A prototype for a tilt-free seismometer

Presentation for T1500485

Alessandra Marrocchesi

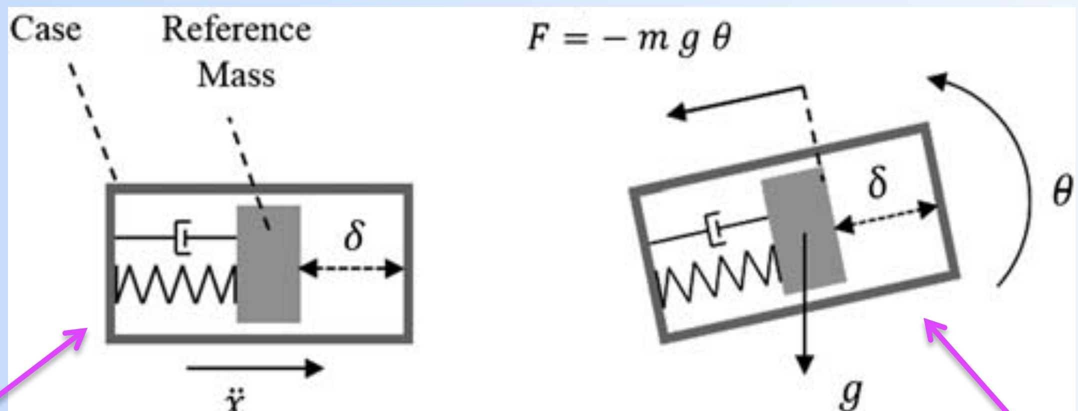
Outline

- The tilt problem
- Possible solutions
- The tilt-free seismometer
- My activity here

The tilt problem

- Seismometers in LIGO: used to keep the optics isolated from ground motion.

- At low frequencies: seismometers signals contaminated by ground tilt.



F. Matichard et al, DCC PI 200007

No tilt: relative motion between mass and ground gives spectrum of ground motion.

With tilt: no distinction between ground motion and ground tilt.

- Tilt-horizontal coupling : g/ω^2

Possible solutions

1. **Measuring tilt**: measure tilt and then subtract it

sensor noise injection

errors from large numbers subtraction

2. **Filtering tilt**: design a seismometer that directly filters out ground tilt.

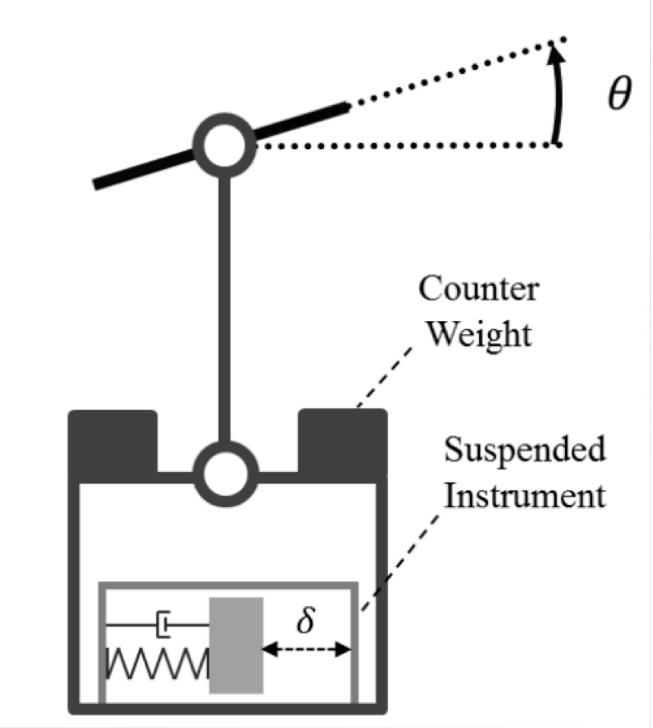
ground displacement determined by only one measurement

Filtering tilt: suspended structures

- Basic principle: mass suspended with a wire unaffected by tilt of the suspension point.
- MIT group and Giazotto idea: commercial seismometer on a suspended structure.

