Vibration attenuation system for a cryogenic Coating Thermal Noise measurement

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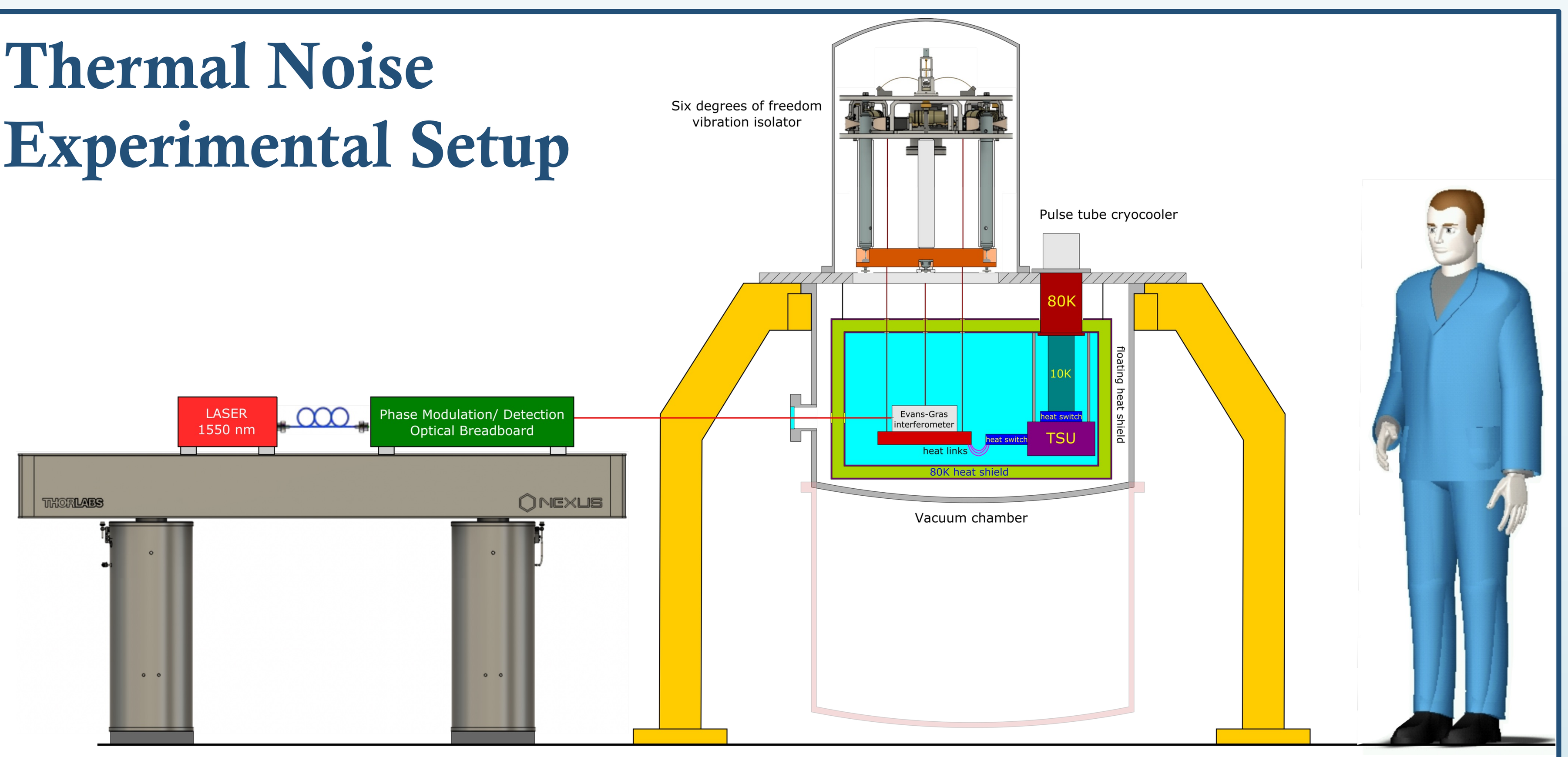
Motivation & goals

