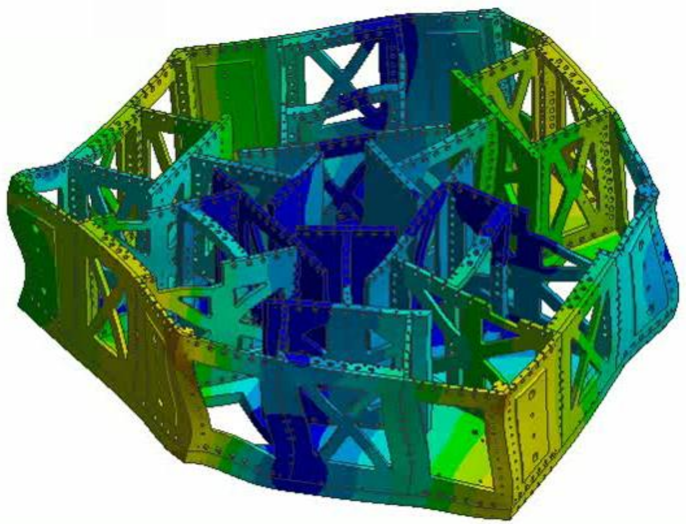
First Flexible mode of Active Platform above 300 Hz
To obtain better control performance



CAD Views

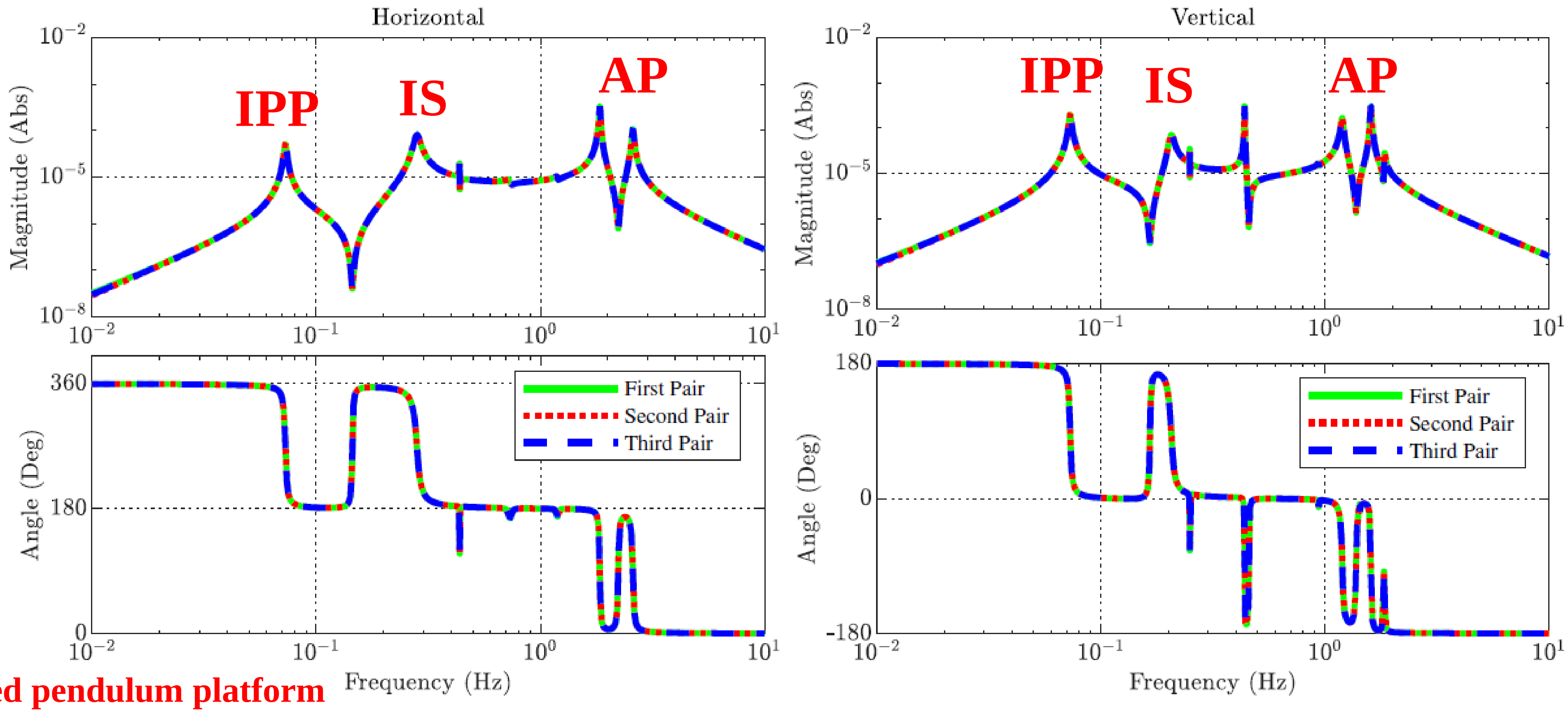






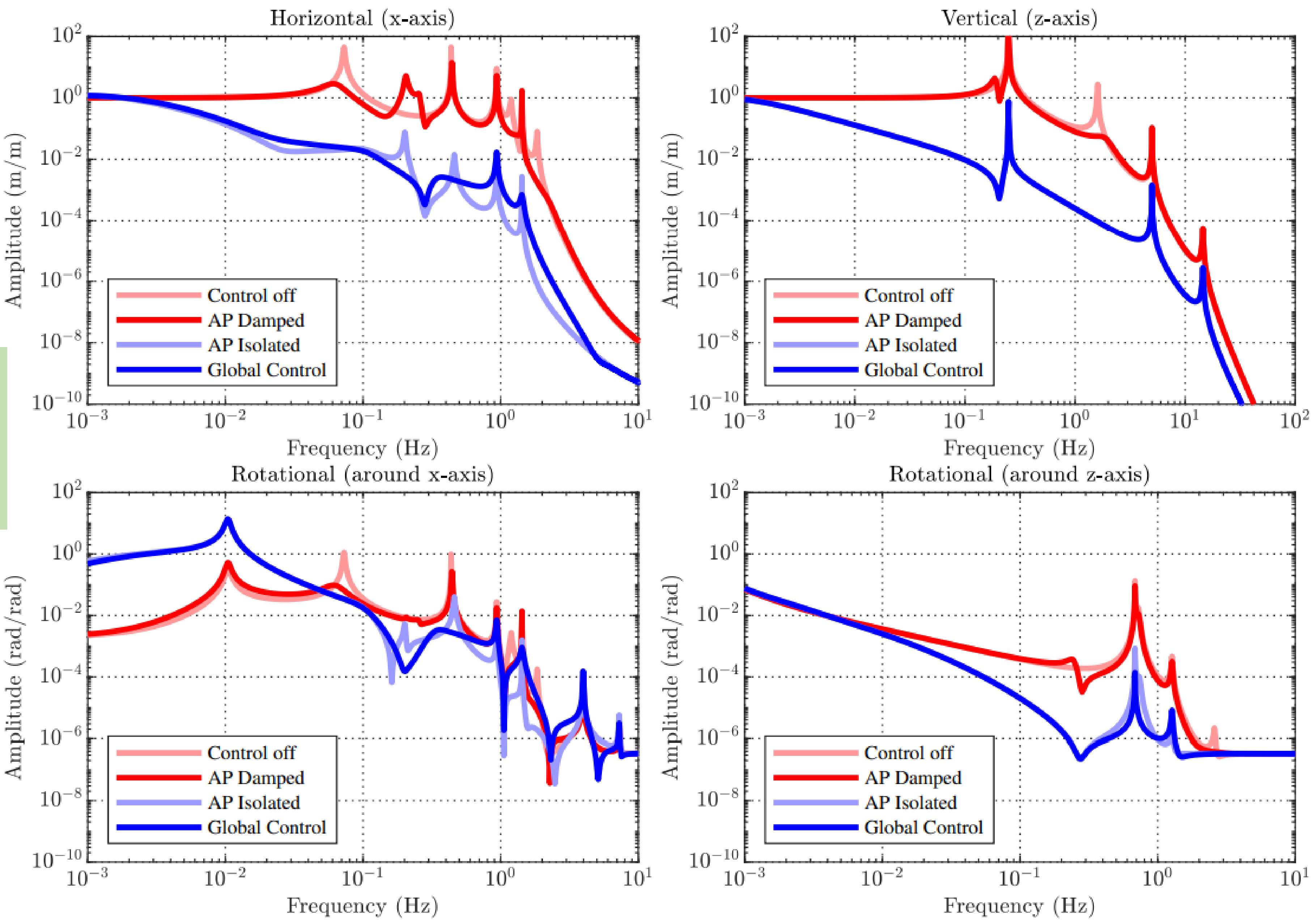
Transfer function (three pairs of inertial sensors/actuators) at active inertial platform

Force by the actuator on AP disturbs the alignment of IPP (that provides soft horizontal compliance) with the gravity field and causes tilting of the IPP (motion). This tilting motion appears as a coupling on the AP



IPP: inverted pendulum platform
IS: inertial sensor
AP: active inertial platform

Transmissibility mirror/ground



Not realistic controller is used to show that the system is not constrained by mechanical design.