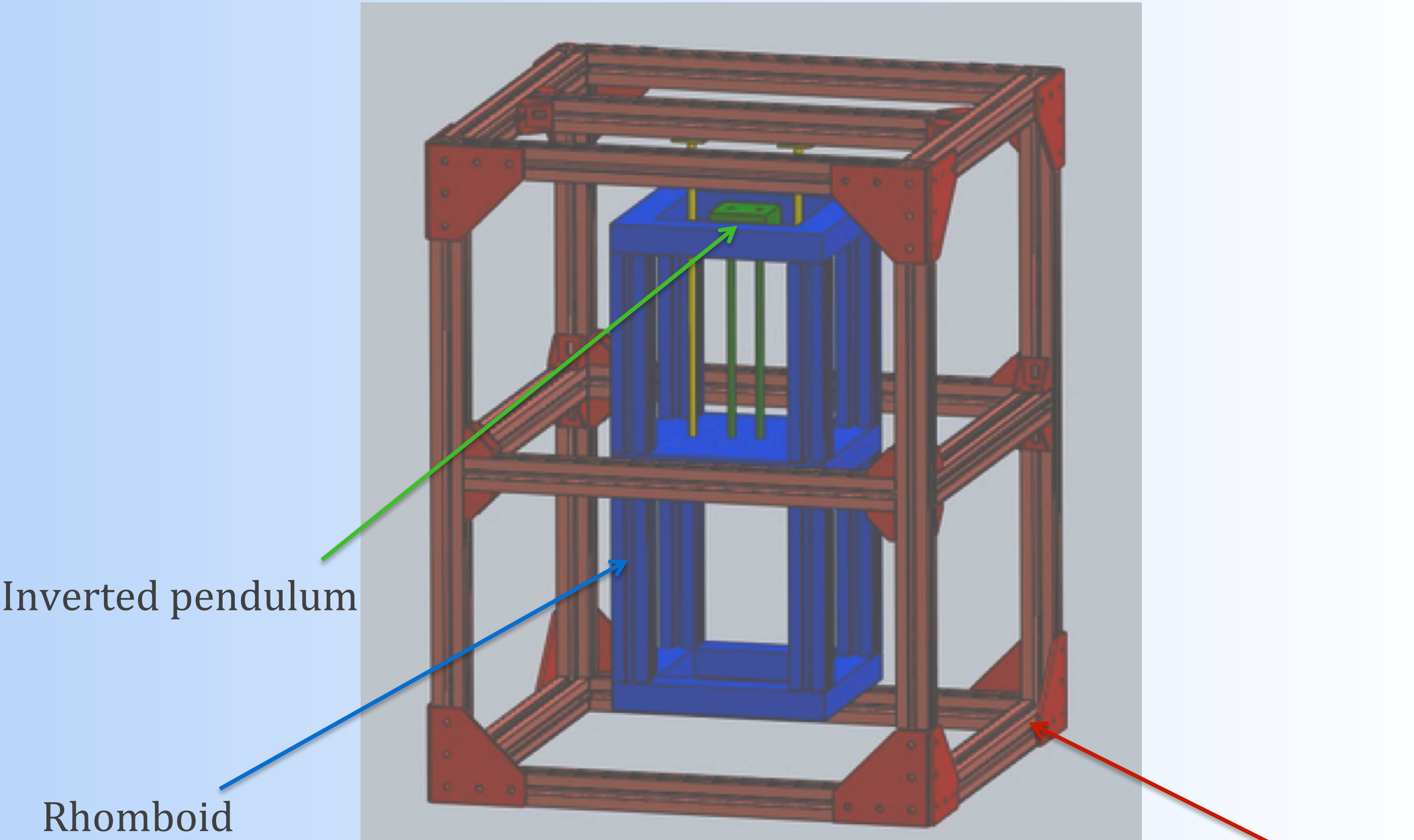
Noise limits

- Our seismometer: inverted pendulum and Michelson interferometer.



