E-TEST Einstein Telescope EMR Site & Technology

A Compact Isolation Concept for Future Einstein Telescope

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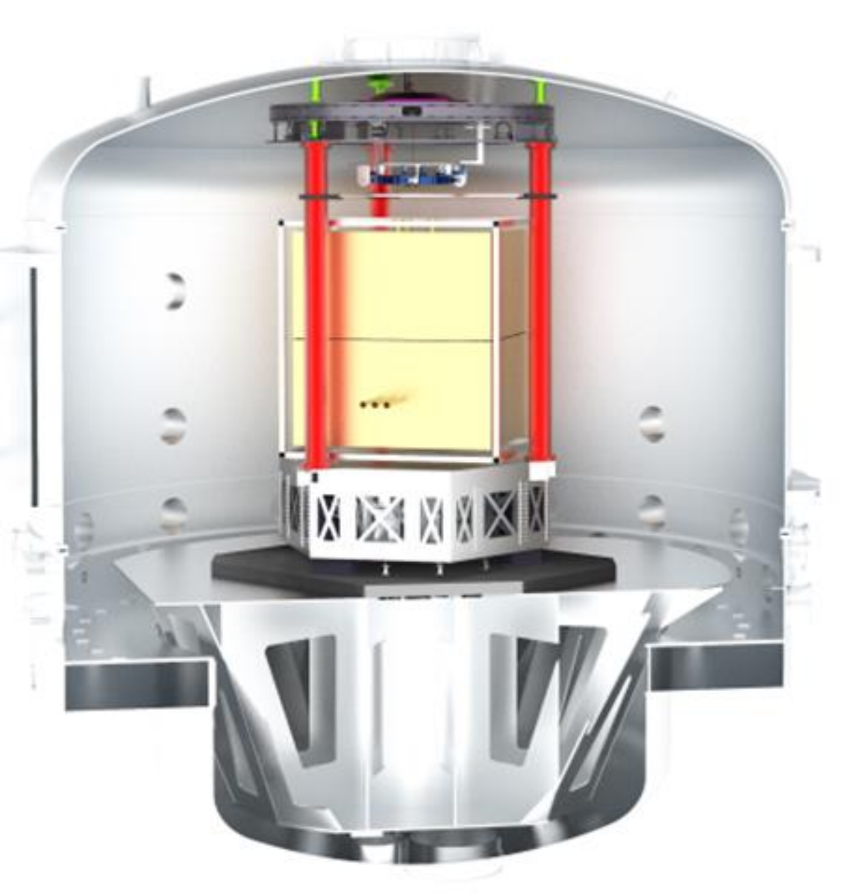
GWADW2022 - Jaban

24 May 2022



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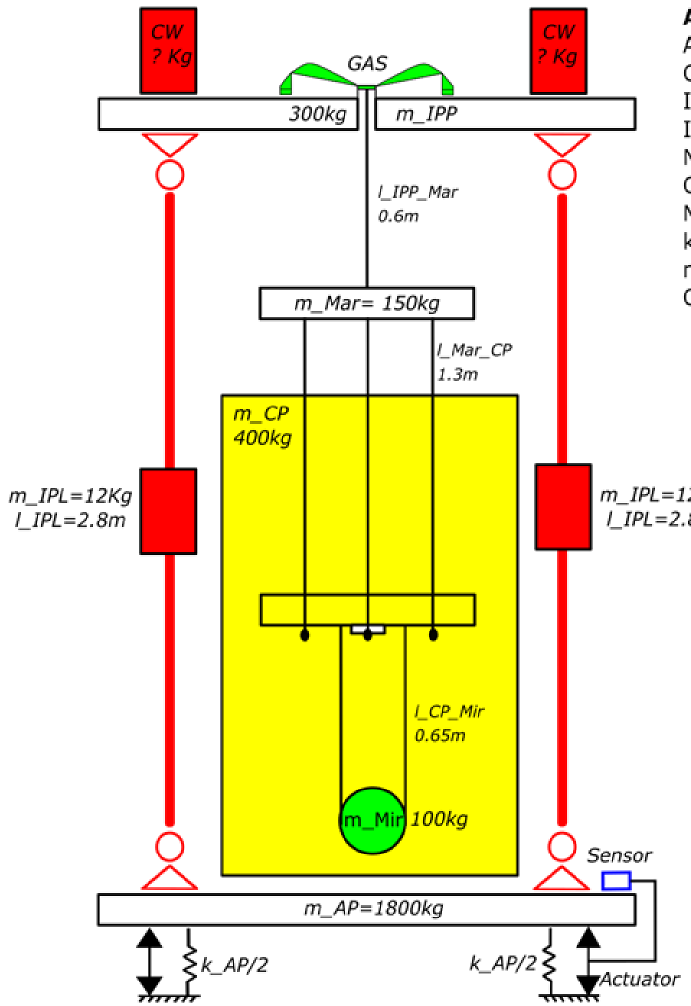
Outline

https://www.etest-emr.eu/

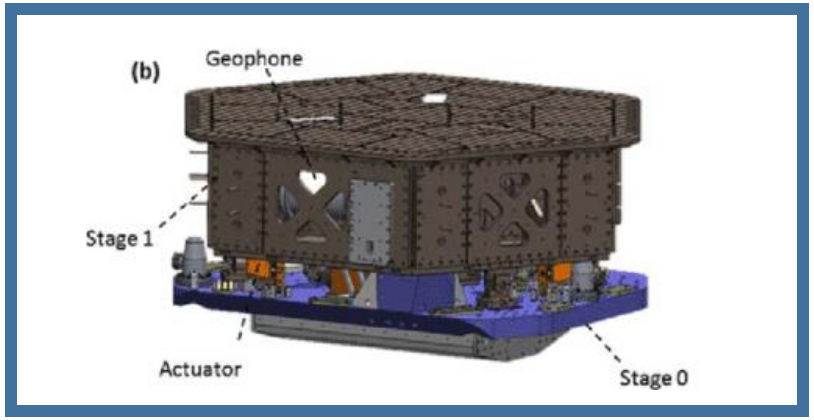
- E-TEST: new isolation approach.
- E-TEST prototype.
- Closed loop for E-TEST prototype.
- Future work.
-



Abbreviation:
AP: Active Control Platform
GAS: Geometric Anti-Spring Filter
IPL: Inverted Pendulum Leg
IPP: Inverted Pendulum Platform
Mar: Marionette
CP:Cryostat+Cold Platform
Mir: Mirror
k: Stiffness
m: Mass
CK: Counter Weight

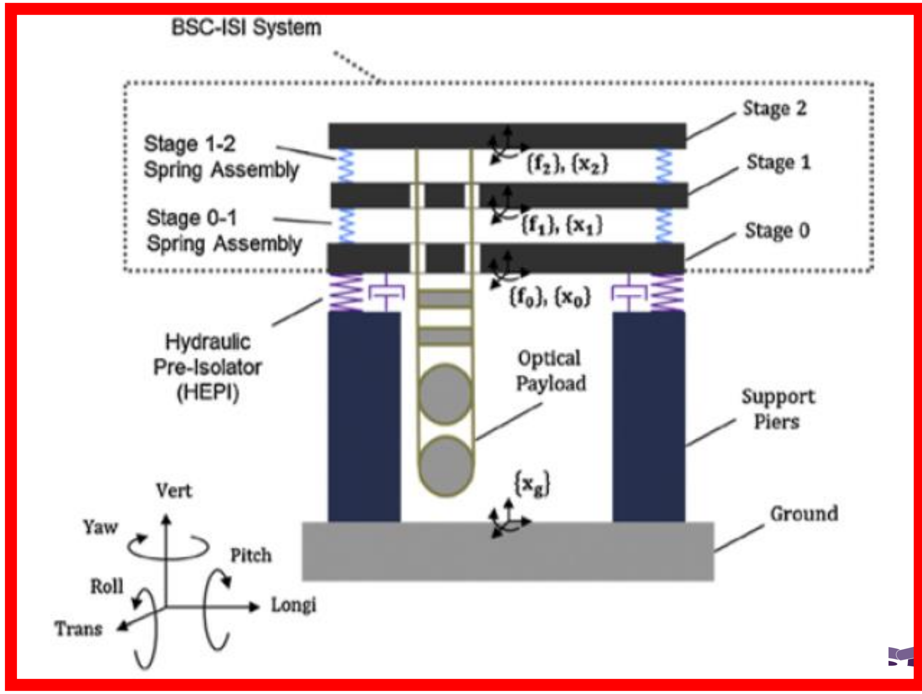
Common GW Suspension System

Active Control Approach
LIGO: HAM-ISI (1m)



[1]

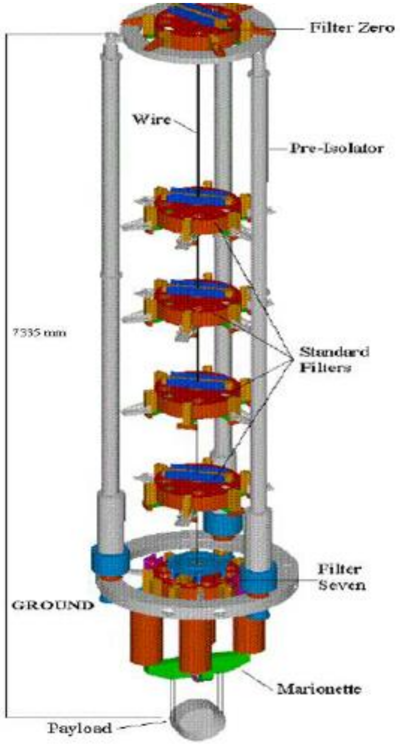
Active/Passive Control Approach
LIGO: HAM-ISI (1m)



Passive Control Approach

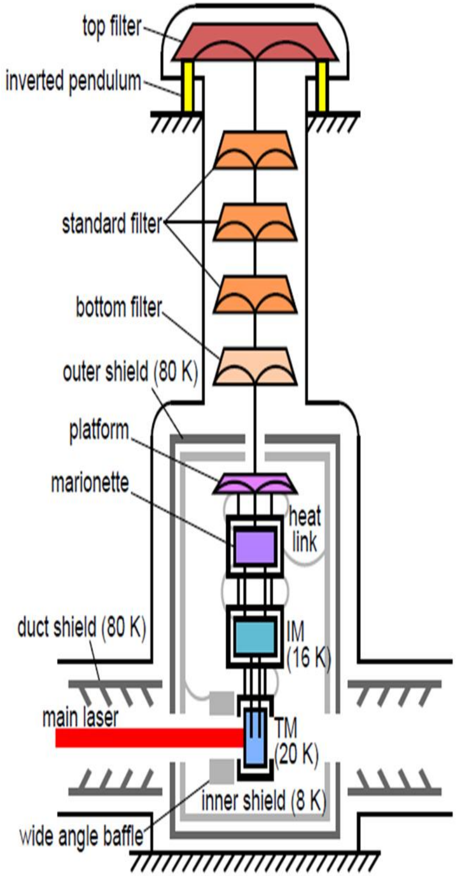
[3]

Virgo (11.5m)