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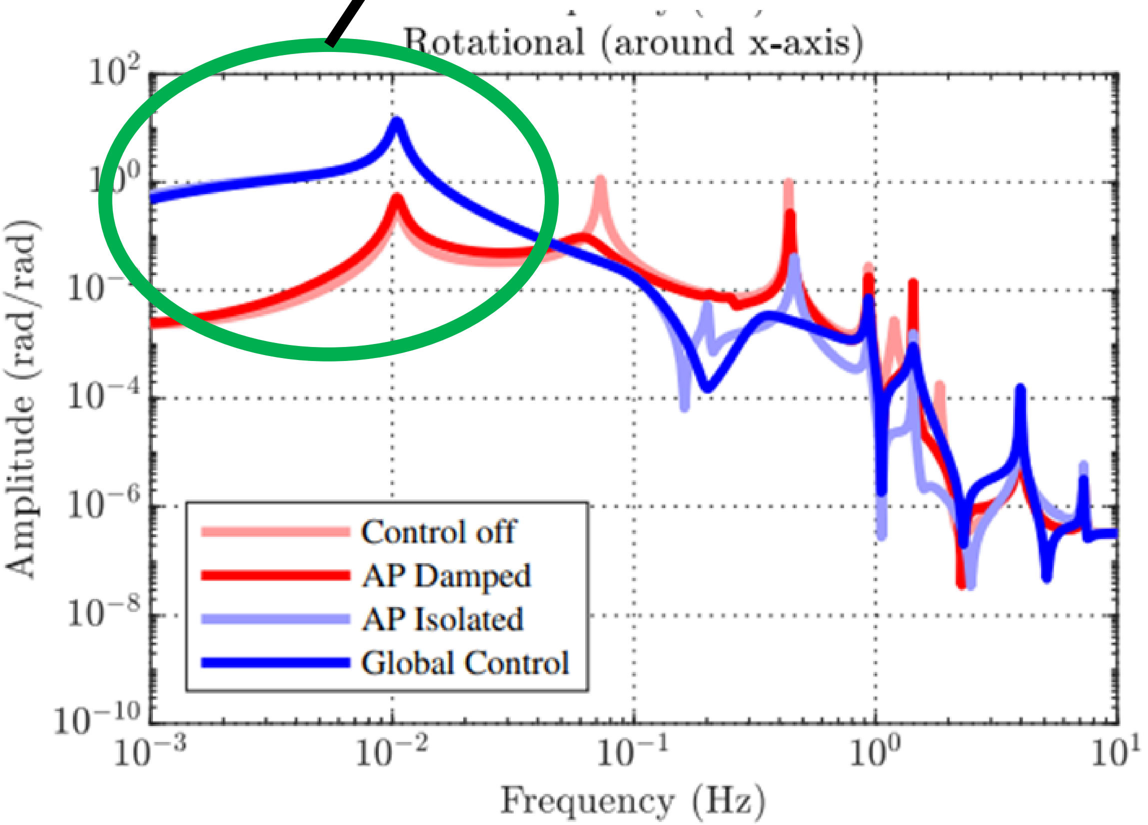
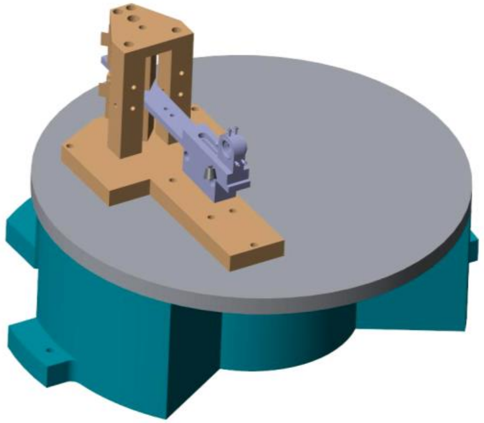
Transmissibility mirror/ground