F. Matichard, DCC PI 400061

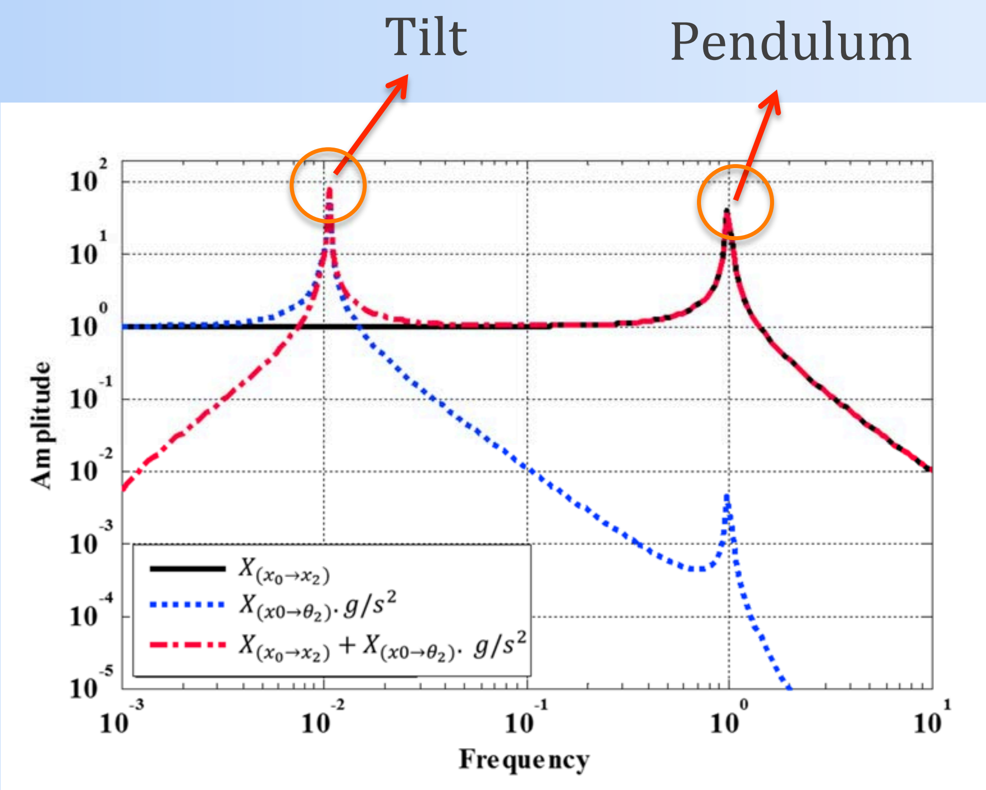
Seismometer design



K. Dooley et al, DCC GI 500 315

Goal: low resonant frequencies

- Rhomboid sensitive to ground motion between tilt and pendulum resonant frequencies



F. Matichard, DCC P1400060

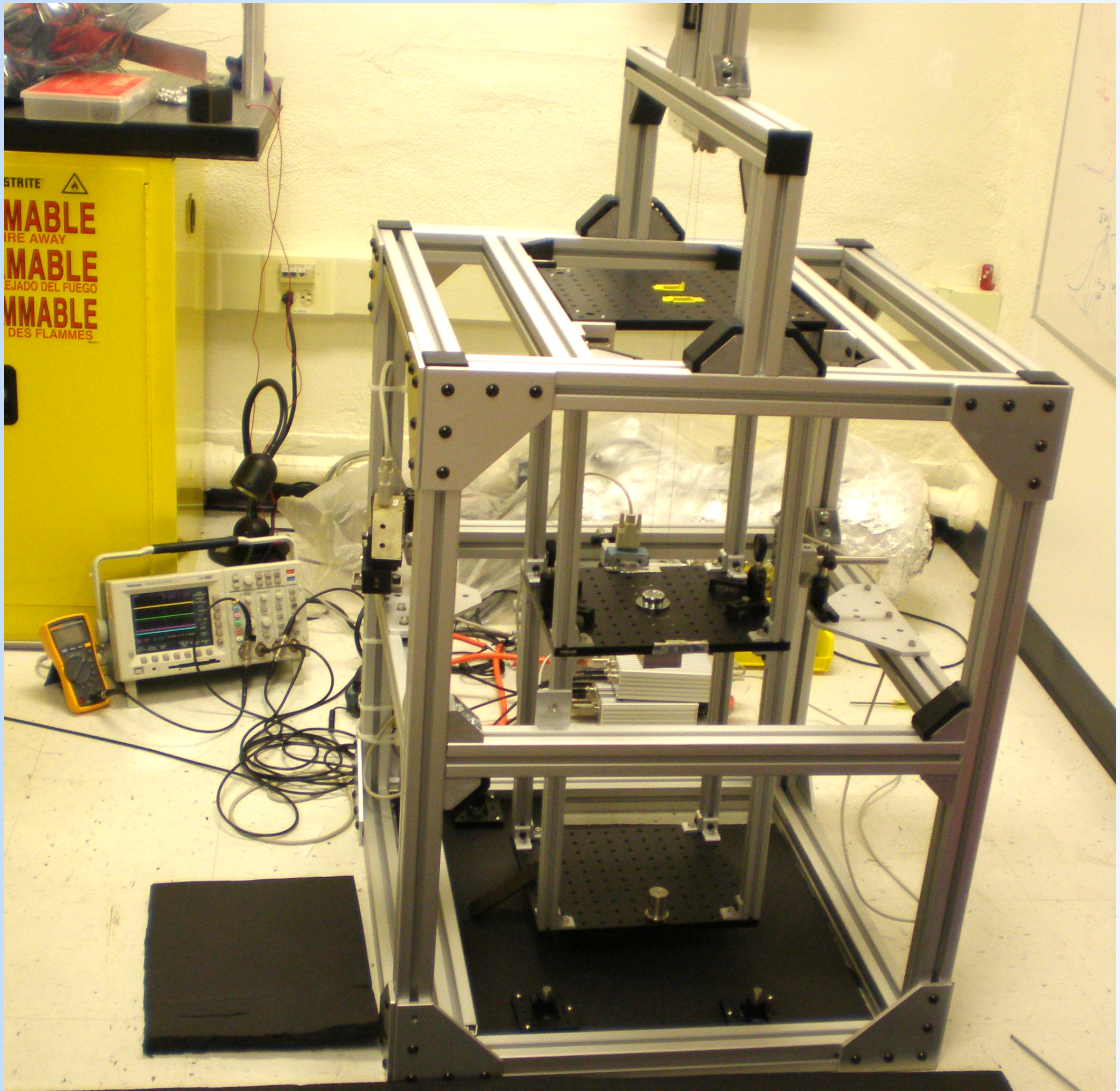
- Above the tilt resonant frequency tilt-coupling is attenuated
- Use of Michelson interferometer: accurate measurements (Zumberge, Araya)
- Below the IP resonant frequency SNR is low