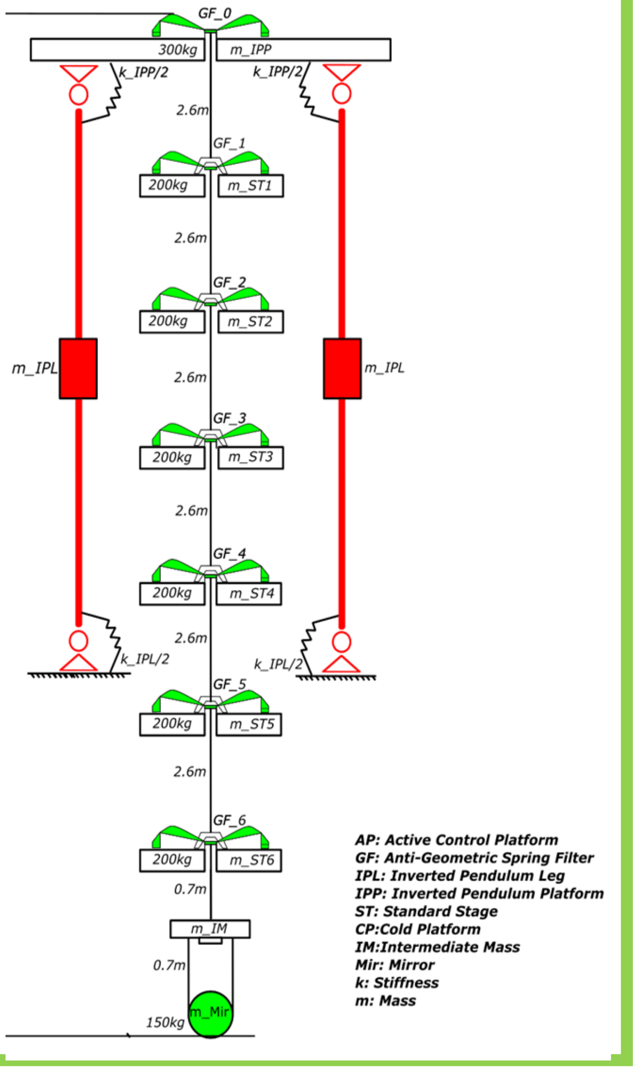


[2]

KAGRA (13.5m)



ET (17.5 m)



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E-TEST New Isolation System

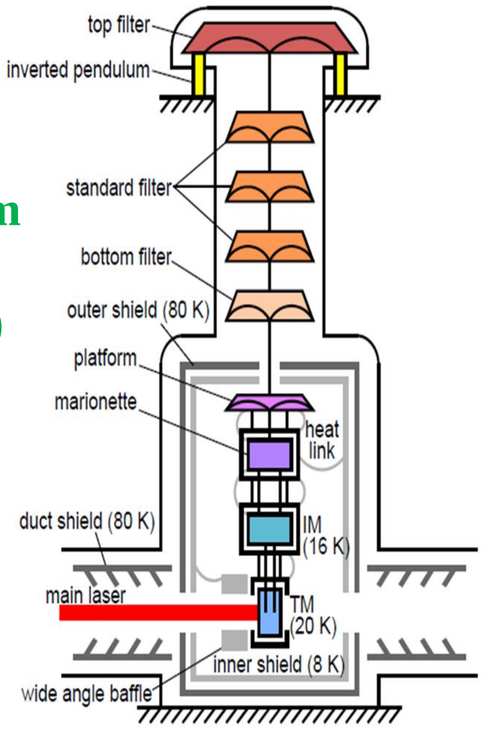
E-TEST (new isolation system):

- Shorter.
- Extra isolation in low frequency.

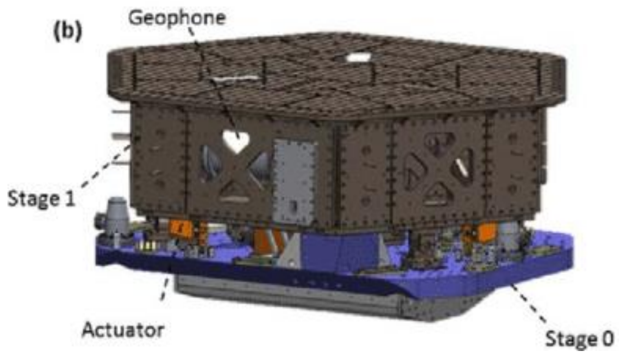
ET Superattenuator

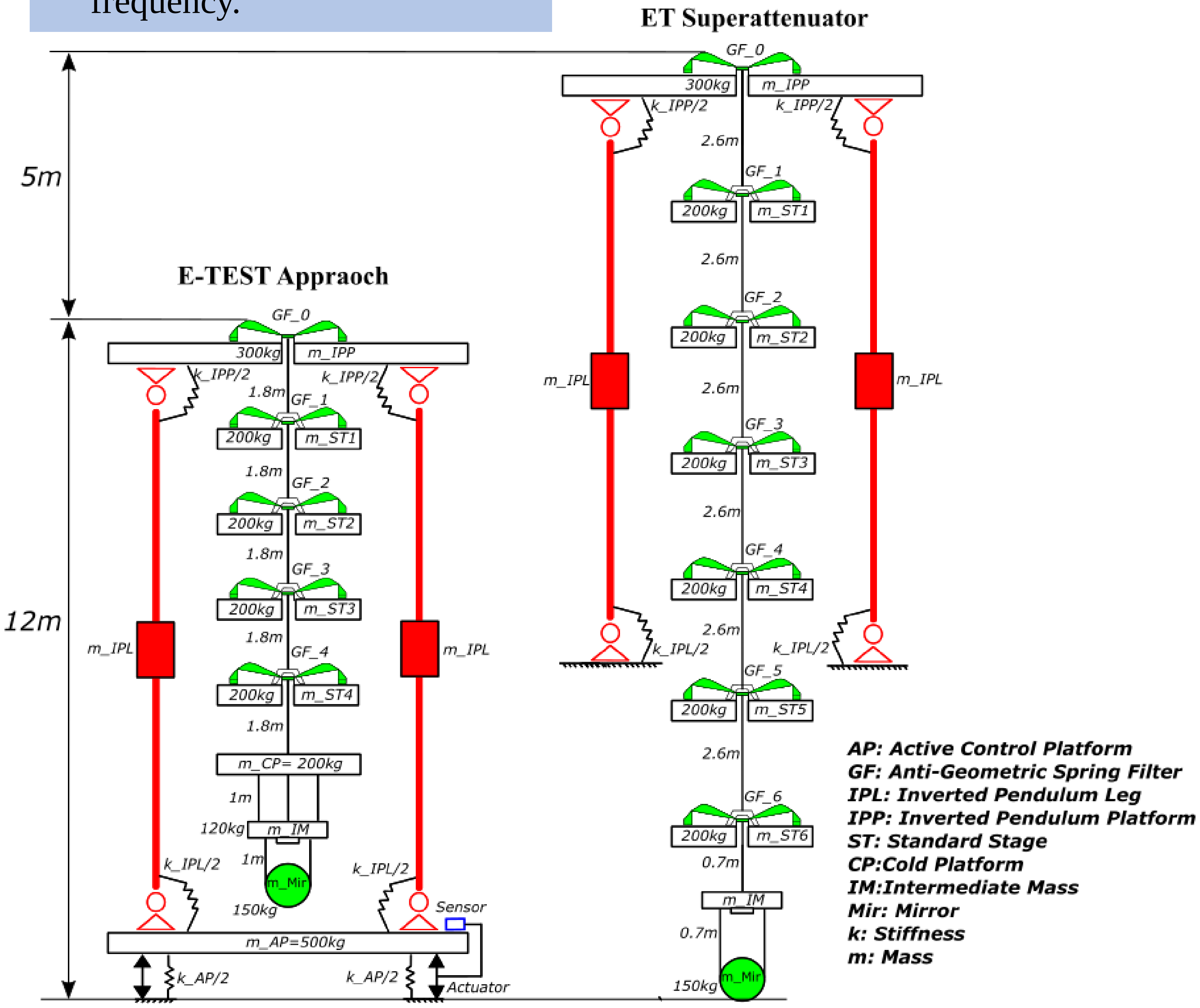
- Too long.

Passive Isolation (Inverted Pendulum + Simple Pendulum)



Active Isolation

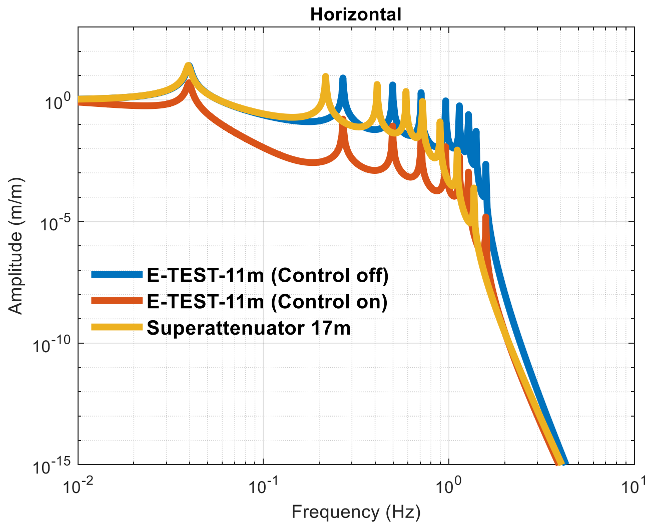


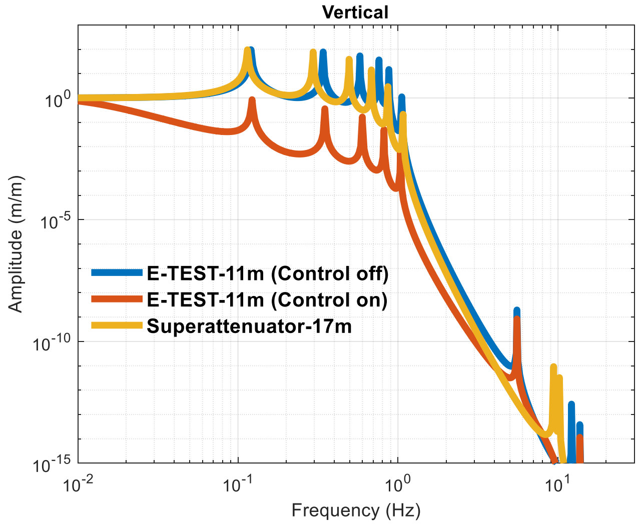


Output Response of ET Superattenuator & E-TEST Isolator

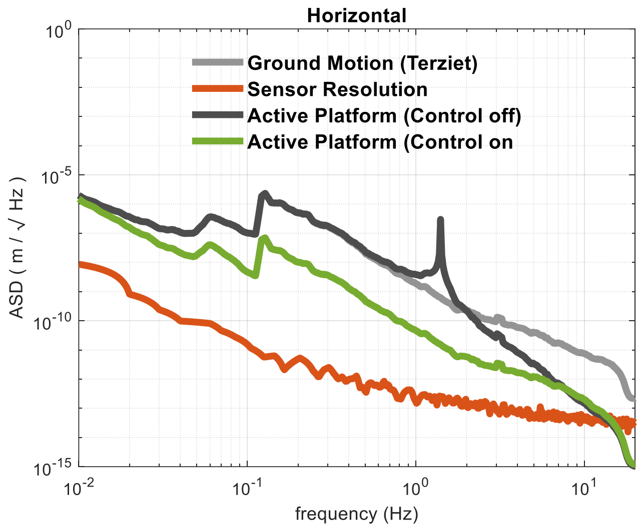
E-TEST Isolator achieves Superattenuator with less 5m of height