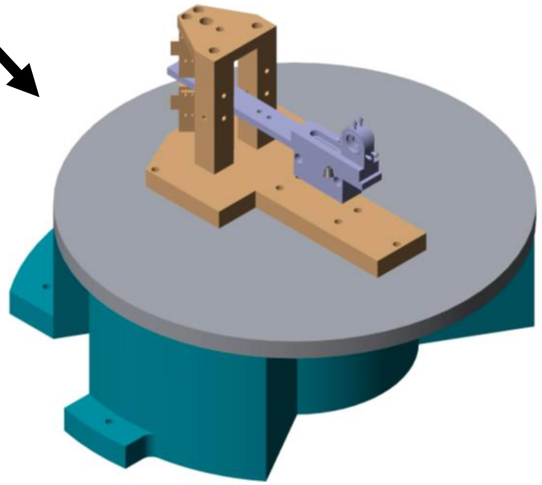
Comes from inertial sensor coupling
(residual coupling between the mechanics of the sensor (spring-mass) and gravity)



Inertial sensor response for horizontal motion



Inertial sensor response for rotational motion



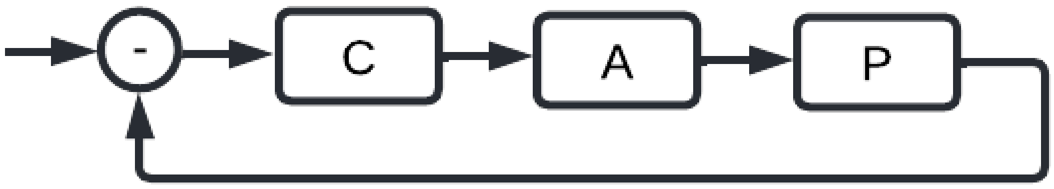
Inertial sensor coupling → non-minimum phase zero → larger dc gain of the controlled system than the uncontrolled system

Solution: complementary filter (relative displacement sensor & inertial sensors)

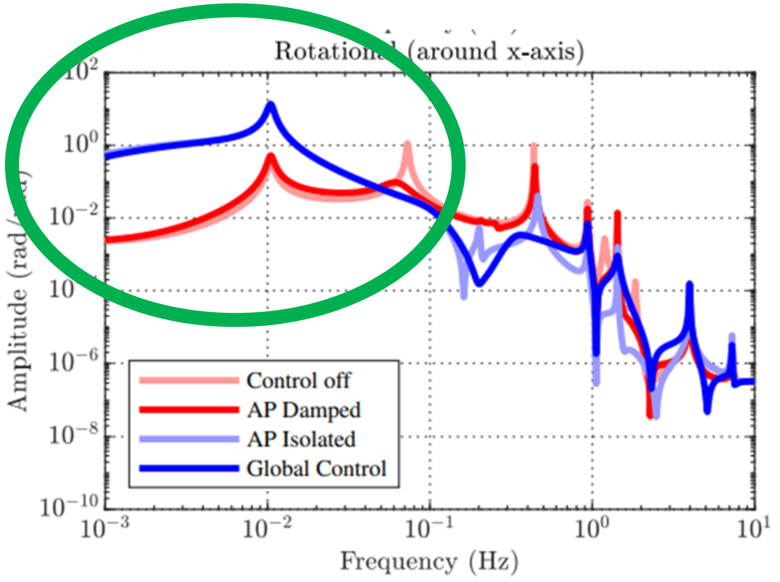
A → inertial sensor dynamic with non-minimum phase zeros $A = \frac{(s-a)^2}{(s-b)^2}$

P → entire E-Test plant.

C → controller used.



$$T(s) = \frac{CAP}{1+CAP} = \frac{CP(s-a)^2}{(s+a)^2+CP(s-a)^2}$$



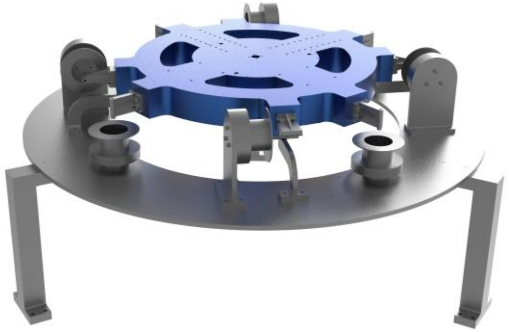
- Nonminimum phase zeros are shifted into the characteristic equation next to the controller. This reduces the magnitude of the denominator compared to the numerator, resulting in a larger dc gain for the entire closed-loop transfer function.
- The controlled system will always have a larger dc gain than the uncontrolled system with nonminimum phase zeros. Closed-loop dc gain is proportional to the controller gain.
- Modifying the sensor mechanics can reduce the effects of non-minimum phase zero, but at the expense of sensor resolution at low frequencies.