Goal: low rhomboid tilt and IP resonant frequencies.

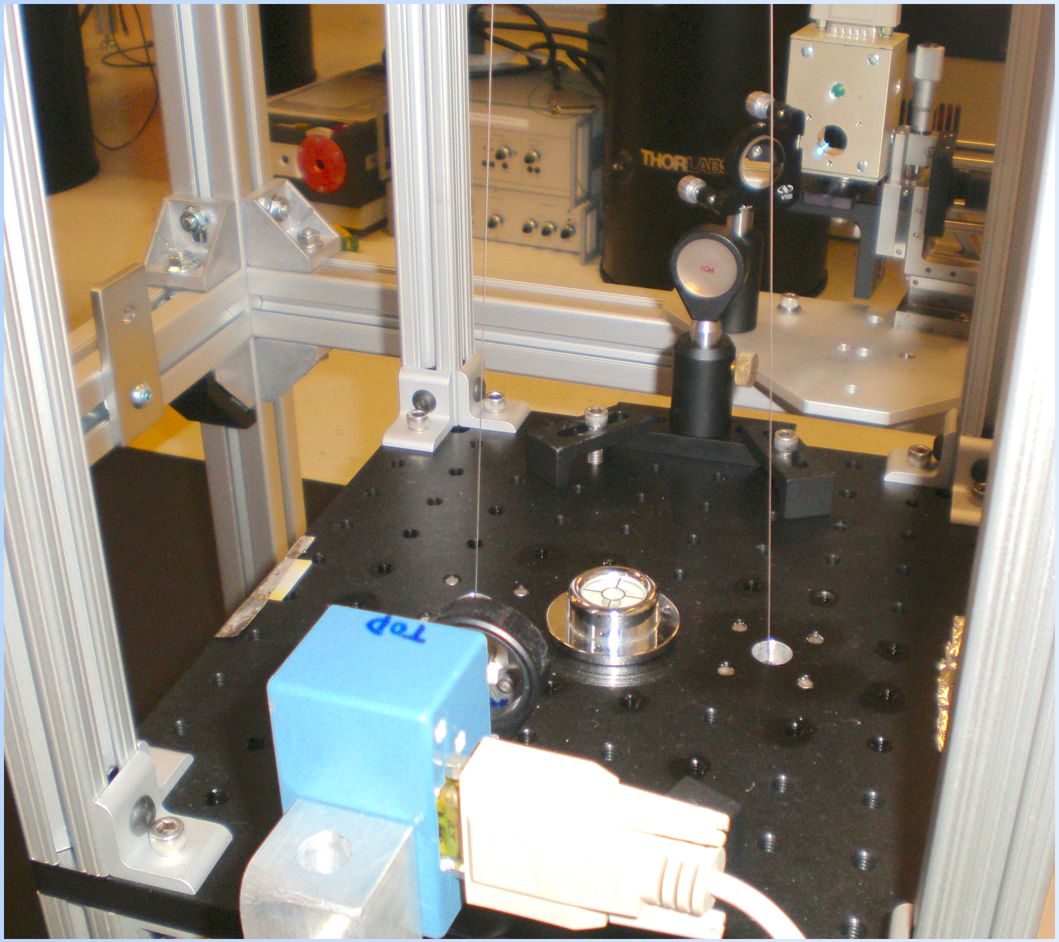
My activity here

- Measure the rhomboid resonant frequencies.
- Find the parameters to make the IP reach 40 mHz resonant frequency.
- Temperature stabilization of the structure.

Rhomboid resonant frequencies



Rhomboid resonant frequencies

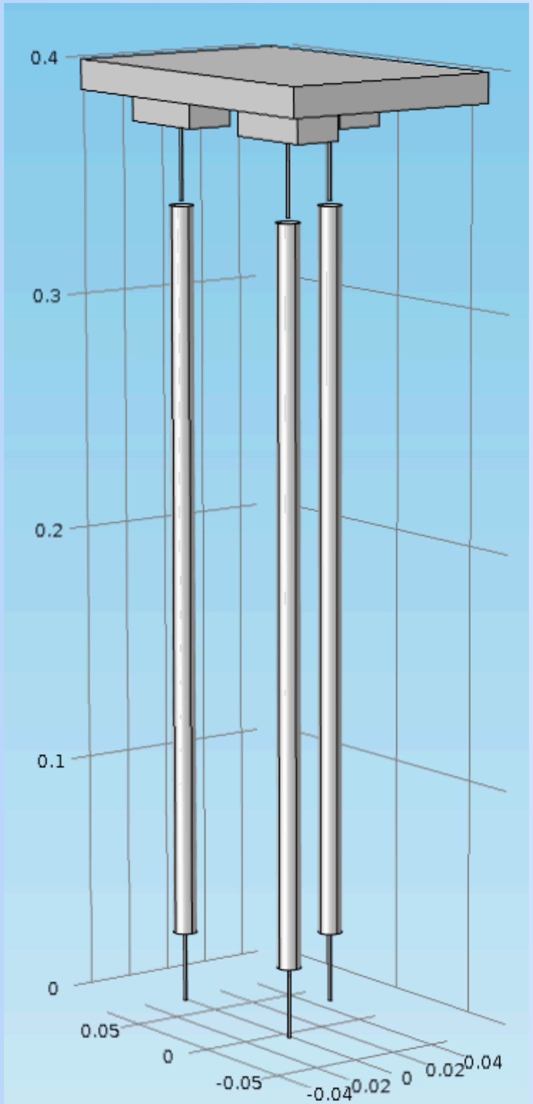


- LED light and photosensors
- Laser and QPD
- Spectrum analyzer
- Results for main interest resonant frequencies:

Mode	Frequency (mHz)
Tilt	108 ± 1
Pendulum	645 ± 5
Yaw	139.5 ± 0.5

Can make the tilt frequency lower

The inverted pendulum

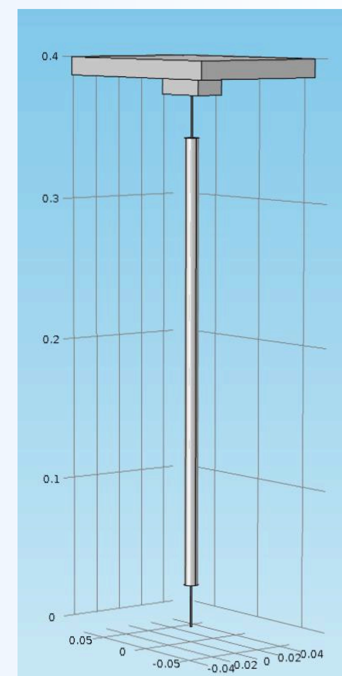


- Three legs structure: more stable
- For simplicity consider a structure with one leg.
- The resonant frequency expression is given by:

$$f_{IP} = \frac{1}{2\pi}\sqrt{\frac{k}{I} - \frac{g}{I}\left[m_1(2l_1+l_2)+m_2\left(l_1+\frac{l_2}{2}\right)+m_3\left(2l_1+l_2+\frac{c_3}{2}\right)+m_4\left(2l_1+l_2+c_3+\frac{c_4}{2}\right)\right]}$$