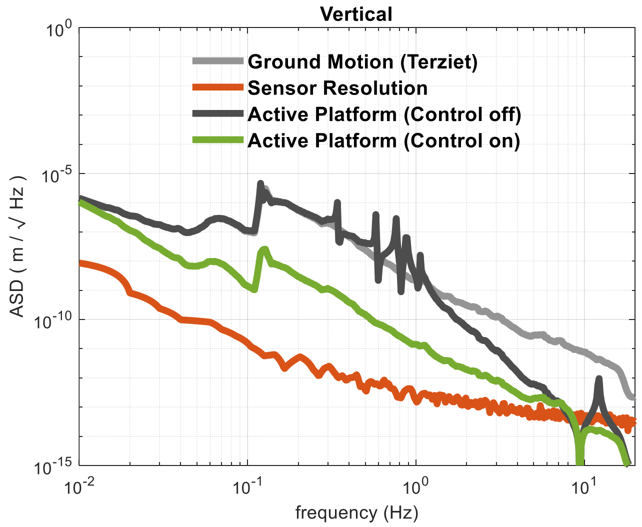
Transmissibility



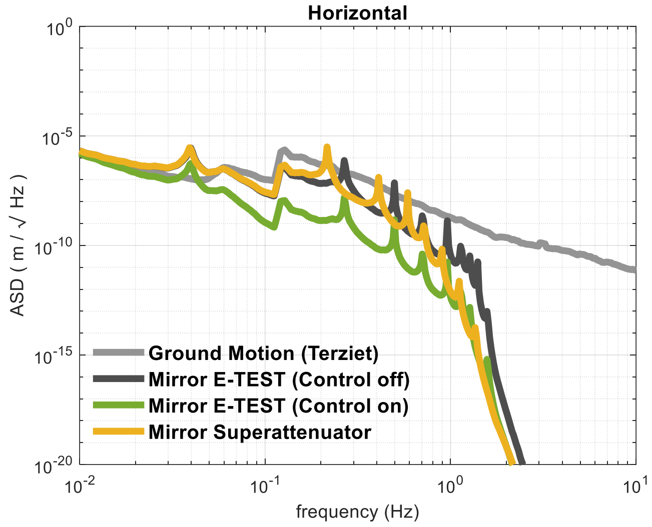


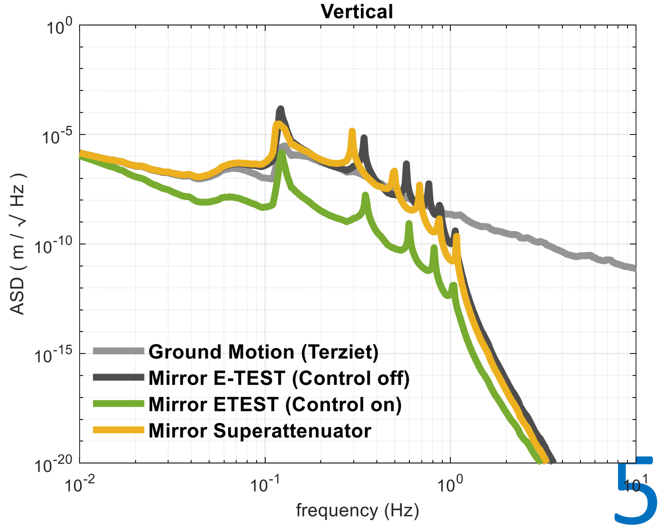
ASD – Inertial Platform





ASD – Mirror





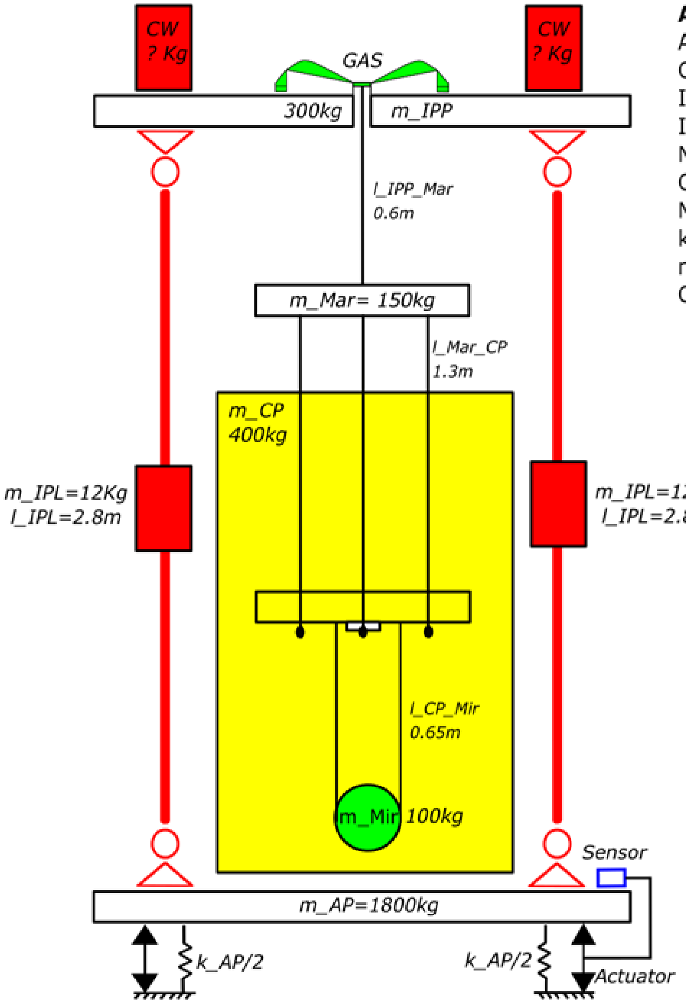
E-TEST Prototype

Features of E-TEST Project:

https://www.etest-emr.eu/

- Suspended heavy mass (about 50 kg, 300mm X 300m).
- At cryogenic temperature (20k).
- Radiative cooling strategy (no contact).
- Developing cryogenic sensors and electronics.
- Operation of the laser and optics at 2 microns.
- **Developing isolation system → concern of this presentation.**

Isolation System is a prototype (5.5m height) due to budget & vacuum limitations



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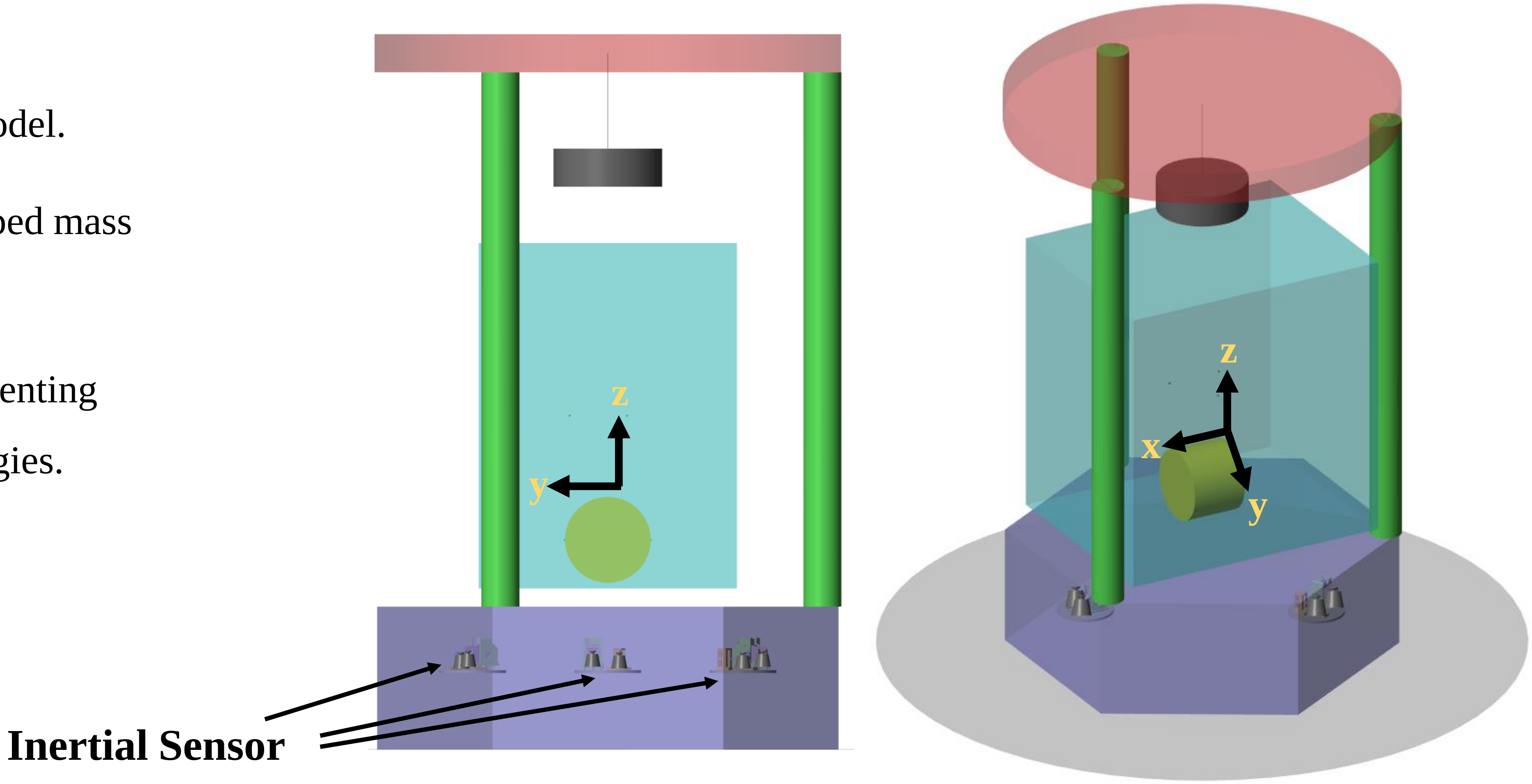
Dynamics of The Prototype in 3D
(Obtained by Simscape Simulink Toolbox (MATLAB))

Simscape:

- To build multi-body model.
- Allowing to study lumped mass systems under gravity.
- Convenient for implementing feedback control strategies.