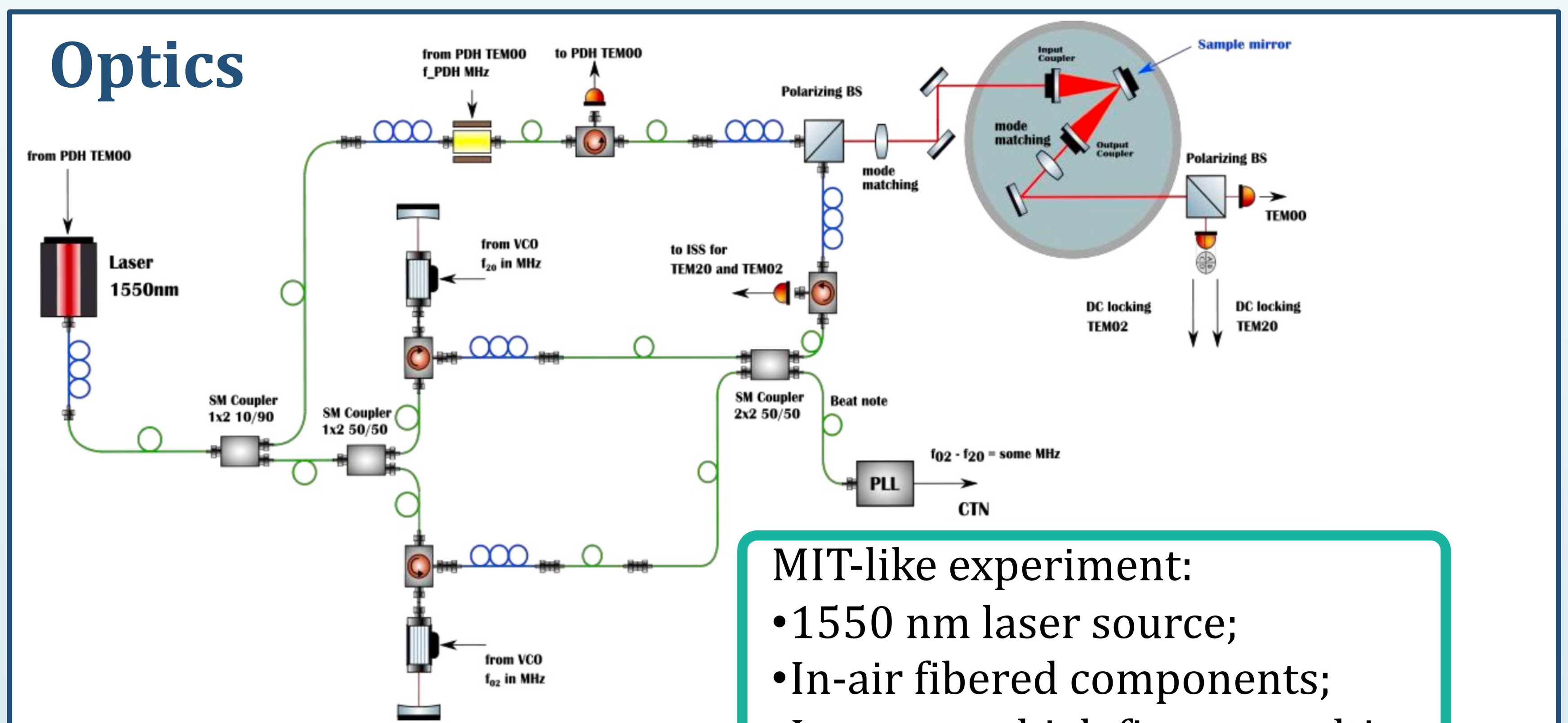
- Major improvements in GW instrumentation science are expected from the Thermal Noise (TN) reduction in the mid-frequency range of the detectors, achievable also by cooling down the mirrors to cryogenic temperature. In order to select the coating material that are intended to be used in the 3rd generation of detectors, the TN of new coatings should be directly measured using an interferometric method in a cryogenic environment.
- Reduction of local control noise in cryogenic 3rd gen. detectors requires new sensors and actuators compatible with low temperature environment. A low noise fast turn around cryogenic test bench would be essential.
- Liquid free low noise cryogenics is more and more required in many fields of fundamental physics. R&D on new low noise technology is of wide interest.