- To reach 40 mHz we can change:

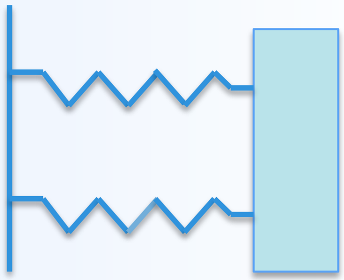
1. The top and bottom cylinder parameters
2. Mass on top of the IP



From one to three legs

To calculate the resonant frequency of our final IP we can do the following consideration:

6 flexures = 6 spring in parallel

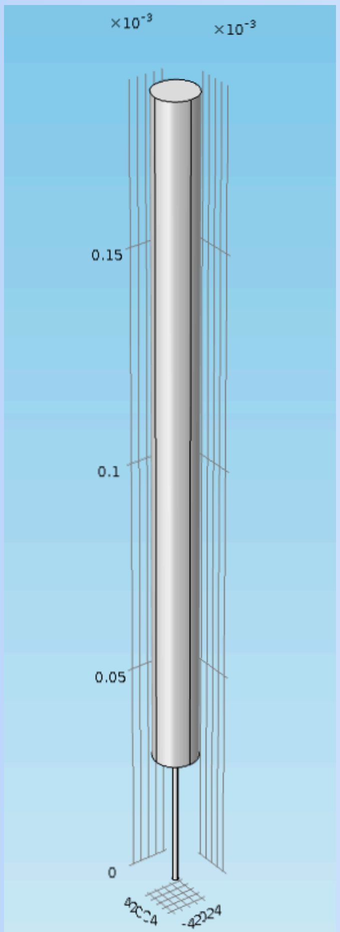


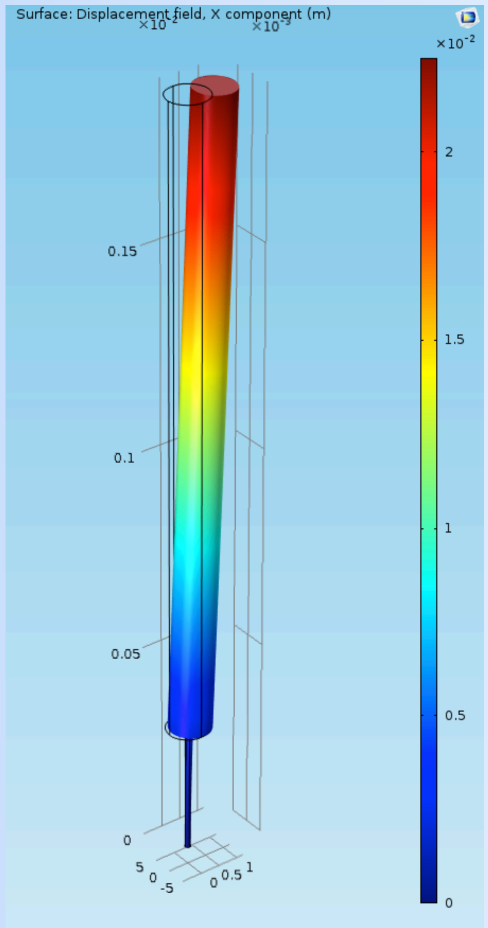
Measure the spring constant (k') of a single flexure structure

$$k = 6k'$$

Determination of the spring constant

- To determine the IP spring constant I first used Comsol.





- Single flexure stainless steel structure (height h)
- I applied 1 N force on top and measured the displacement x

$$k' = \frac{h^2 F}{x} \Rightarrow k$$

Parameters estimate with Comsol

- Changing the bottom rod parameters and using Comsol I could:

1. Measure different values for k.
2. Select the parameters which lead to the lowest resonant frequency.
3. Determine the top mass value to reach 40 mHz.