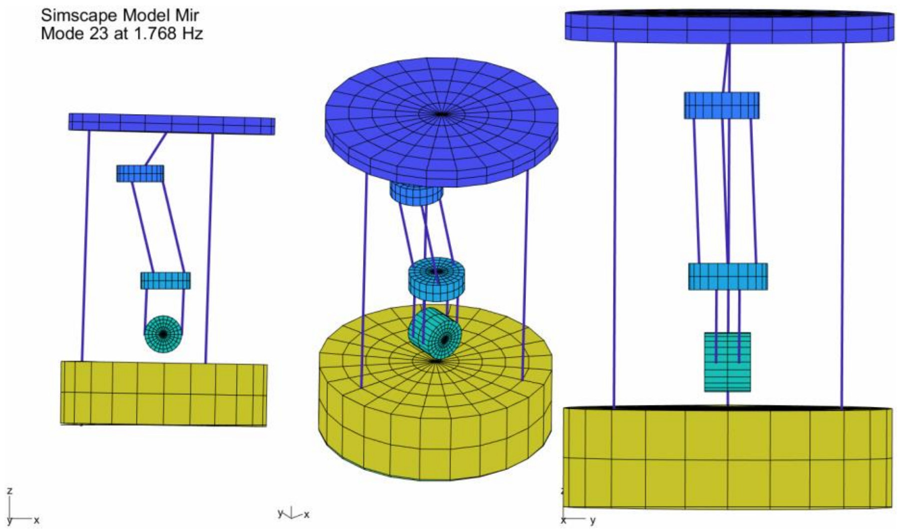


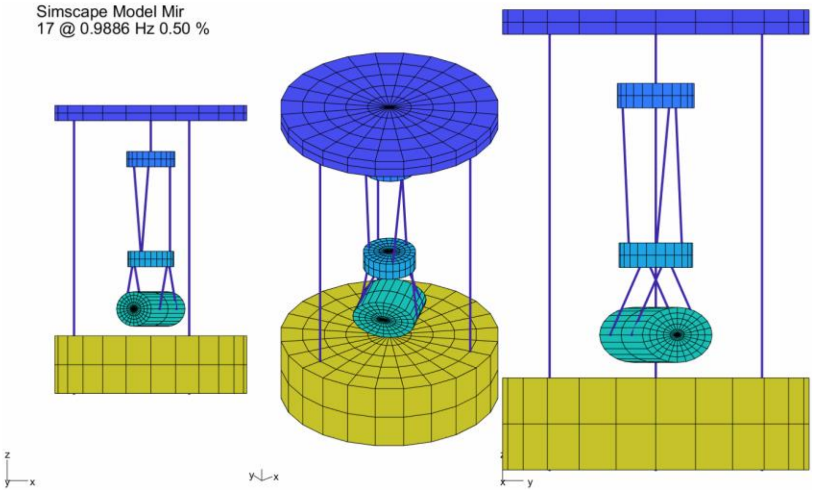
3D View of the E-TEST Simscape Model (Left: Front View) and (Right: Isometric View)

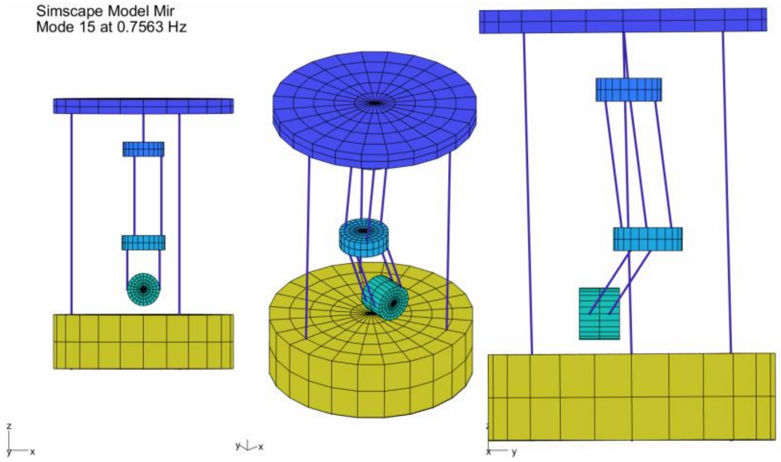
Mode Shape Visualization
(Obtained by Structural Dynamic Toolbox (SDT))

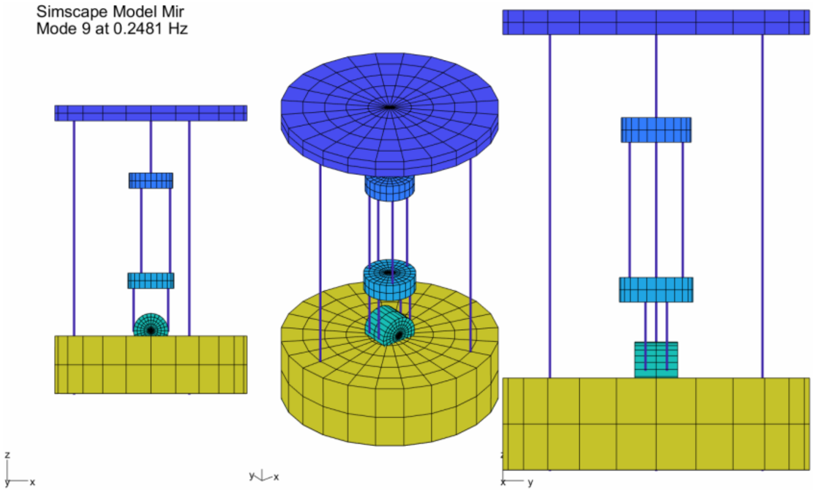
Three steps to obtain mode shapes:

1. Extraction of a state space model from Simscape.
2. Calculation of eigenvalues and eigenvectors in MATLAB.
3. Projection of these modes on a finite element representation of the system.





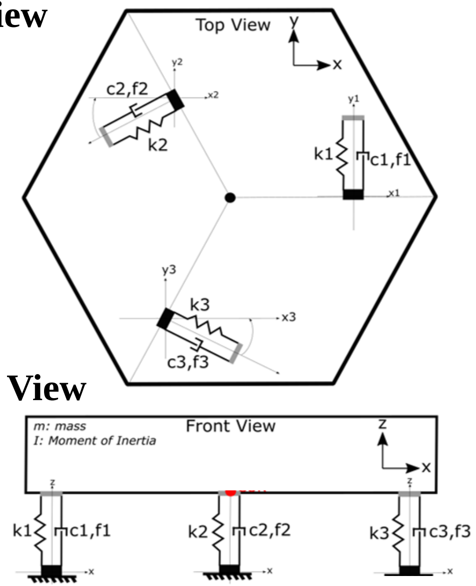


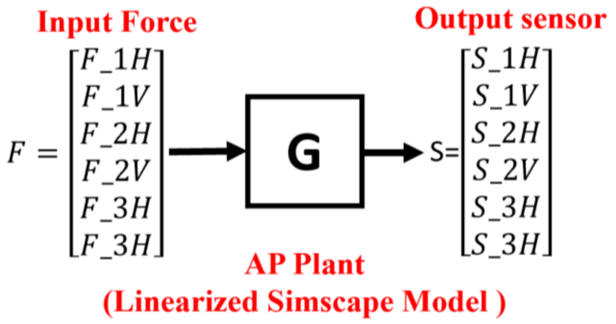


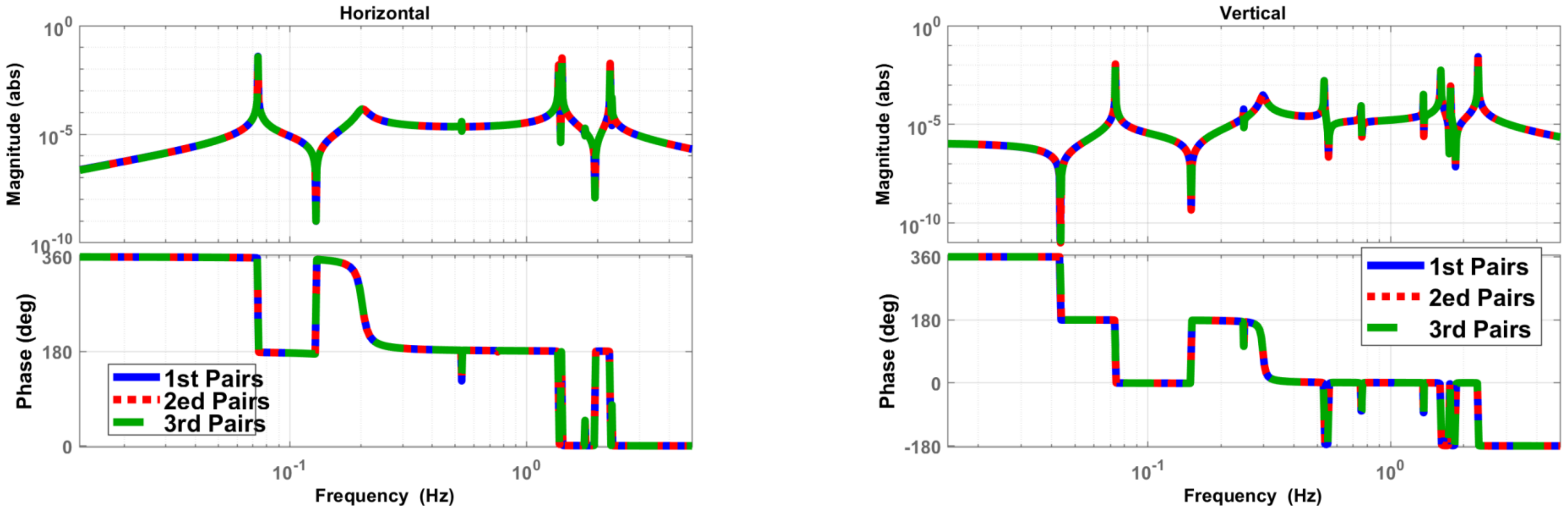
Input/Output of Active Platform of E-Test