➡ A cryogenic optical bench with $\sim 10^{-13}\ \mathrm{m}/\sqrt{\mathrm{Hz}}$ residual motion above **30 Hz**.

Thermal Noise Experimental Setup



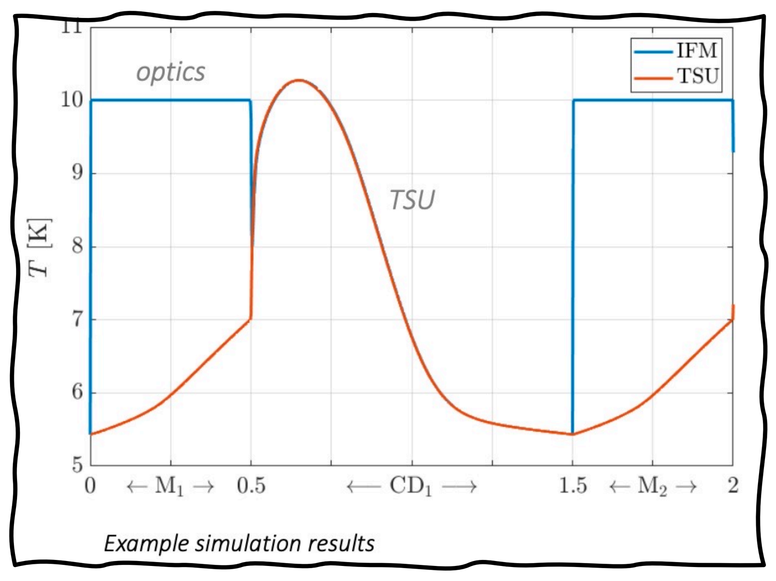
Optics



MIT-like experiment:
- 1550 nm laser source;
- In-air fibered components;
- In-vacuum high finesse multi-resonant folded cavity

Cryogenics

- **Dual stage cryocooler (CC)** to cool the heat-shields (80 K and 4 K) and to charge a **Thermal Storage Unit (TSU)**.
- **Ultra-pure Aluminum low stiffness wires heat links**.
- **CC off during the measurement** to avoid vibrations, **TSU used as a heat sink**.



➡ **0.5 hour quiet condition to make measurement.**

Mechanics

- Vibrations and thermal isolation: the optical bench is suspended by means of three titanium wires.
- Vertical & Tilt vibration isolation: each wire is connected to a pair of blade springs in Geometric Anti Spring (GAS) configuration located on the top platform. All three rigid body modes below **0.3 Hz**.
- Horizontal isolation: Three inverted pendulum (IP) legs support the top platform. Translational modes at **~0.1 Hz** and the yaw mode **at 0.5 Hz.**