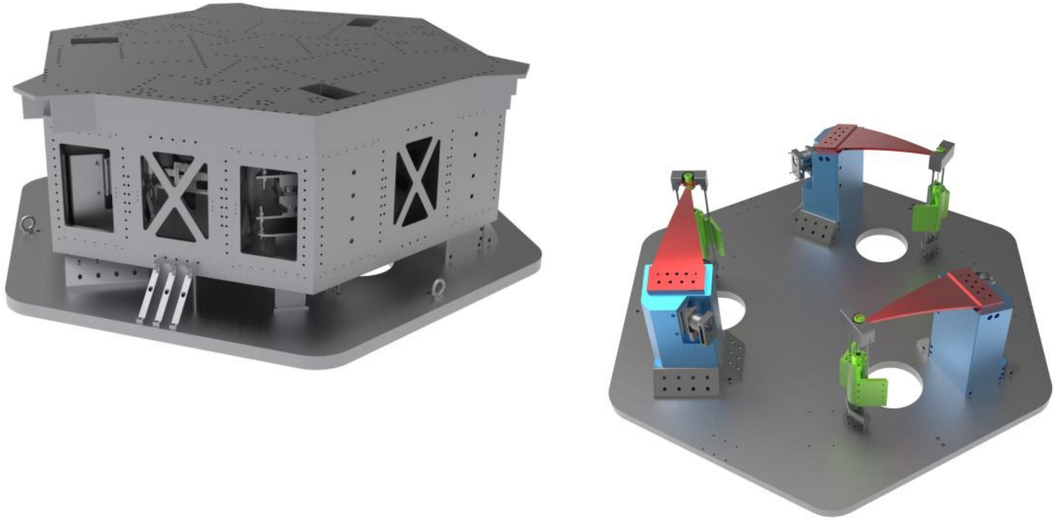
Mechanical design

Assembly starts in June (next month)

Inverted pendulum

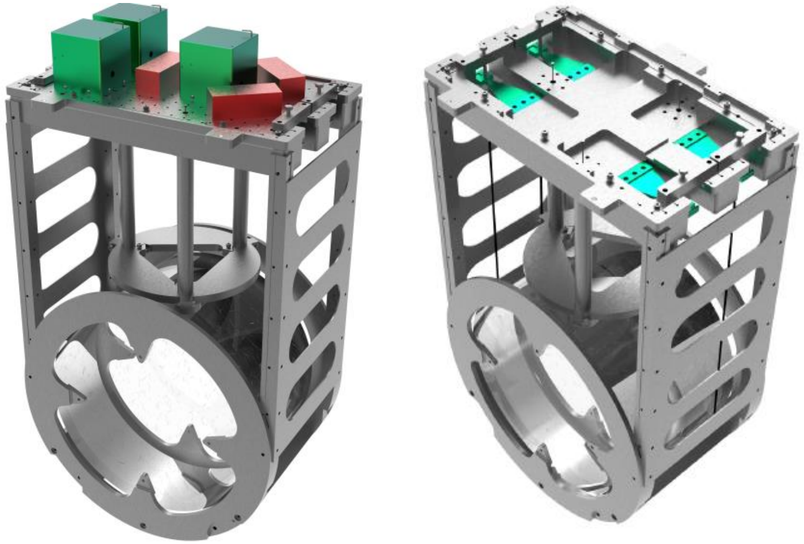
Marionette





Active inertial platform

Cryogenic payload



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Conclusion

The isolator is compact & provides isolation in low frequency but has an inertial sensor and IPP couplings

Done:

- Dynamic model is obtained.
- Mode shape is obtained.
- First control strategy is applied (simulation).
- Parts and components are manufactured.

Next:

- Apply complementary filter.
- Assemble the system → June (next month).
- Experimental work → Cryogenic test with AL dummy mass(Q4 2023).
- Experimental work → Cryogenic test with silicon mirror (Q4 2024). .