Top View

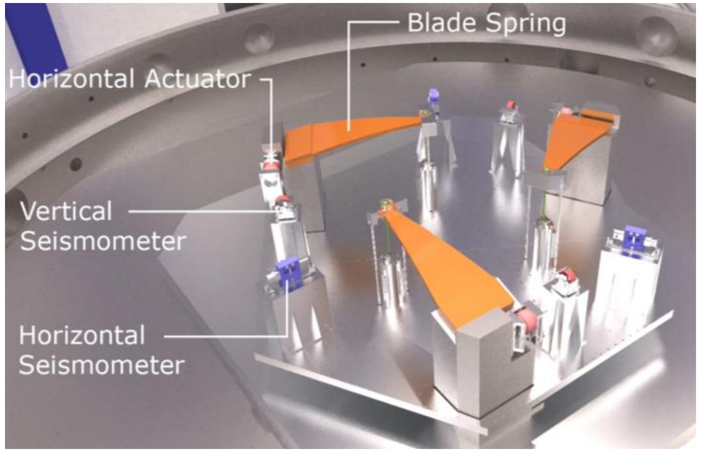
Front View





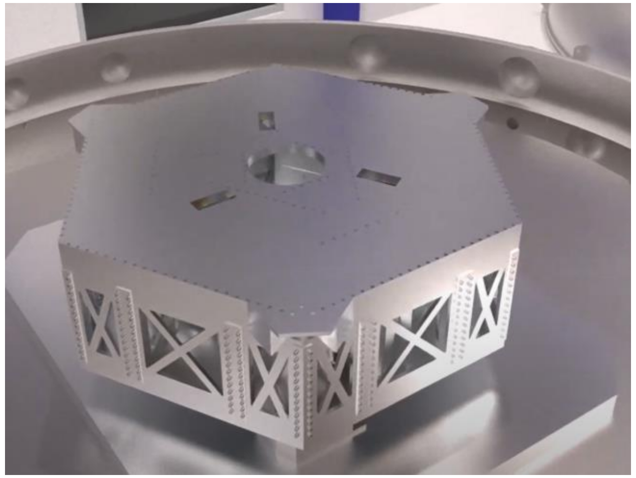


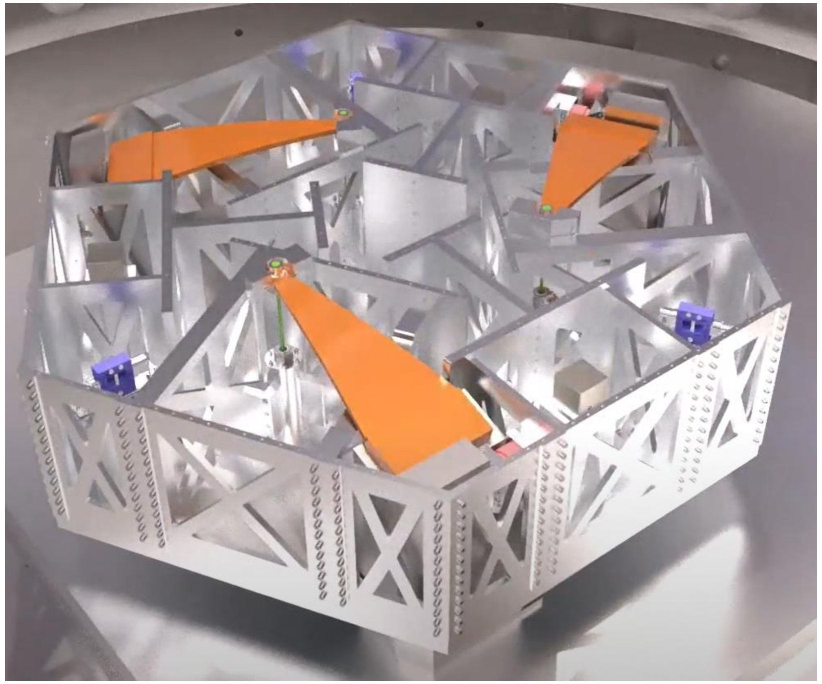
First Flexible mode of Active Platform above 300 Hz

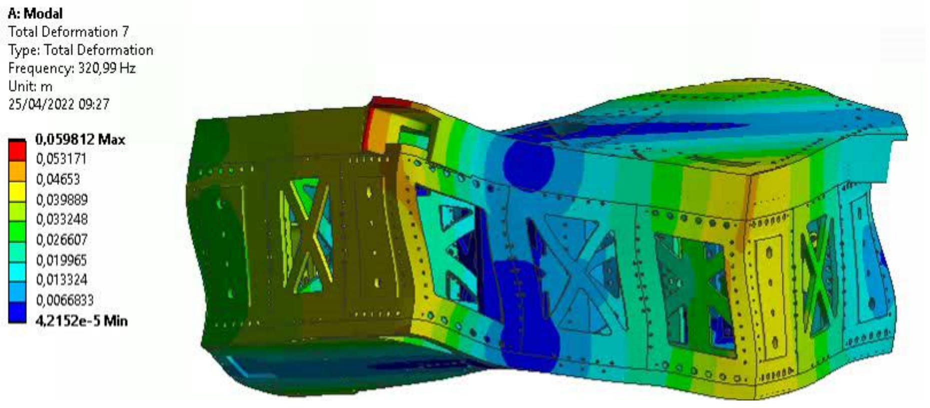


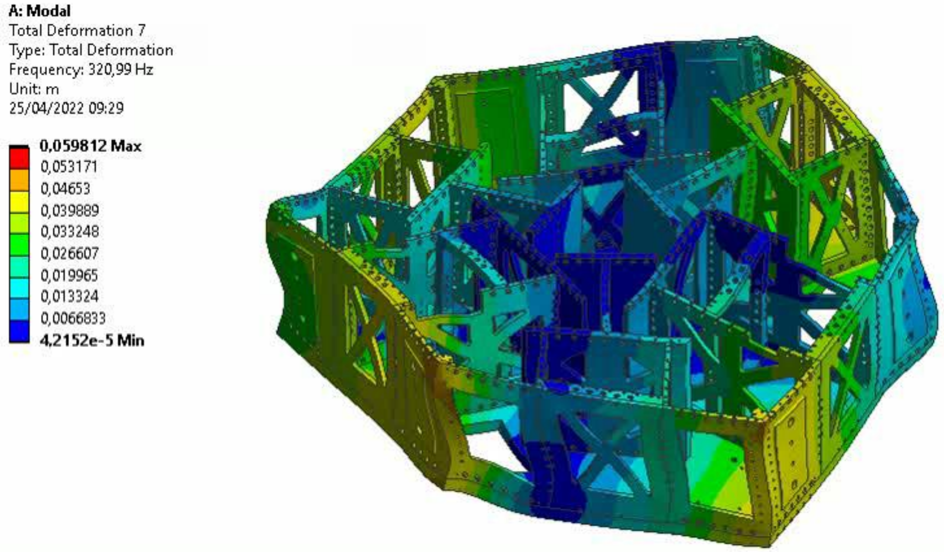
CAD Views

By Simon Roure



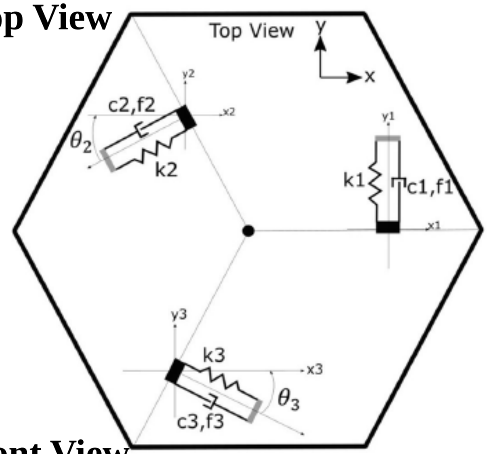




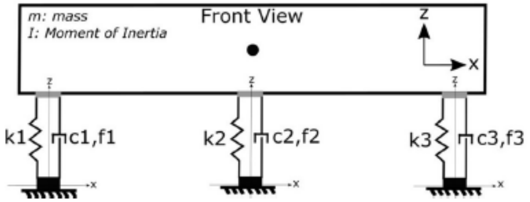


Decoupled System

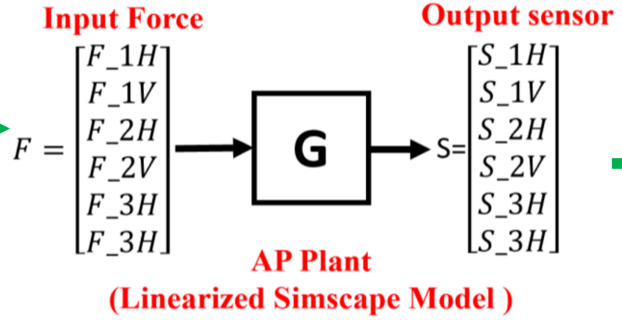
Top View



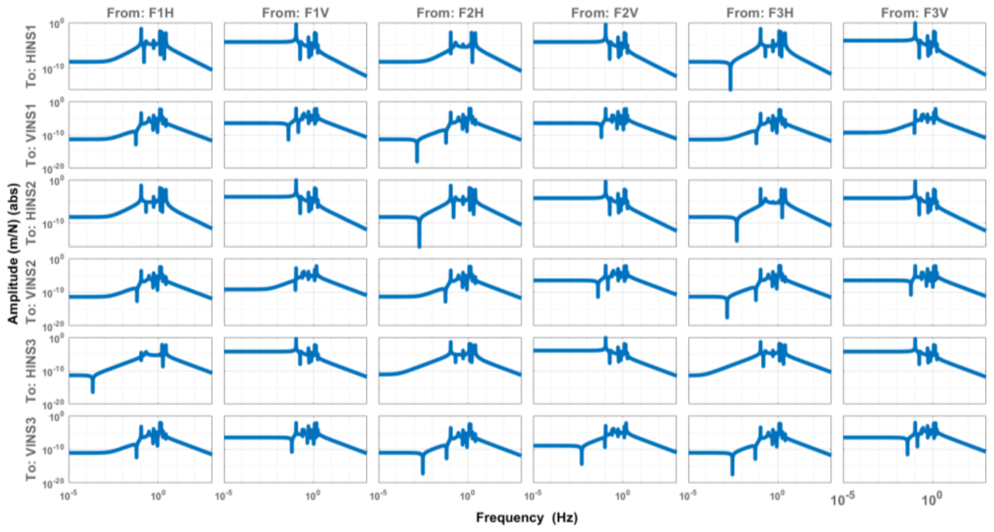
Front View



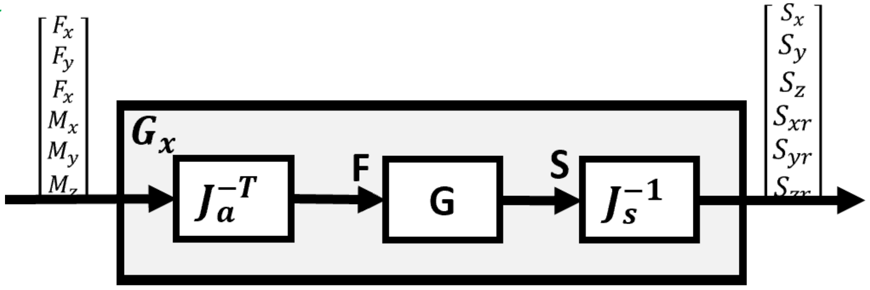
Active Platform (AP) of E-Test



Lots of off diagonal coupling

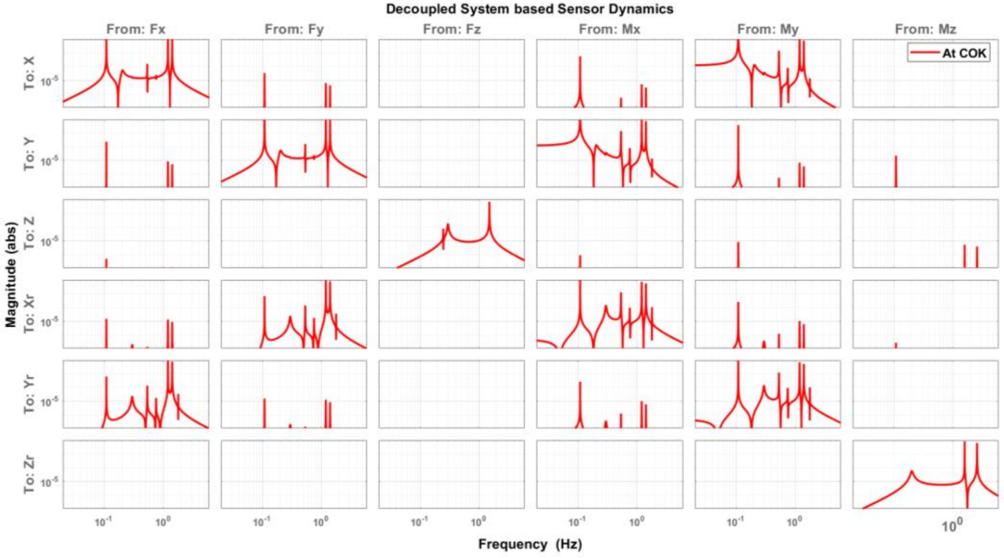


$G_x = J_s^{-1} . G . J_a^{-T}$ ......new plant



Decoupled Plant G_x based Jacobian

Few of off diagonal coupling



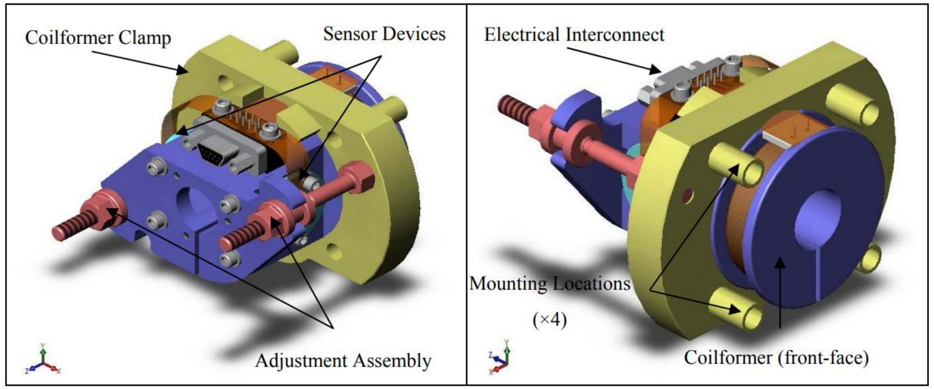
Sensors & Actuators of Inertial Platform (vacuum compatible)