Sensors and Actuators

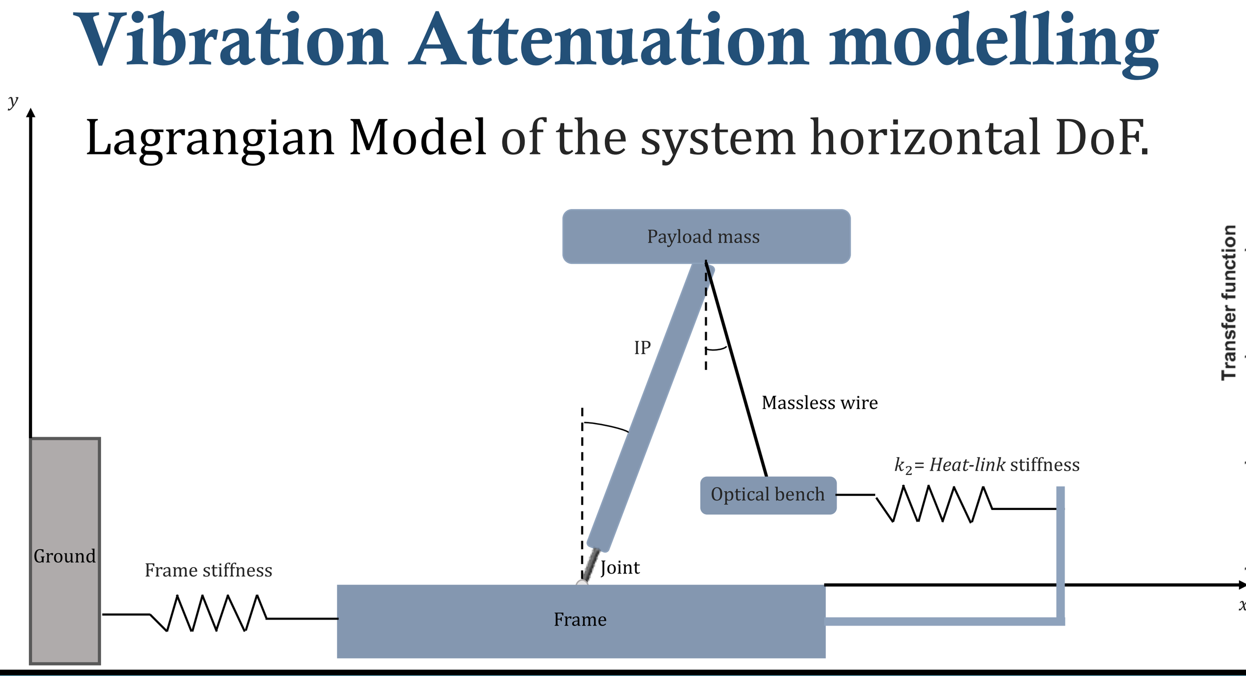
- Three horizontal and three vertical LVDT displacement sensors at the top platform level.
- Tri-axial seismometer "Trillium 120" at the center of the top platform inside a vacuum pod.
- Three Maxwell-pair actuators collocated to the horizontal LVDTs.
- Three voice-coil actuators collocated to the vertical LVDTs.

