Sensing and Control of Suspended Optics Breadboard in Crackle2 Experiment

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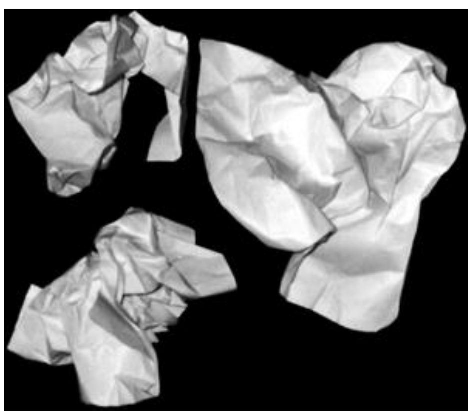
Outline

- Introduction
  - » What is Crackling noise?
  - » How to measure Crackling noise?
- Problem statement
- My work:
  - » Experimental setup
  - » Control system design:
    - – Sensing
    - – Experimental characterization of mechanical response
    - – Analytical model
    - – Damping filter design
    - – Characterization of damping system
- Conclusion

What is Crackling Noise?

- **"Crackling noise arises when a system responds to changing external conditions through discrete, impulsive events spanning a broad range of sizes."** [1]
  - » [1]James P. Sethna et. al., "Crackling noise", *Nature*
- In this case:
  - » Direction of stress: vertically downwards
  - » Change in external conditions? Seismic noise!
- Paper crackles
- Barkhausen noise in magnets



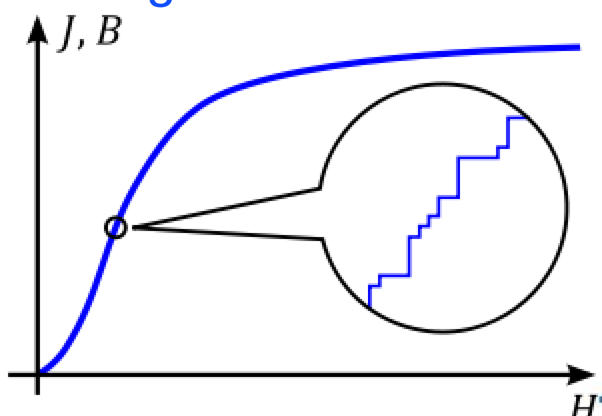
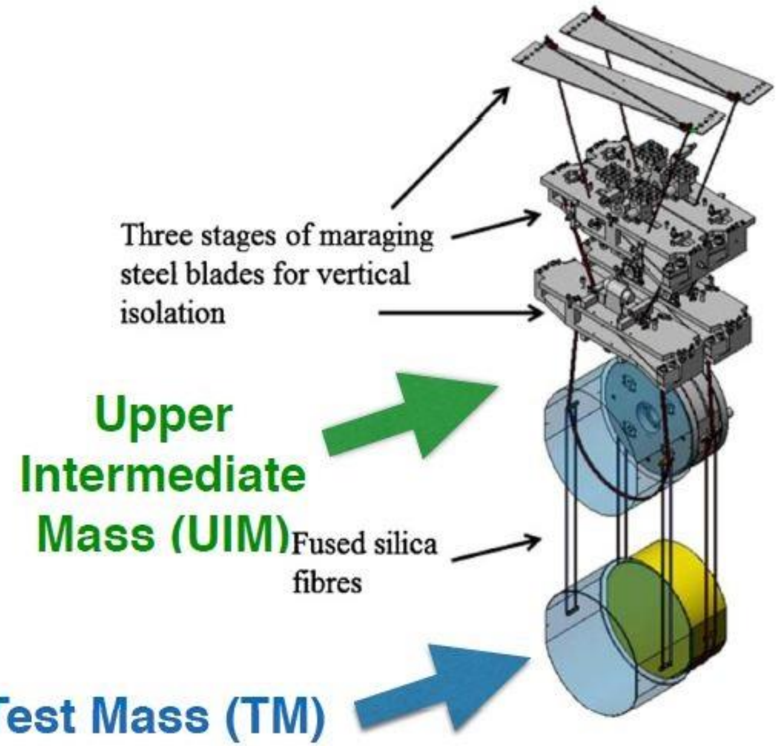
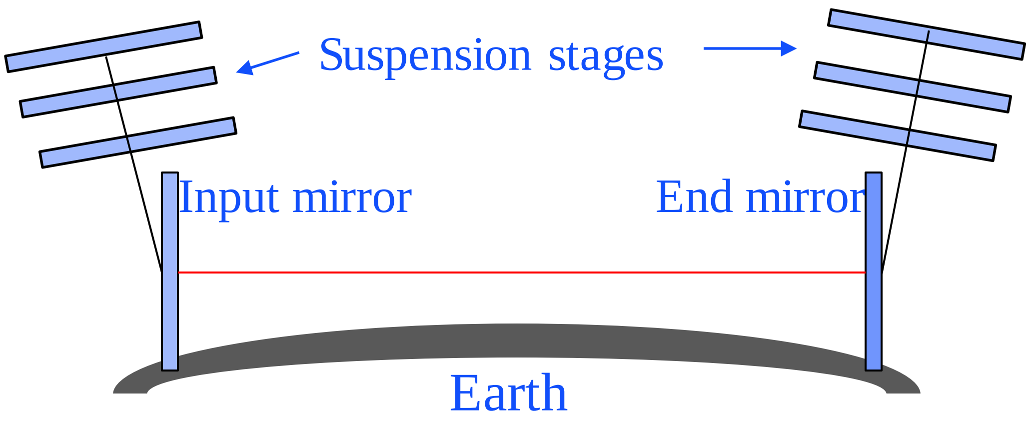