Useful links:

CDR: E-TEST prototype design report
https://arxiv.org/abs/2212.10083

E-TEST Project website
https://www.etest-emr.eu/

E-TEST: a compact low-frequency isolator for a large cryogenic mirror
LIGO Document P2200399-v1

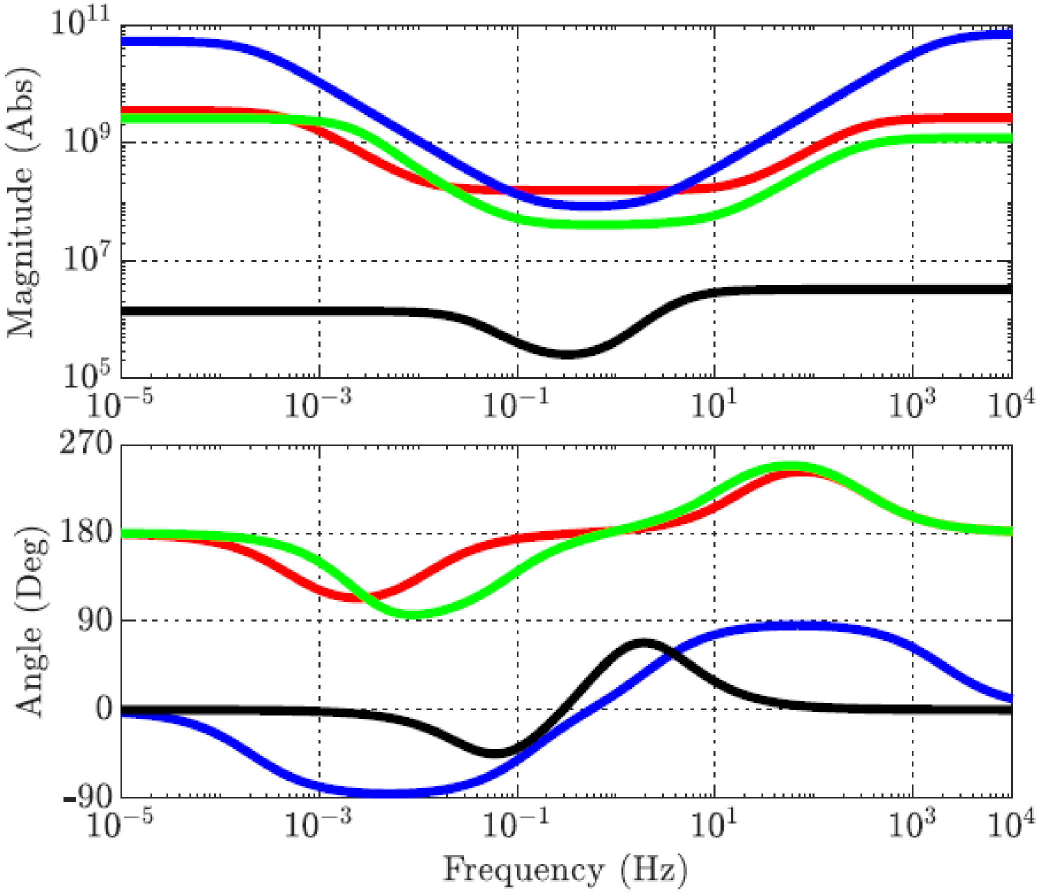
PML website
http://www.pmlab.be/

The End