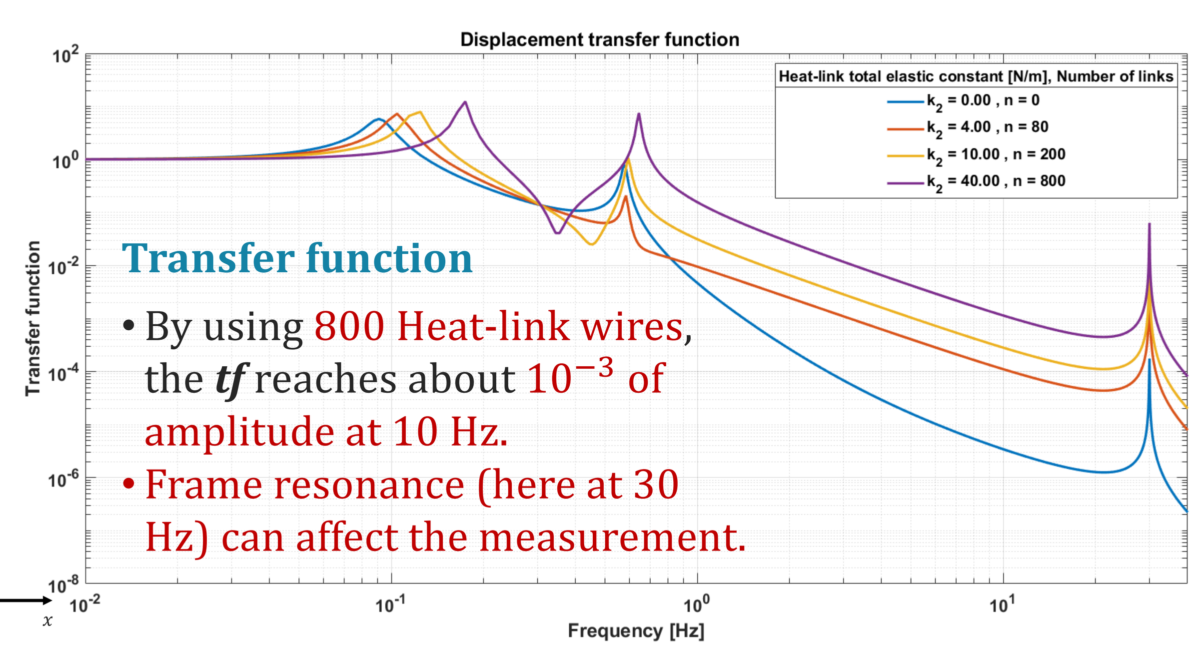
Control strategy

- NO sensors and actuators inside the cryostat.
- Horizontal DoFs controlled by a super-sensor LVDT+Seismometer.
- Yaw DoF controlled only by LVDTs.
- Vertical, Pitch and Roll controlled by sensor corrected LVDTs.

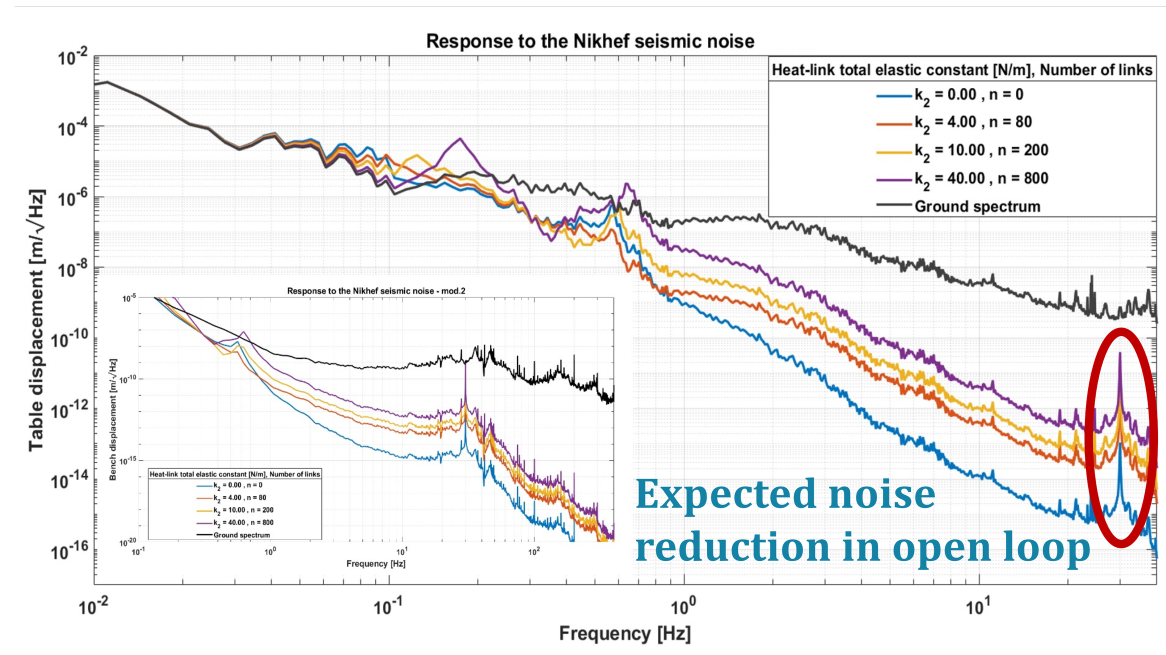
Vibration Attenuation modelling

Lagrangian Model of the system horizontal DoF.