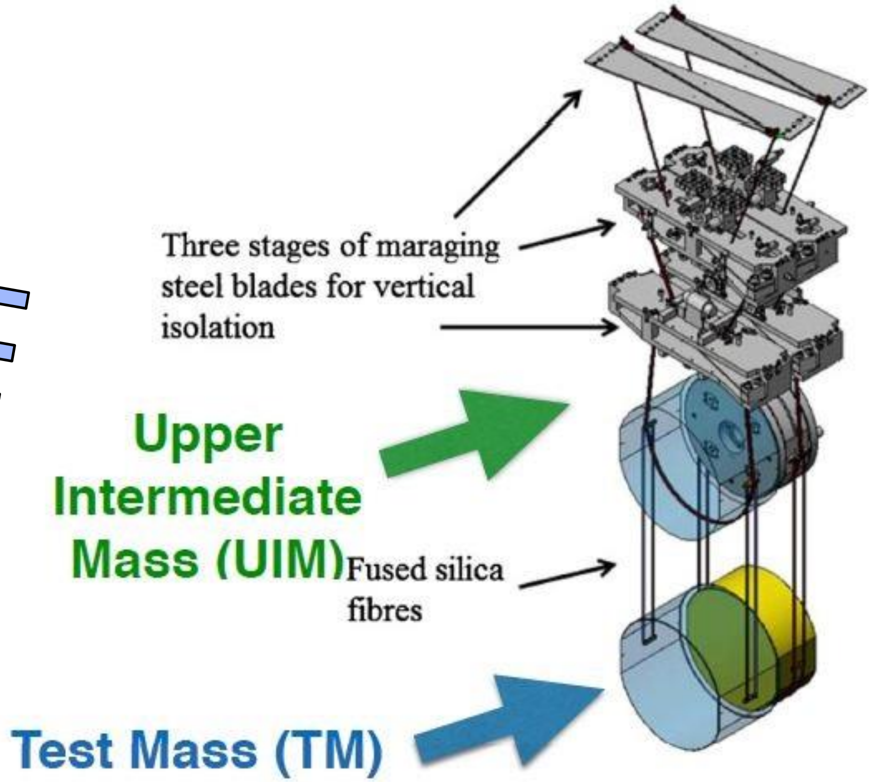
Image: www.en.wikipedia.org



Why do we care?

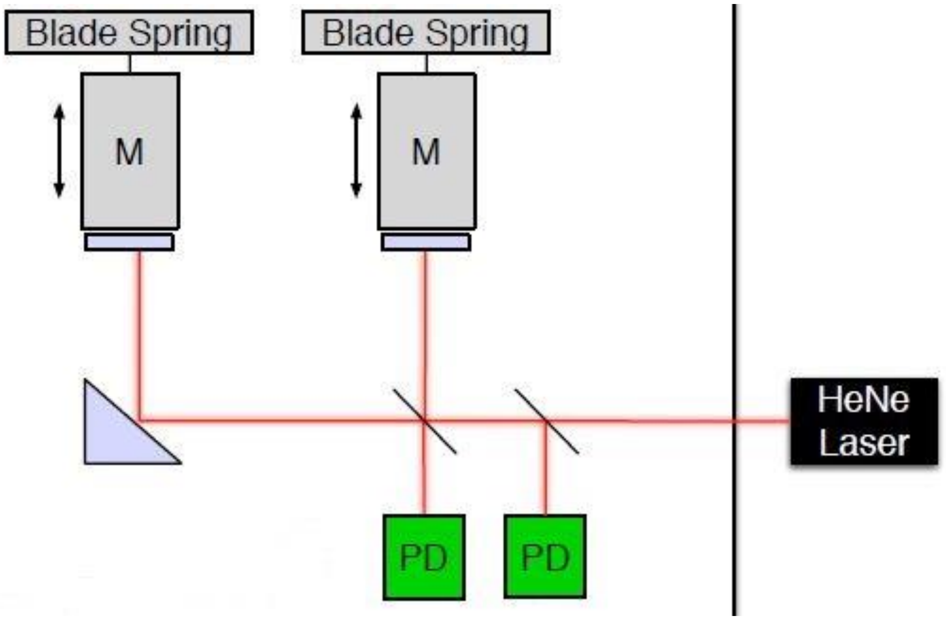
- Displacement noise arising in maraging steel blades due to “crackle” events excited by seismic motion





How to measure Crackling noise?

- “Vertical” Michelson interferometer configuration to measure vertical displacement noise
- “Crackle” events occur incoherently in each blade => differential displacement



But…

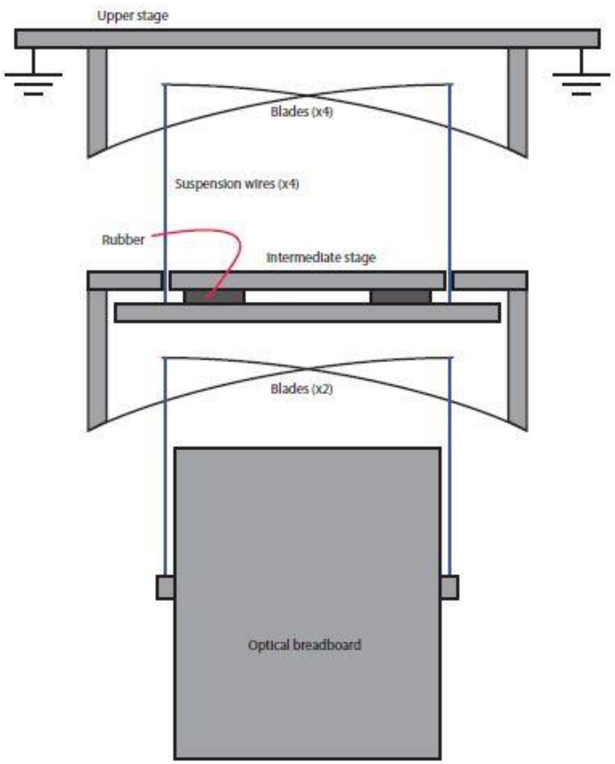
- Seismic noise
- Acoustic noise
- (Laser) Intensity noise
- Shot noise
- ADC noise
- Sensor dark noise