- Actuator → NCCO9-39-190-1V

Same as LIGO

- Inertial sensors → Watt's Linkage

- Displacement Sensor → BOSEM



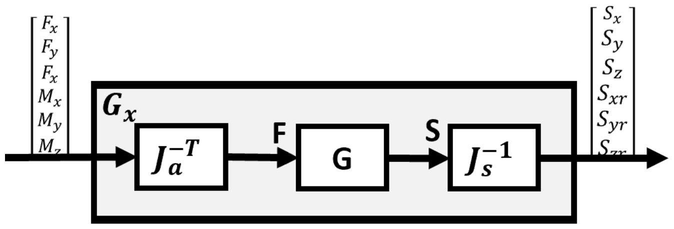
Rear isometric view

Front isometric view

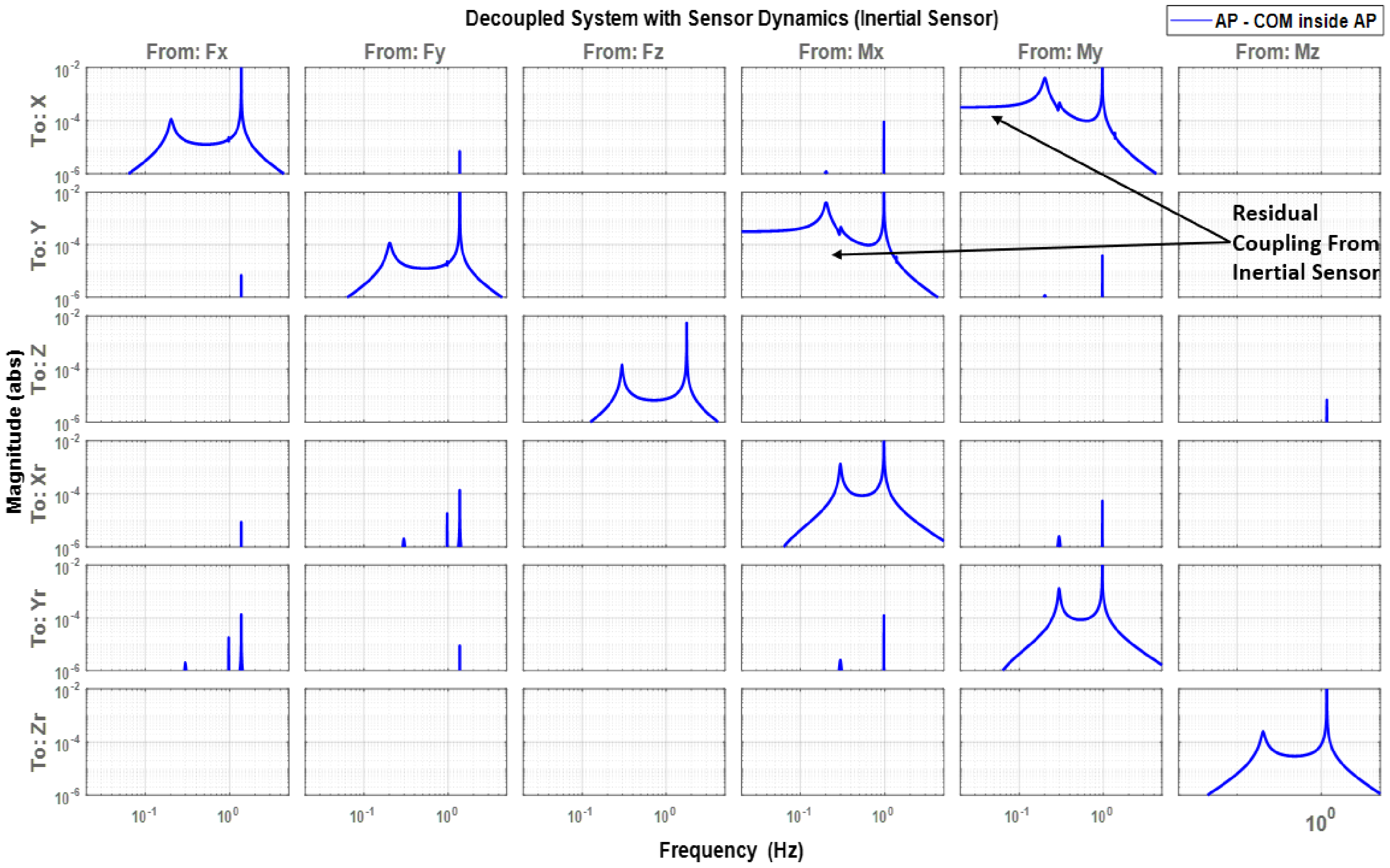
Decoupling Analysis for Active Platform alone

Ideal case → COM & COK at the Same Center

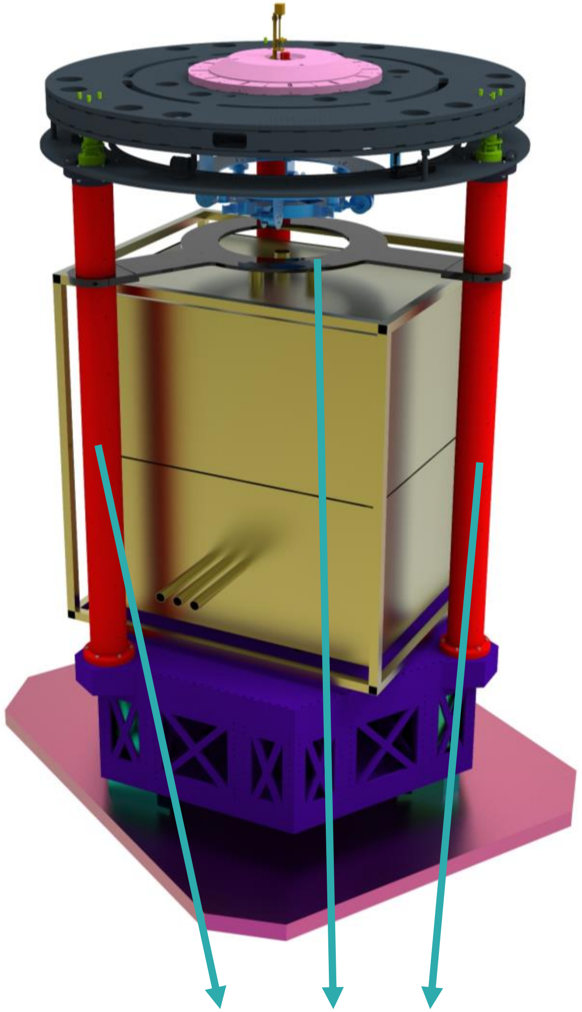
$G_x = J_s^{-1}.\, G.\, J_a^{-T}$ ......new plant