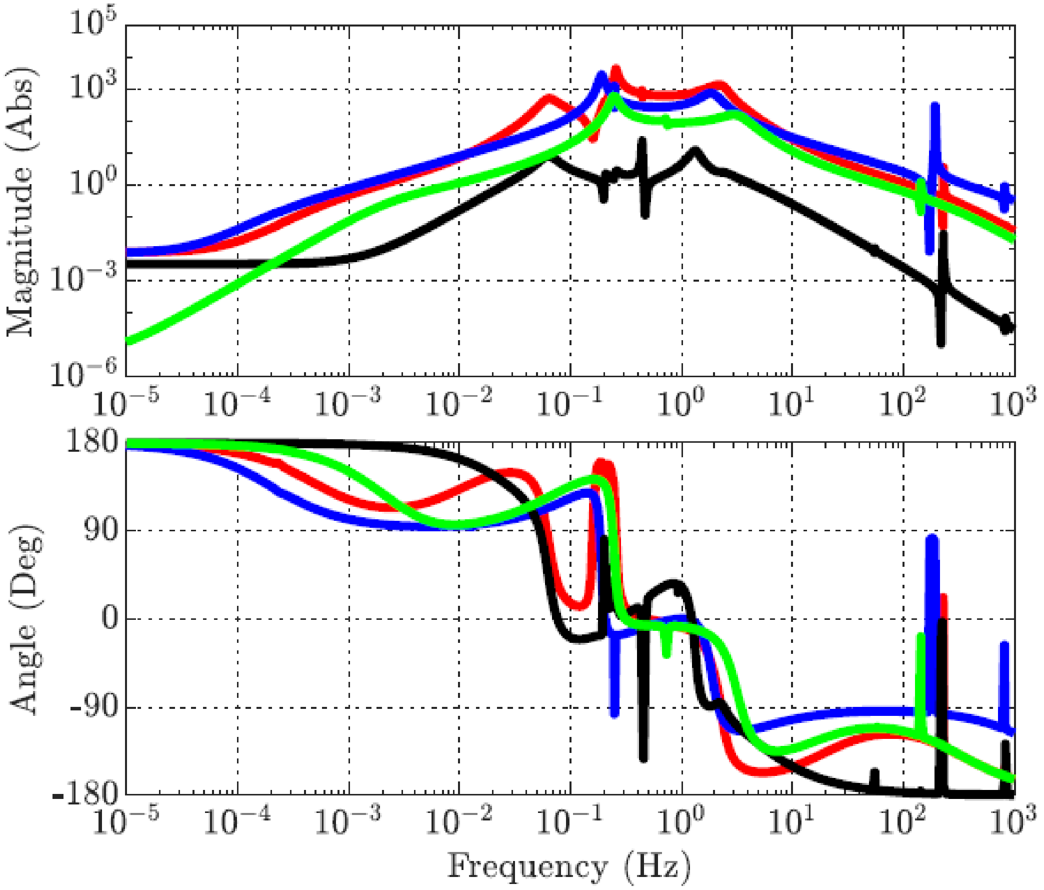
Thank you!

Isolation loop: controllers & loop gain

Controllers are not realistic → No mechanical constrain

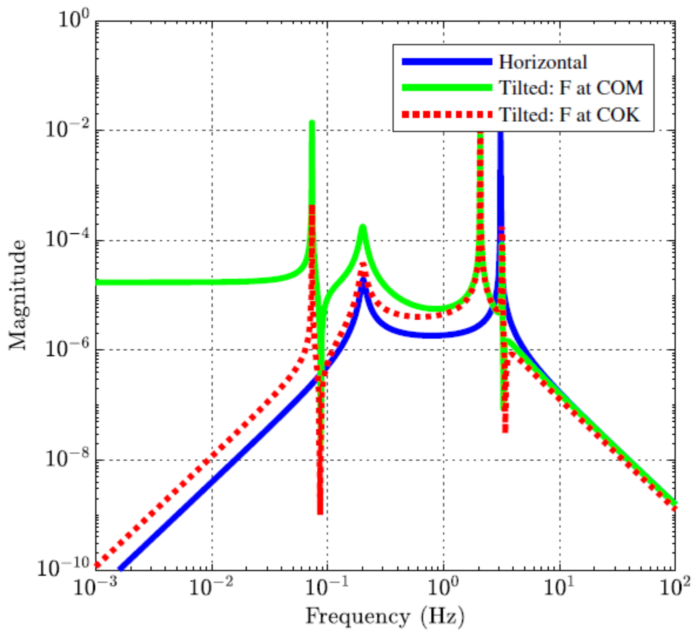


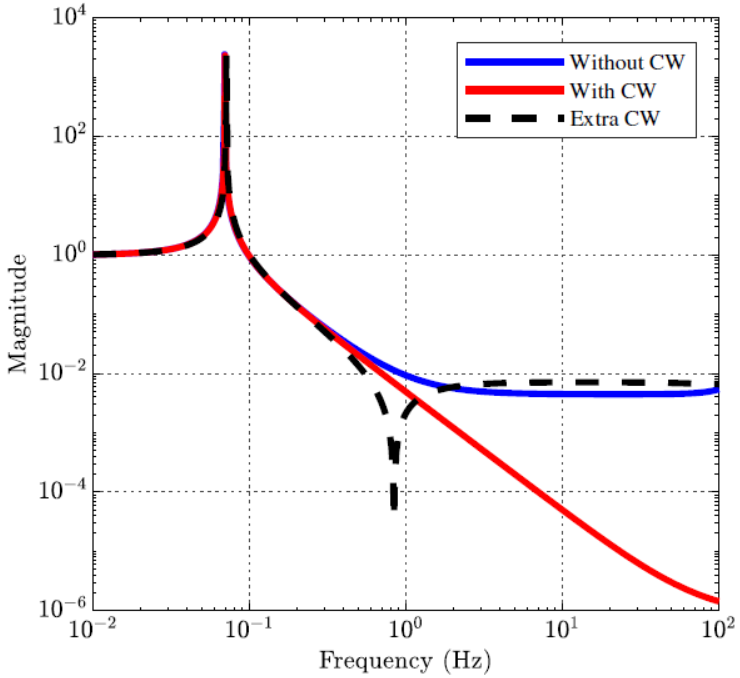
Controller of the isolation control loop
(red: x-axis, blue: z-axis, black: Rx-axis, green: Rz-axis).