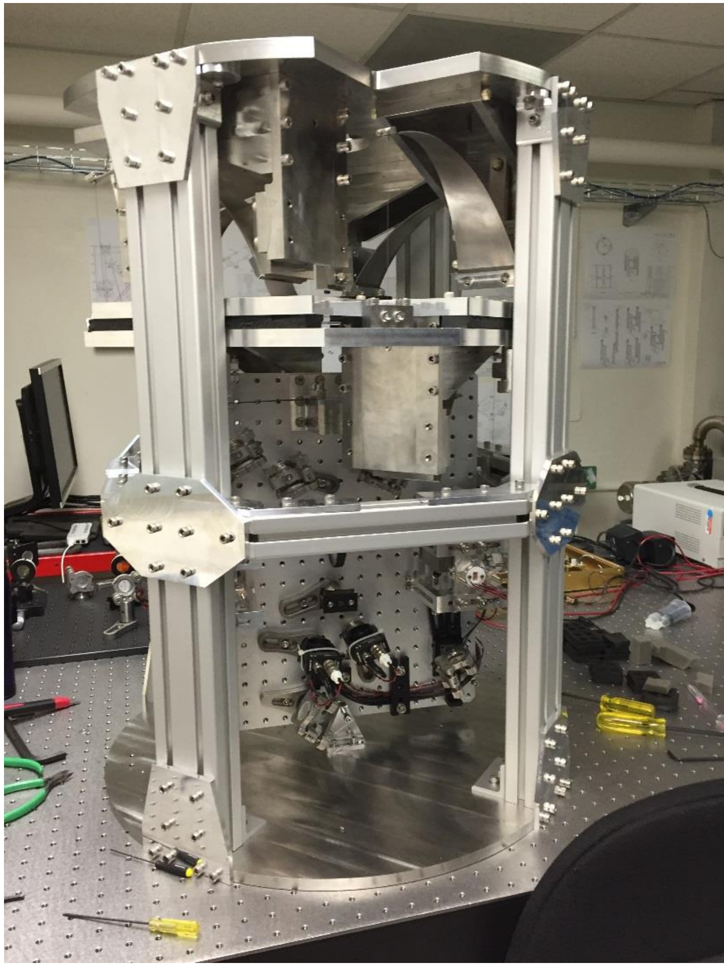
Seismic noise

- Differential displacement due to seismic noise and “asymmetry” in the system -> Bad!

- Seismic isolation scheme:
  - » Two-stage suspension
  - » “Floating” table

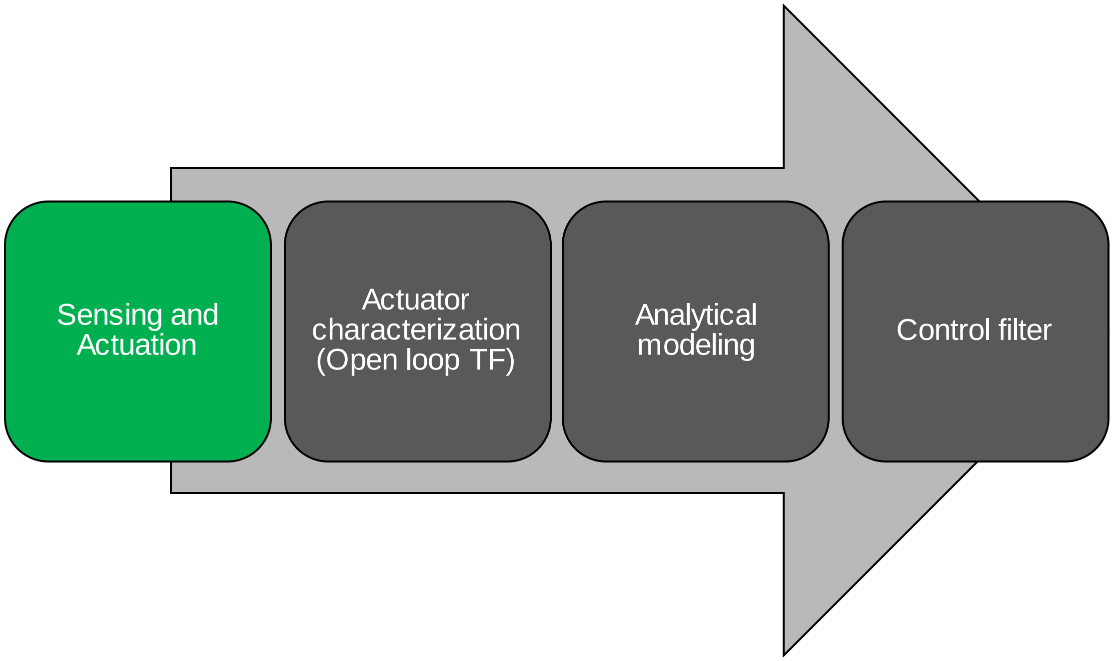
- Two-stage suspension introduces new resonances: double pendulum!





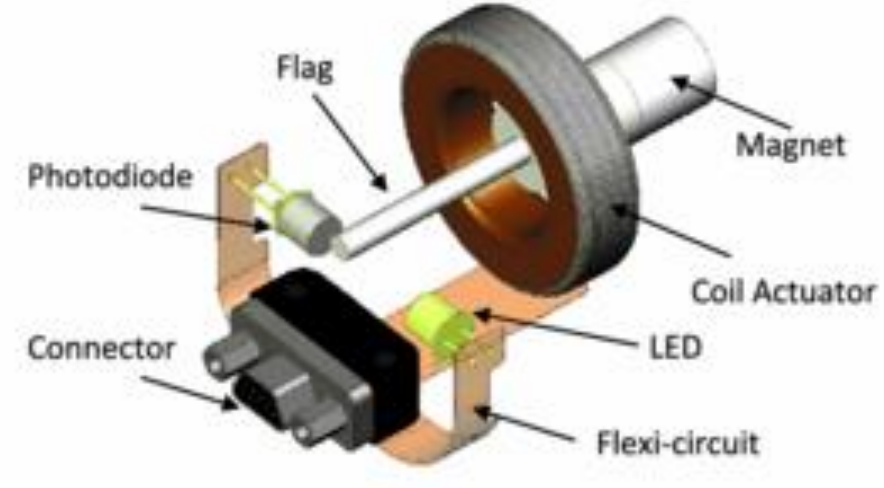
Problem statement

Design and implement a feedback damping system for the suspended breadboard.