Decoupled Plant G_x based Jacobian



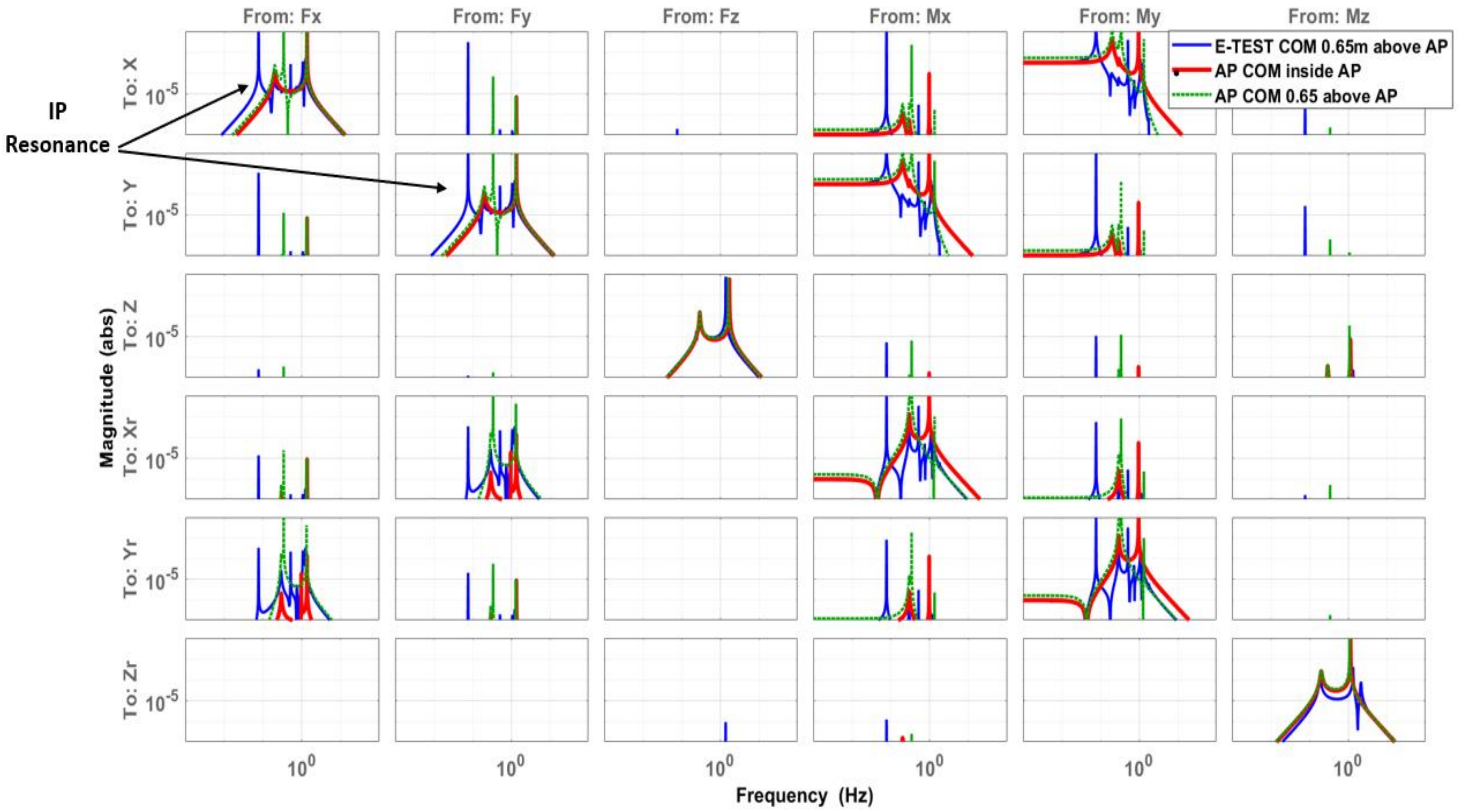
E-TEST – 3D



Safety Tubes & Support Shifts COM Outside AP

Decoupling Analysis for Entire E-TEST System

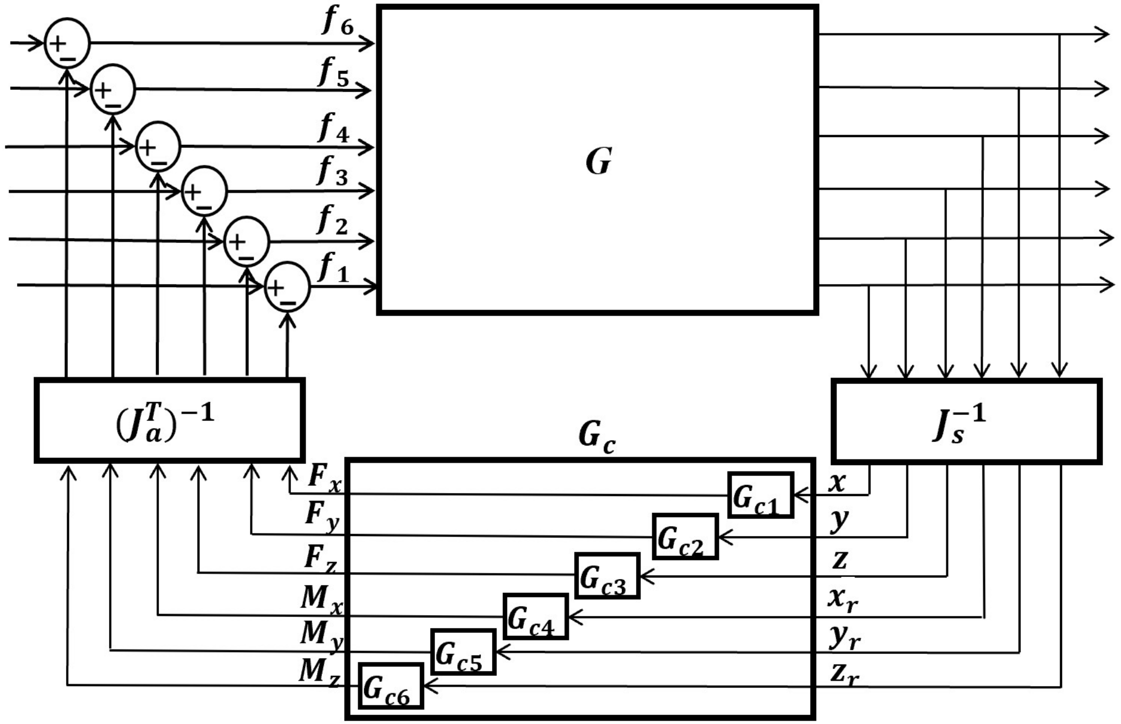
(COM outside Active Platform)

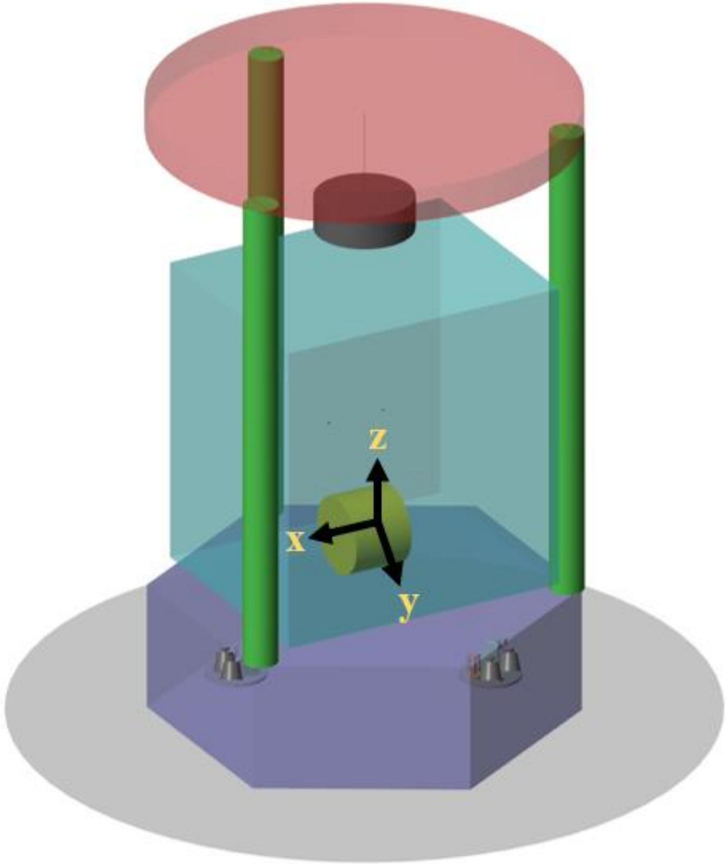


Classical Control For Entire E-TEST System

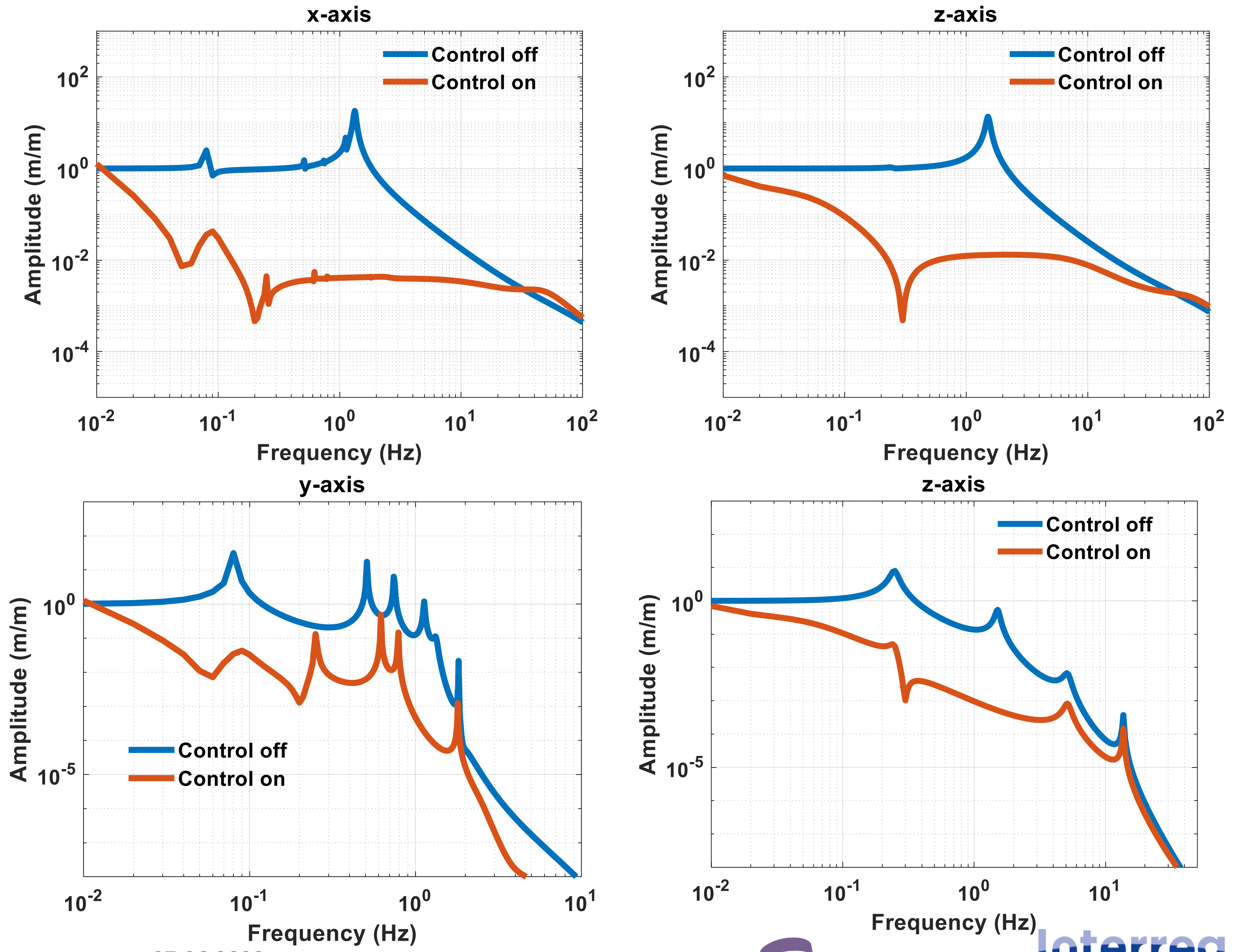
The controller is working in cartesian frame. Jacobian is used to convert forces in the cartesian frame to forces applied by the actuators.