Transfer function
- By using 800 Heat-link wires, the ***tf*** reaches about 10^{-3} of amplitude at 10 Hz.
- Frame resonance (here at 30 Hz) can affect the measurement.

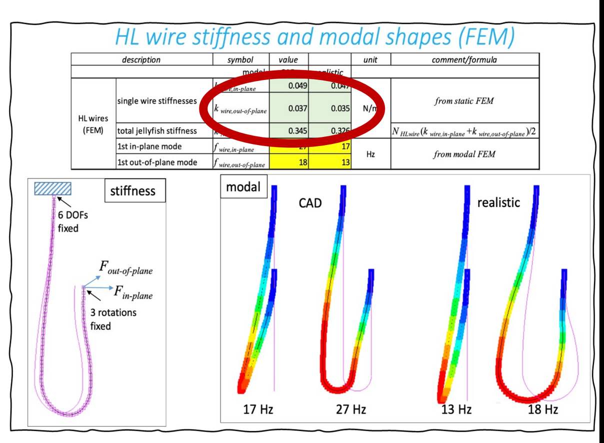


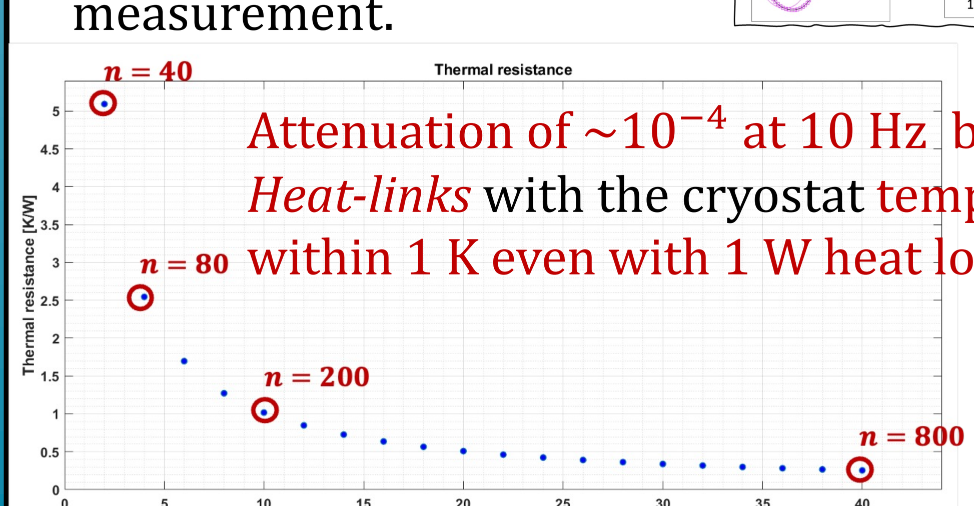
Expected noise reduction in open loop

Heat-links Stiffness and Thermal Resistance

Two competing requirements

- Thermal resistance should be minimized.
- Stiff heat-links can spoil the measurement.