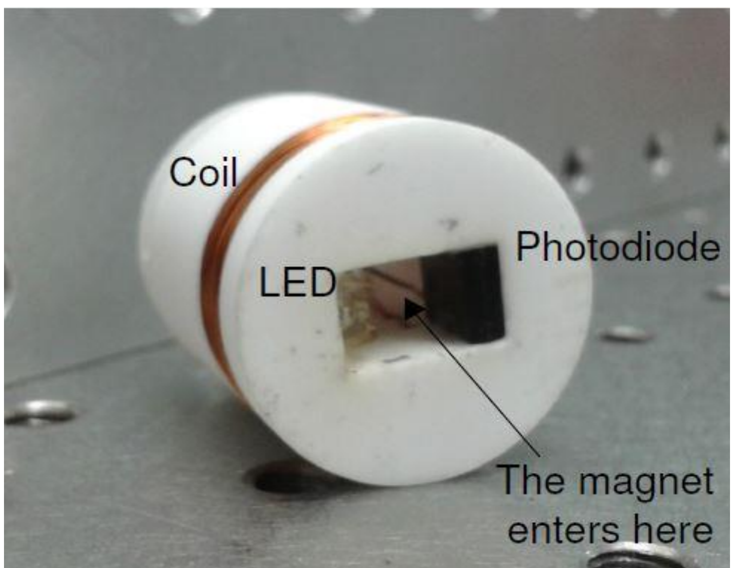


Sensing and Actuation: OSEM

- OSEM: Optical Shadow Sensor ElectroMagnetic Actuator
- A device capable of both sensing and actuation:
  - » Shadow sensing
  - » F=mB actuation

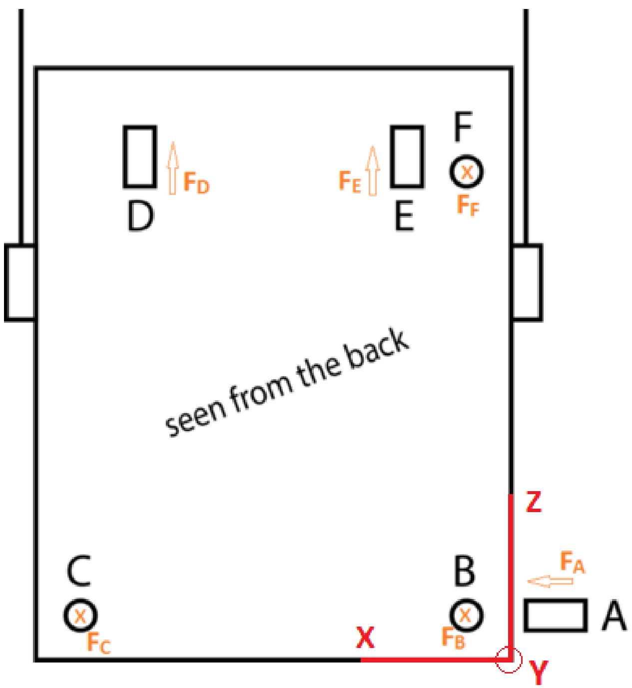


Credits: **L Carbone[1], S M Aston[1] et. al.**, "Sensors and actuators for the Advanced LIGO mirror suspensions", *IOP Science*