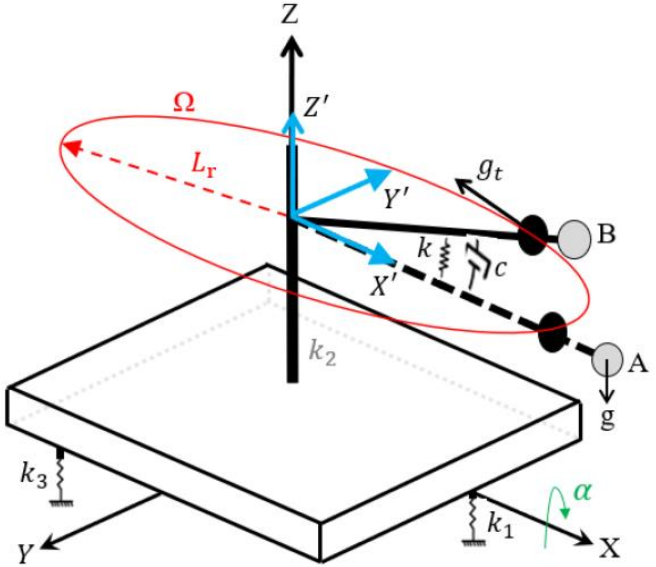


Loop Gains of the Isolation Control loop (red: x-axis, blue: z-axis, black: Rx-axis, green: Rz-axis)

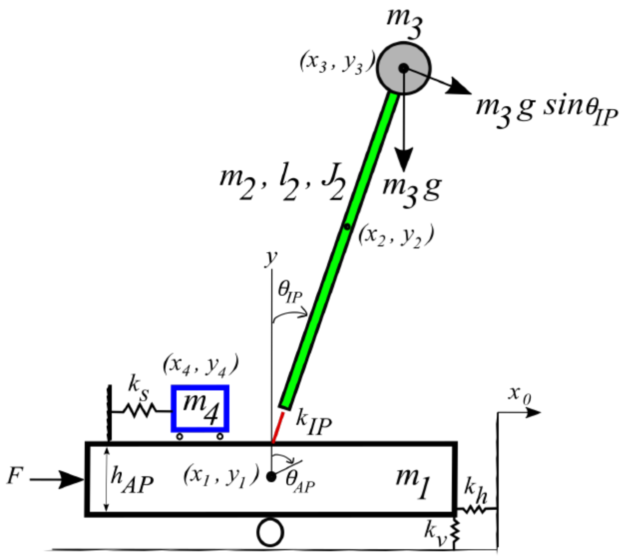
Simplified models are used to deeply understand the dynamics and coupling effects

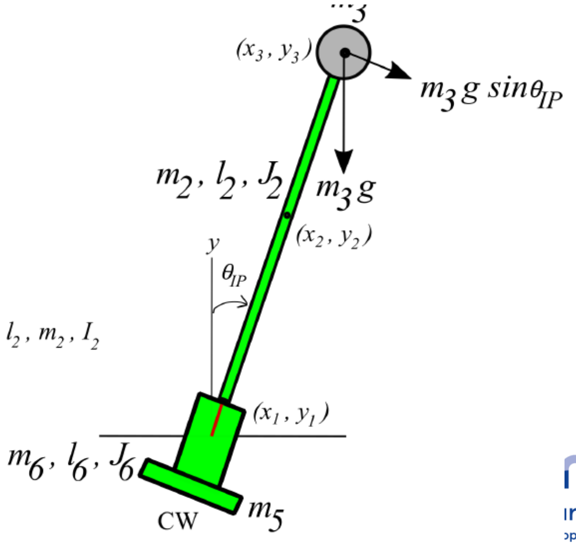






Schematic representation of horizontal inertial sensor





The Financiers

Interreg Euregio Meuse-Rhine — European Union

Wallonie

Vlaams-Brabant

Agentschap Innoveren & Ondernemen — Vlaanderen is ondernemen

provincie Limburg

provincie limburg

Ministerie van Economische Zaken en Klimaat

Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen

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