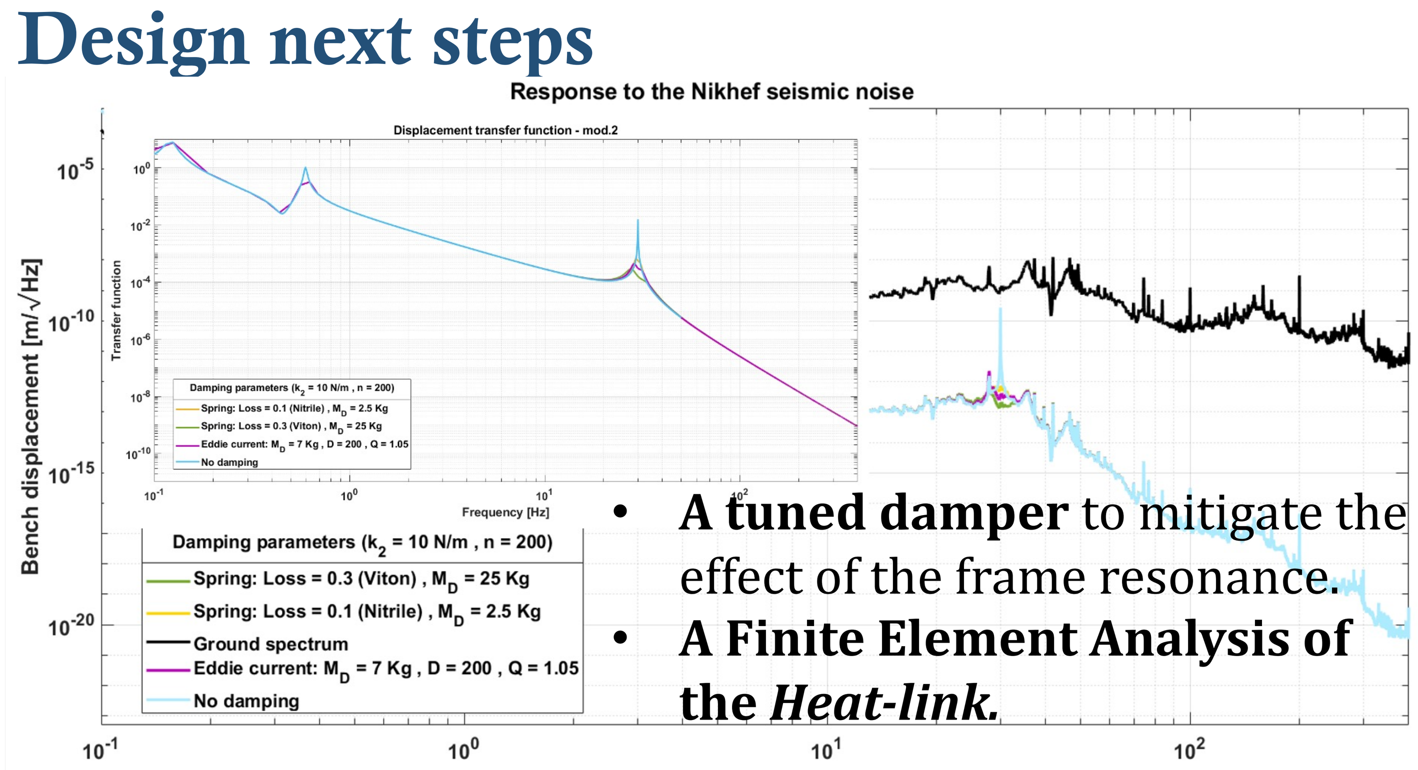




Attenuation of $\sim 10^{-4}$ at 10 Hz by using ~200 *Heat-links* with the cryostat temperature within 1 K even with 1 W heat load.

Parameters	
Thermal conductivity $\chi(10\ \mathrm{K})$	$20000\ \frac{\mathrm{W}}{\mathrm{m \cdot K}}$ (KAGRA)
Linear elastic constant k_2	0.05 N/m

Design next steps



- **A tuned damper** to mitigate the effect of the frame resonance.
- **A Finite Element Analysis of the *Heat-link*.**

Conclusion

Using **200 *heat-links*** seems the best compromise up to now:

- **Vibration attenuation @ 10 Hz: ~3000**
- $R_T = \frac{l}{\chi s n} \approx 1\ \frac{\mathrm{K}}{\mathrm{W}}$ **@ 10 K**
- $\Delta T_{bench-battery}$ **~1 K even by applying 1 W of power.**

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