Sensing and Actuation: Transformation Matrices

- Sensing and driving in physical d.o.f. requires transformation matrices

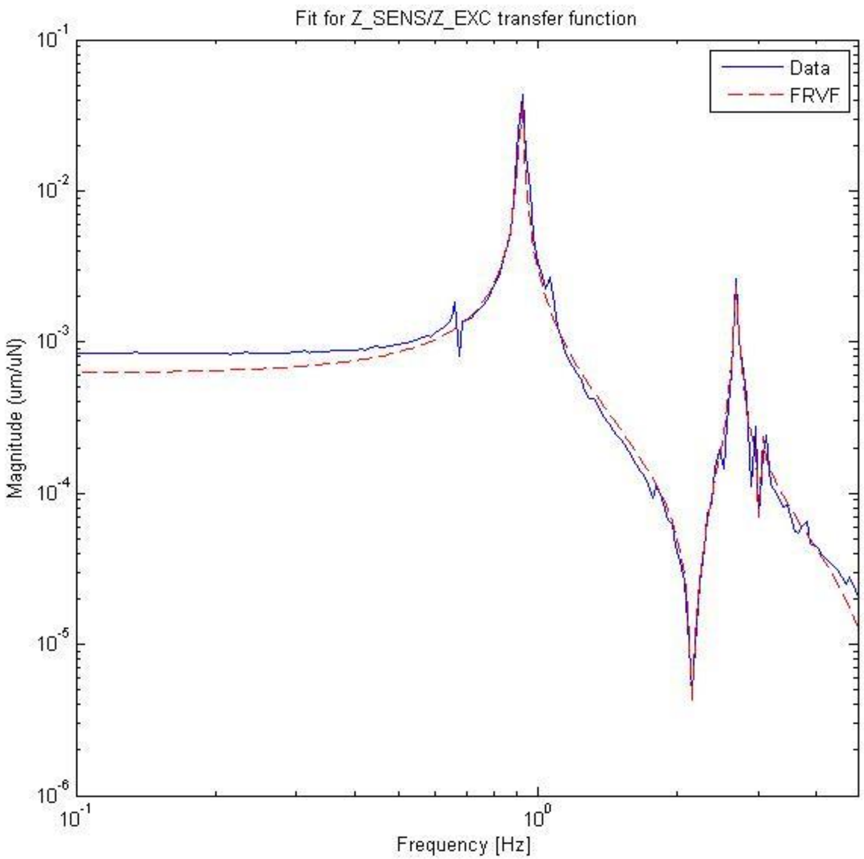


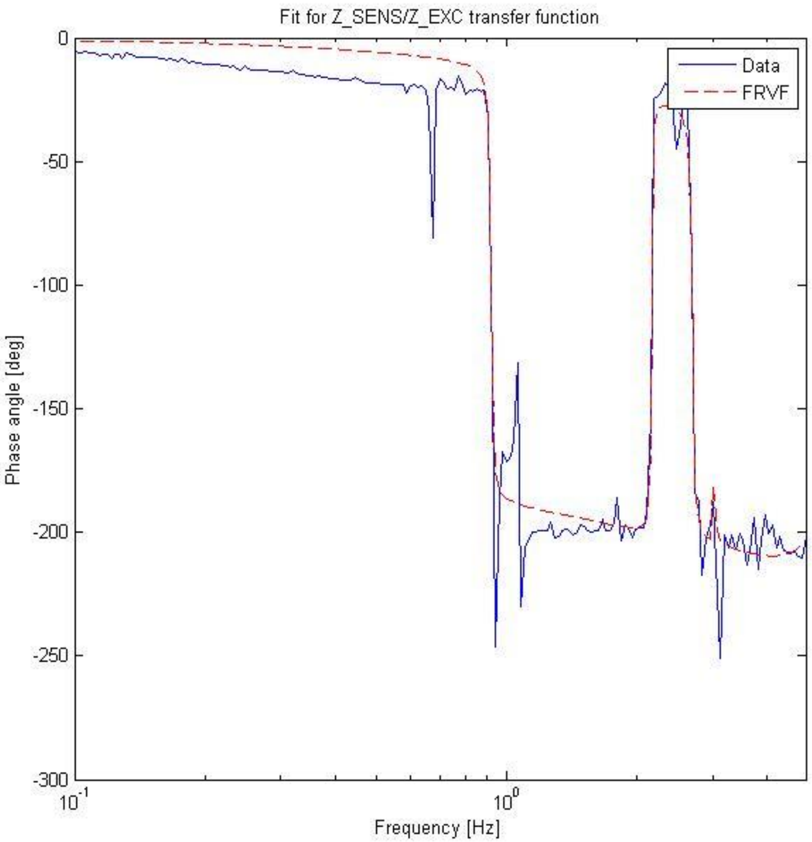
$$\begin{pmatrix} s_a \\ s_b \\ s_c \\ s_d \\ s_e \\ s_f \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & -z_{cm,A} & y_{cm,A} \\ 0 & -1 & 0 & z_{cm,B} & 0 & -x_{cm,B} \\ 0 & -1 & 0 & z_{cm,C} & 0 & -x_{cm,C} \\ 0 & 0 & 1 & -y_{cm,D} & x_{cm,D} & 0 \\ 0 & 0 & 1 & -y_{cm,E} & x_{cm,E} & 0 \\ 0 & -1 & 0 & z_{cm,F} & 0 & -x_{cm,F} \end{pmatrix} \begin{pmatrix} s_{cm,x} \\ s_{cm,y} \\ s_{cm,z} \\ d\theta_x \\ d\theta_y \\ d\theta_z \end{pmatrix}$$

$$\begin{pmatrix} F_x \\ F_y \\ F_z \\ \tau_x \\ \tau_y \\ \tau_z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & -1 & 0 & 0 & -1 \\ 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & z_{cm,B} & z_{cm,C} & y_{cm,D} & y_{cm,E} & z_{cm,F} \\ z_{cm,A} & 0 & 0 & -x_{cm,D} & -x_{cm,E} & 0 \\ -y_{cm,A} & -x_{cm,B} & -x_{cm,C} & 0 & 0 & -x_{cm,F} \end{pmatrix} \begin{pmatrix} F_A \\ F_B \\ F_C \\ F_D \\ F_E \\ F_F \end{pmatrix}$$

Characterization of mechanical response: TF Measurements

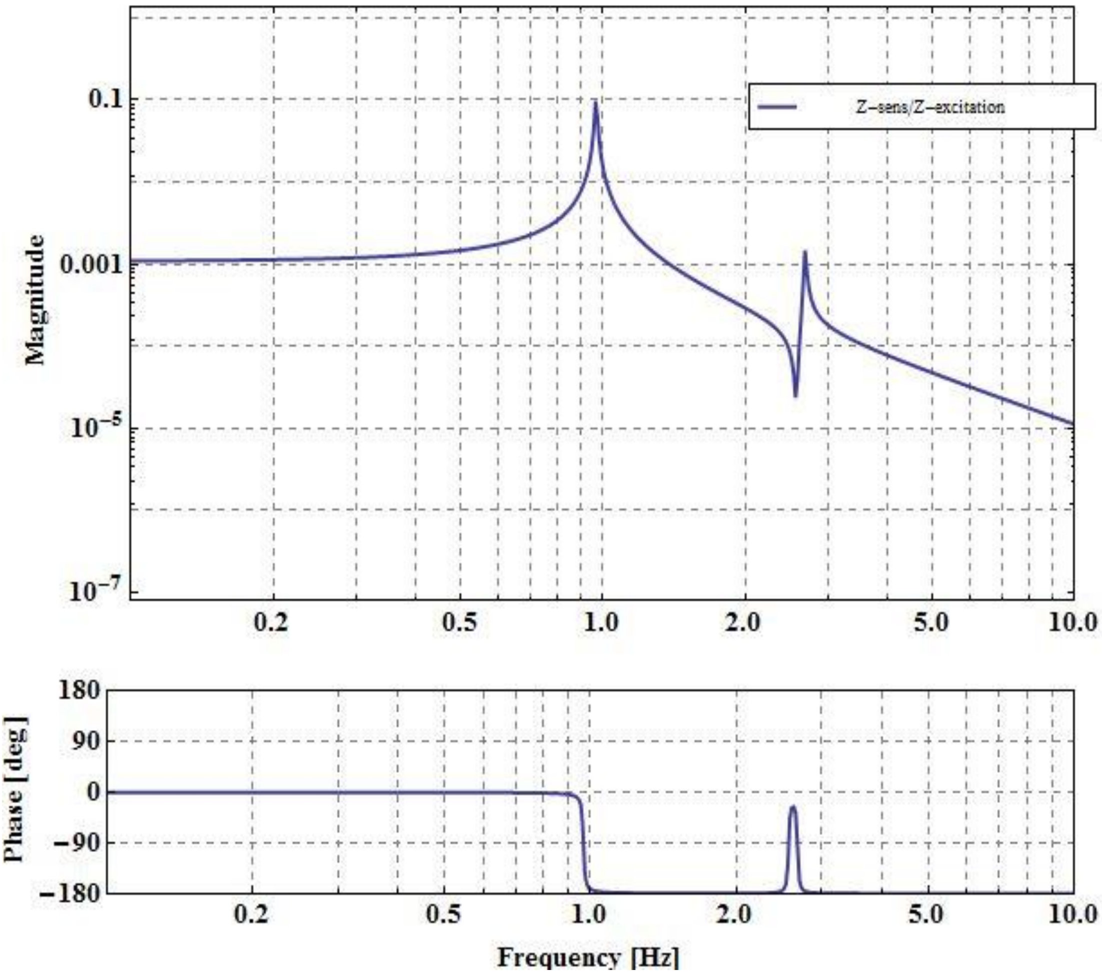
- Characterization: Study the effect of actuation in one direction to motion in all directions, at all frequencies: “Transfer functions” through swept-sine measurements
- 6x6 matrix of (36) transfer functions; diagonal ones important