Controllers are designed based loop shaping; lead-lag compensator

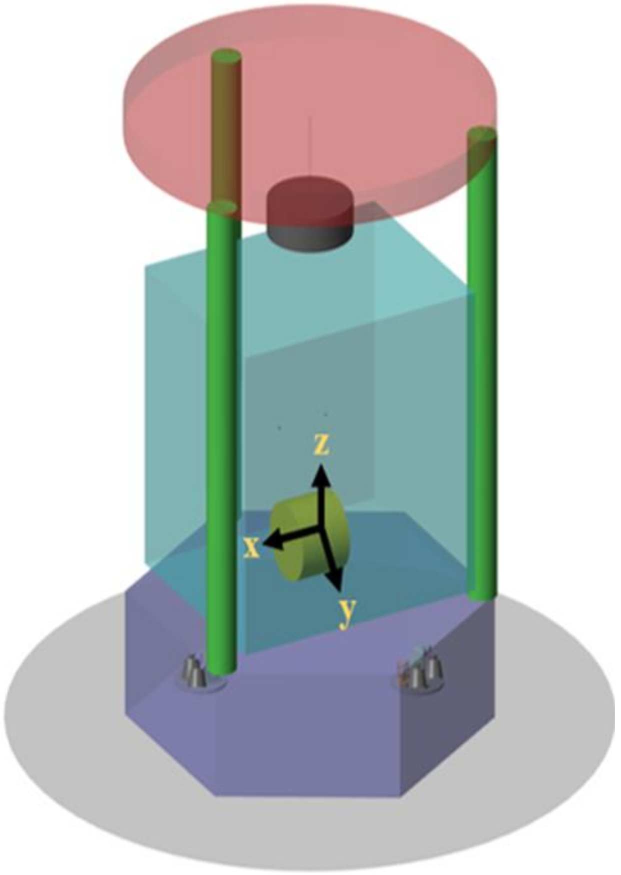




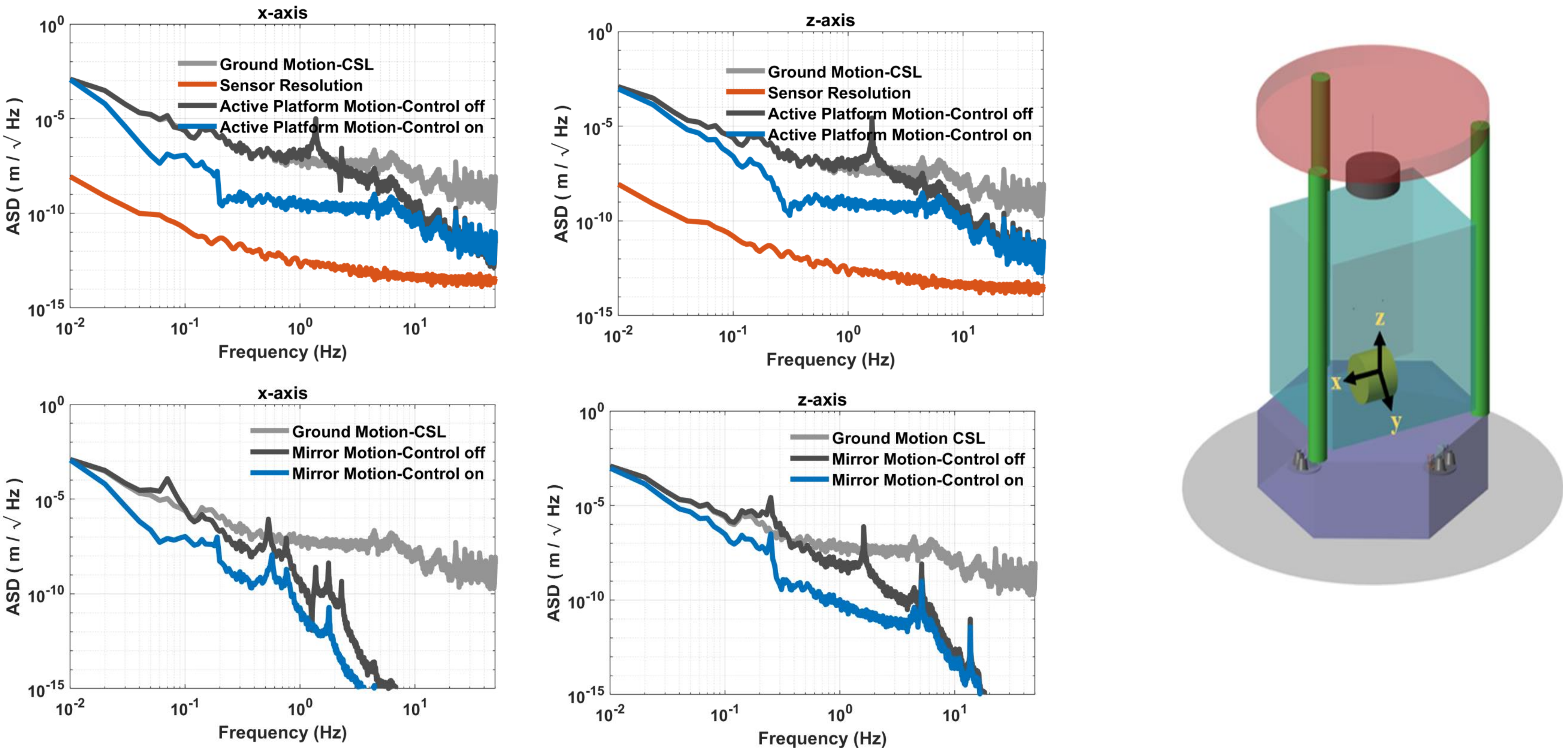
Transmissibility (AP/ ground & Mirror/ground)



Damping Control is not applied yet

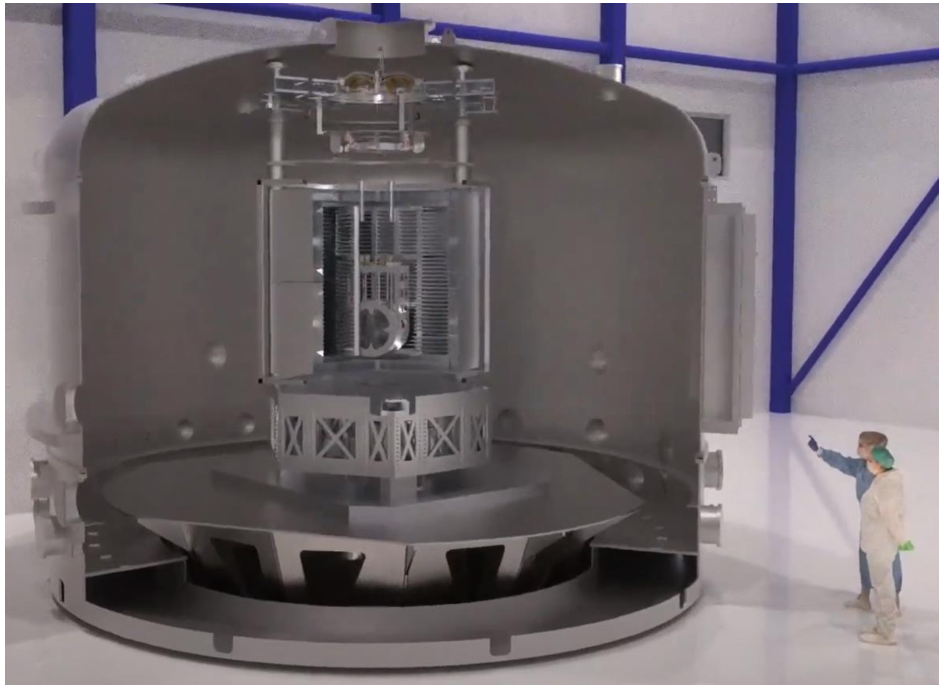


ASD (AP & Mirror)



Future Work

Activities/Years	2020	2021	2022	2023	2024
1. Literature review.					
2. Design compact isolation system.					
3. Obtain and analyze the dynamic equations of the designed isolation system.					
4. 3D design and manufacturing.					
5. Apply control strategy based SISO approach to the inertial platform of the isolation system.					
6. Apply control strategy based SISO approach to damp the resonances of the isolation masses (suspended masses).					
7. Assemble the system.					
8. Experimental Work.					
9. PhD defends.					



https://www.youtube.com/watch?v=hJgoy8Tp8wY

The End

Thank you!

References

1. Matichard, F., et al., *Advanced LIGO two-stage twelve-axis vibration isolation and positioning platform. Part Experimental investigation and tests results*. 2015. **40**: p. 287-297.

2. Michimura, Y., Shimoda, T., Miyamoto, T., Shoda, A., Okutomi, K., Fujii, Y., ... & Yuzurihara, H. (2017). Mirror actuation design for the interferometer control of the KAGRA gravitational wave telescope. *Classical and Quantum Gravity*, *34*(22), 225001.

3. Accadia, T., et al., *The seismic Superattenuators of the Virgo gravitational waves interferometer*. 2011. **30**(1): p. 63-79.

E-TEST Einstein Telescope EMR Site & Technology

The Financiers

Interreg Euregio Meuse-Rhine — European Union

Wallonie

Vlaams-Brabant

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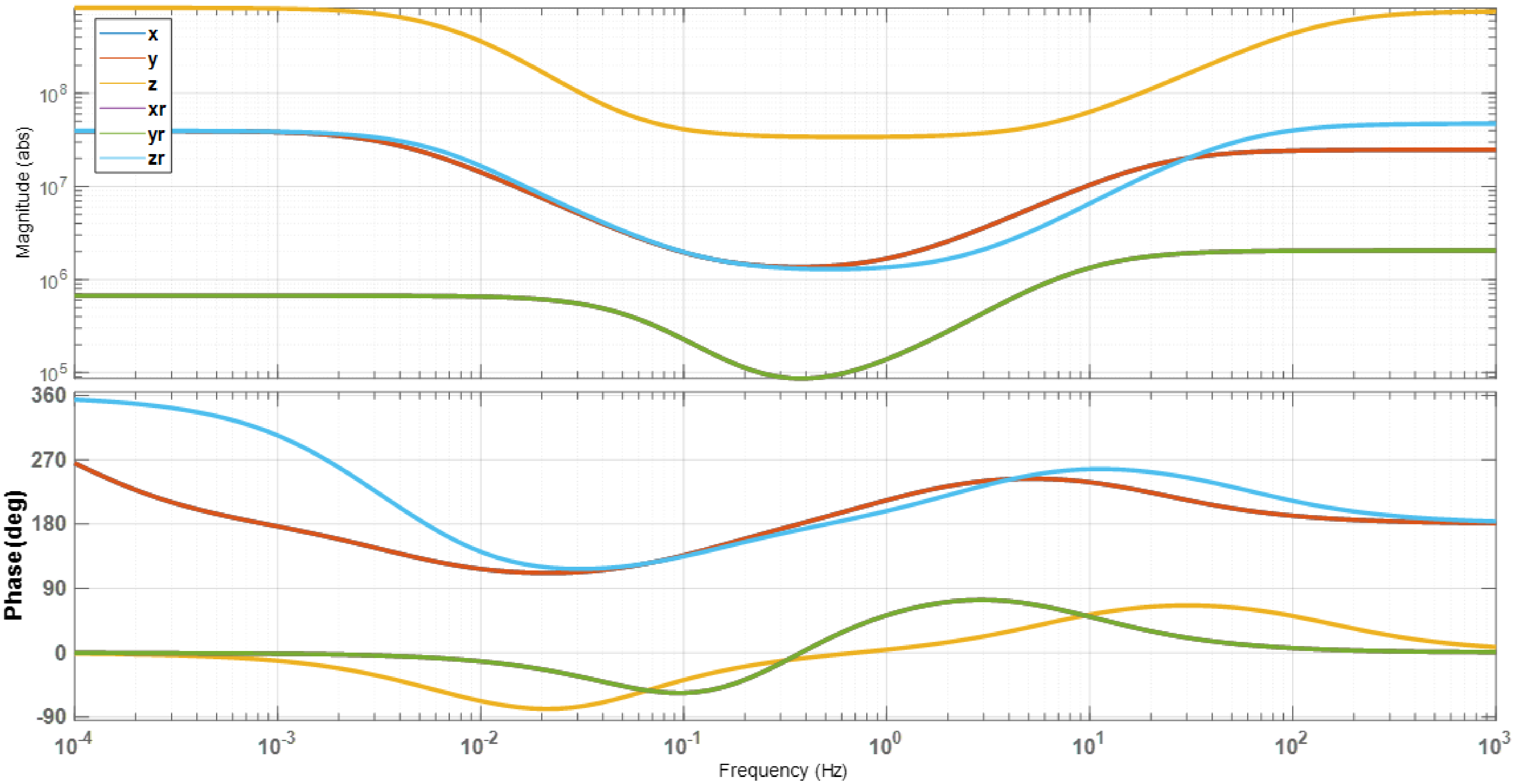
Controller



x
y
z
xr
yr
zr
Magnitude (abs)
10^8
10^7
10^6
10^5
Phase (deg)
360
270
180
90
0
-90
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
Frequency (Hz)