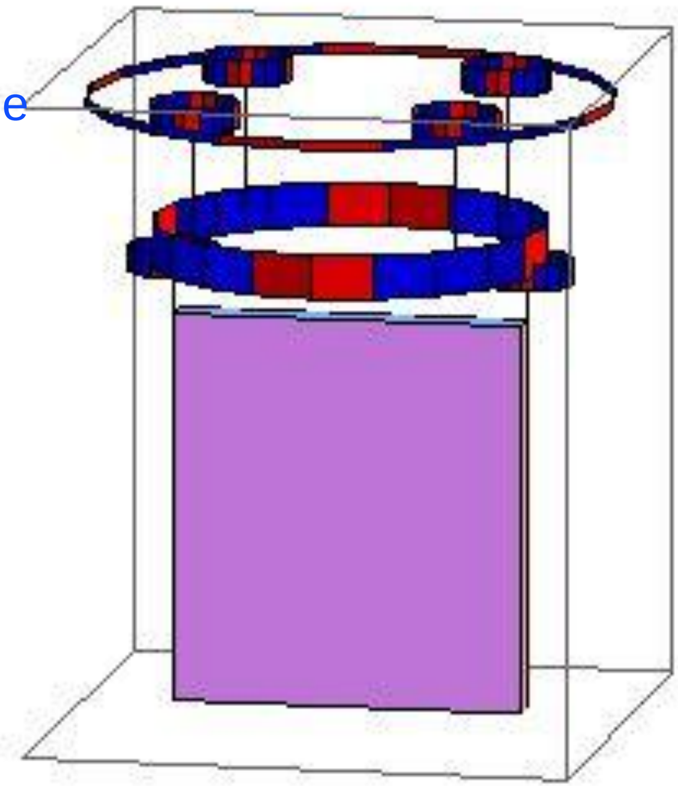




Characterization of mechanical response: Analytical model

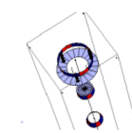
- Plots generated from State-Space Matrix outputs of the simulation.





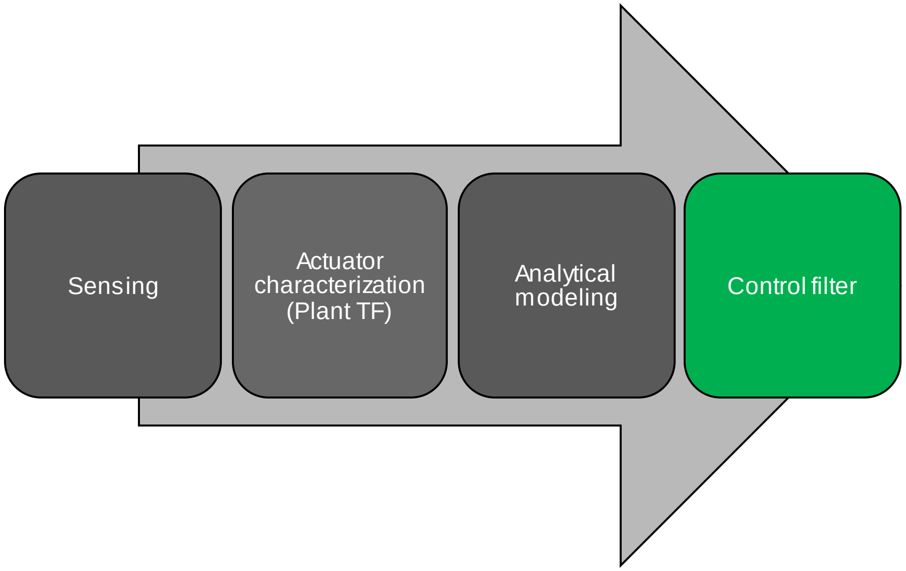
SUMCON in *Mathematica*

spension odel structor

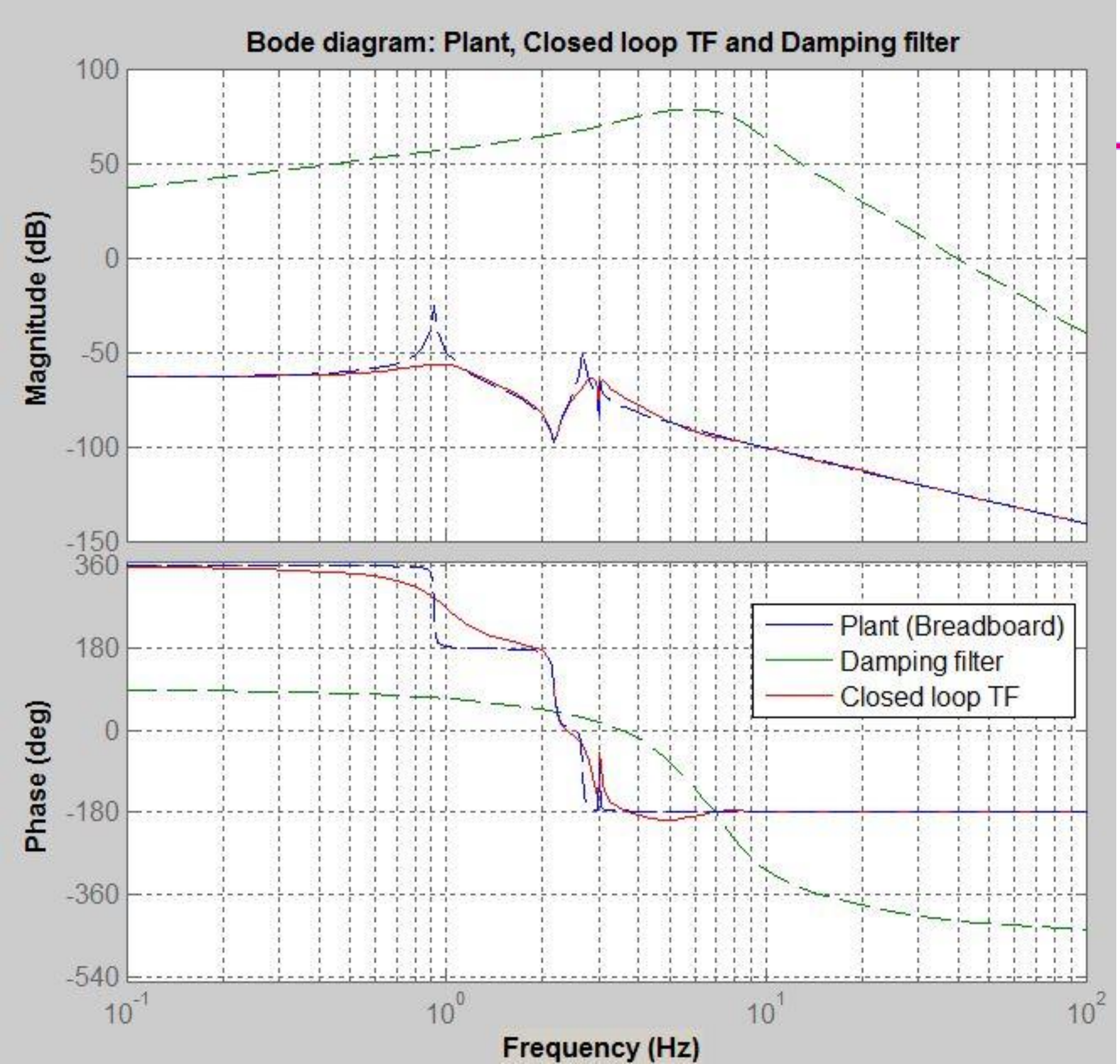


Damping filter

- Goal:
  - » Damping motion (reducing Q) of "pendulum" (suspension) resonances
  - » Introduce as less noise as possible at higher frequencies
- Structure:
  - » Differentiator: $\dot{x}$ term for damping
  - » Complex pole pairs for roll-off



Damping filter: Design on MATLAB

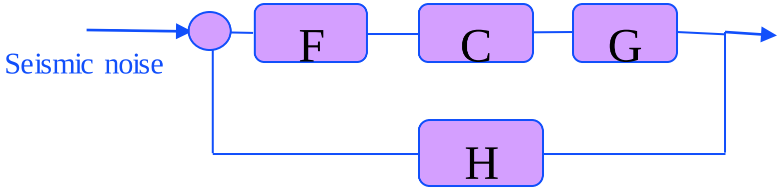


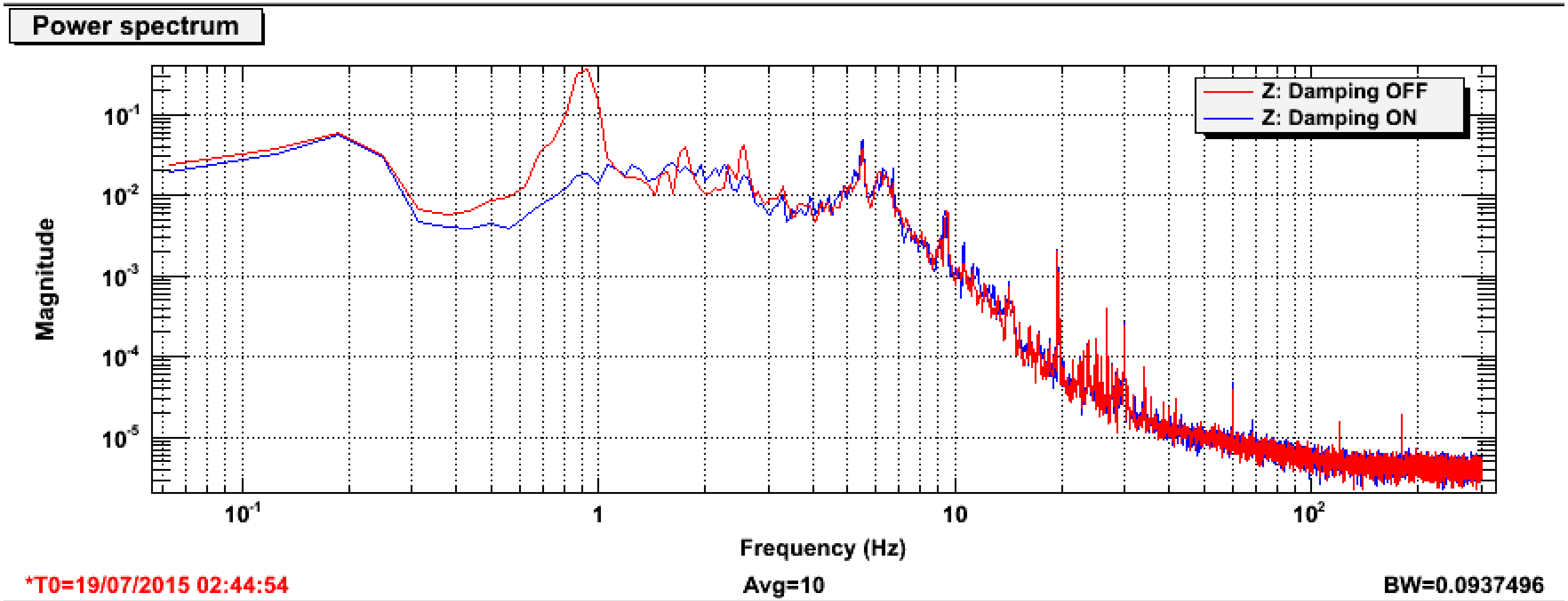
For this particular example:

- Phase margin: 42º
- Gain margin: 10.5dB

Damping filter: Implementation, Results

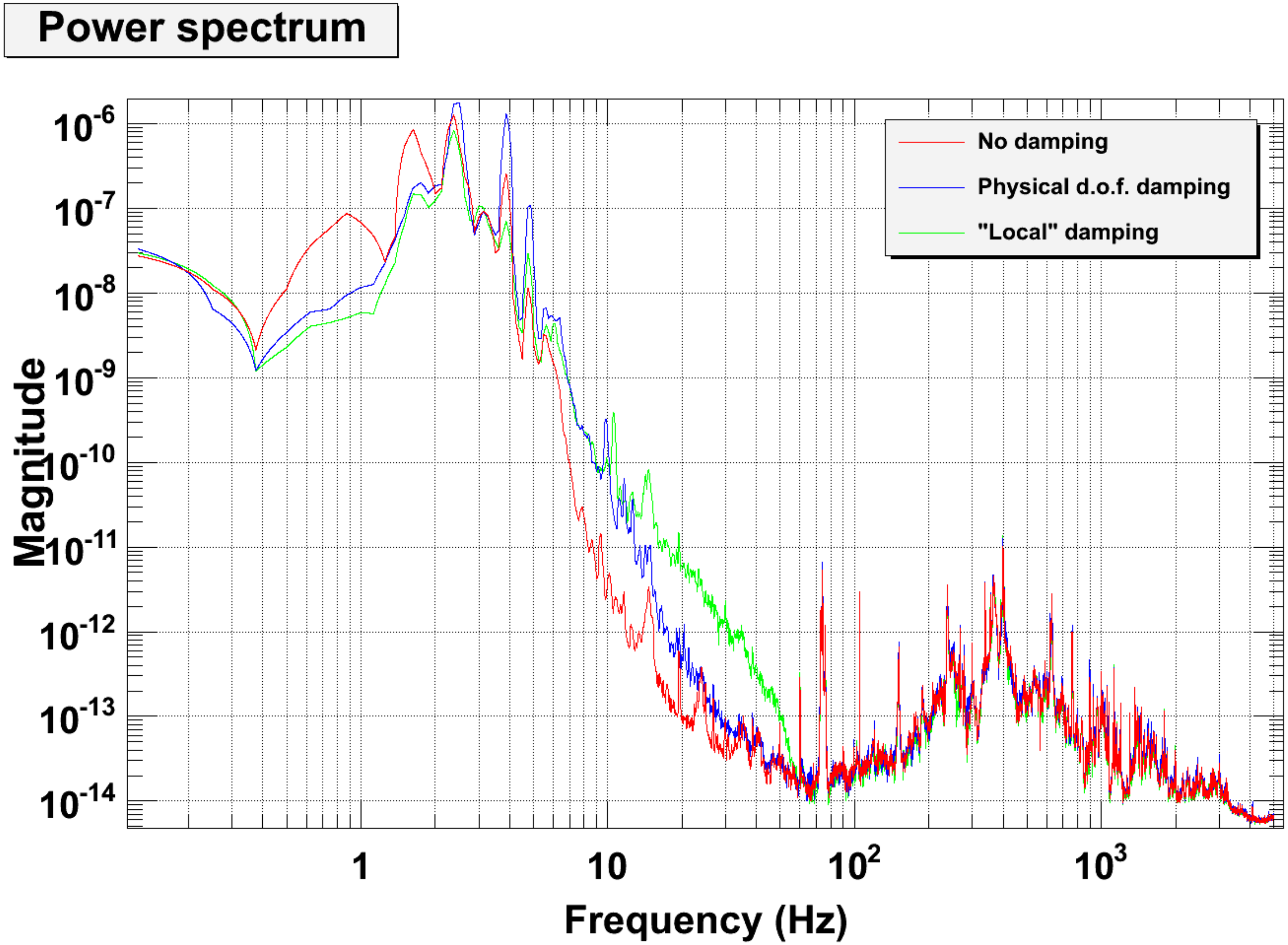
- Example: Damping along Z
  - » Red: Damping OFF
  - » Blue: Damping ON





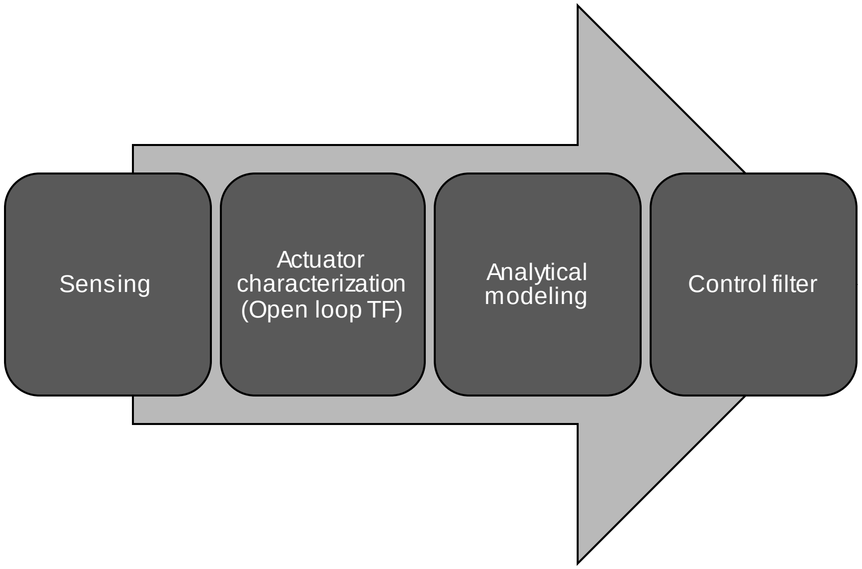
LIGO-G09xxxxx-v1

Final result: Michelson spectrum

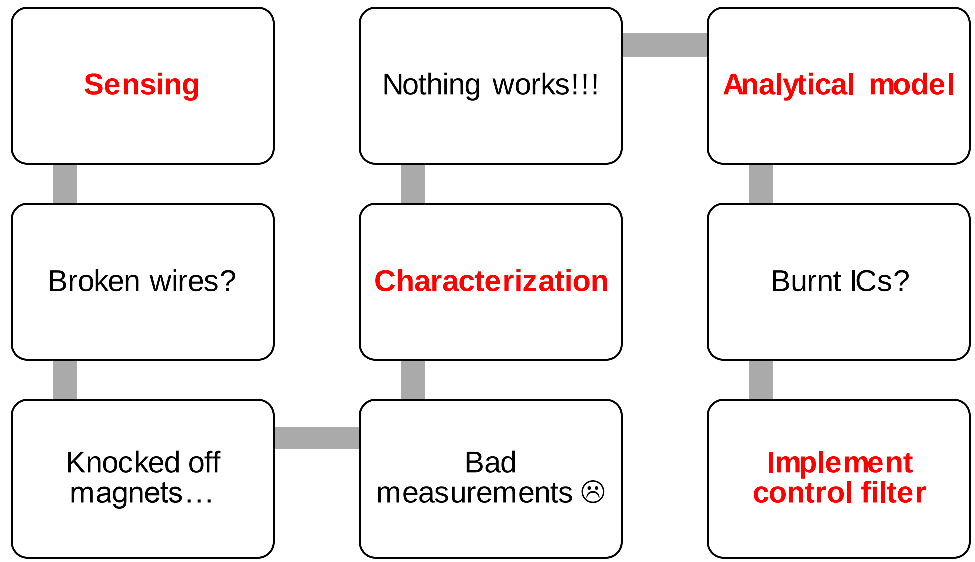


Summary

- What I wanted to do:



- What I ended up doing…



- For more, check out my DCC page: T1500228

Acknowledgements

- Gabriele Vajente: For being such an amazing mentor!
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Questions?