- Results:

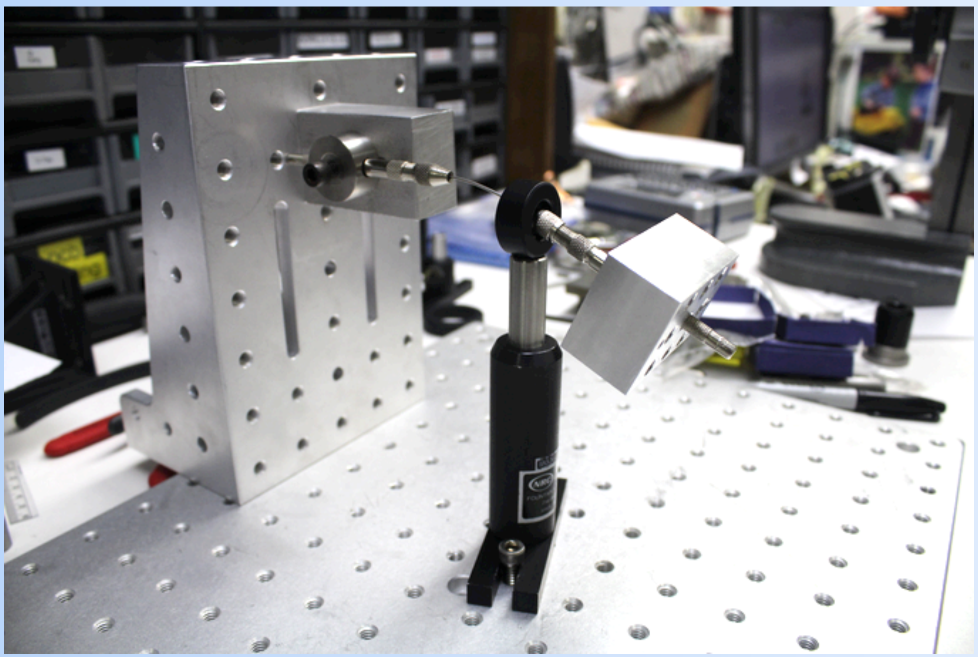
Rod diameter: ≈ 1.4 mm

Rod length: ≈ 3 cm

Top mass: ≈ 2.9 kg

Experimental test

- Build an IP with three different rods of same length of 3.2 cm and different radii
- Measure K' from displacement of the top mass when in horizontal position (no anti-spring constant)



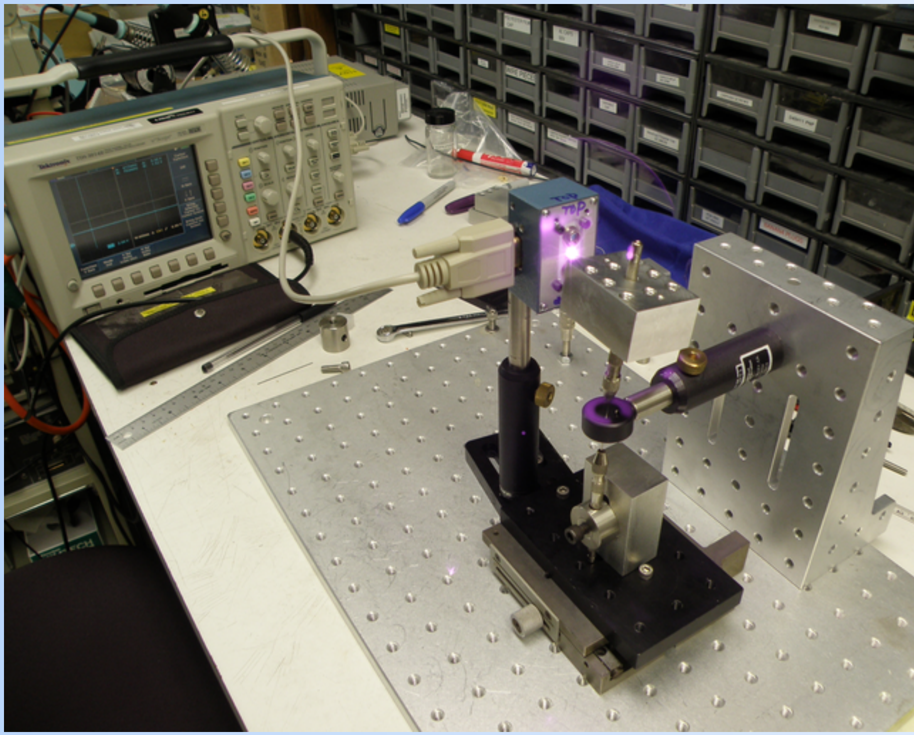
- Results:

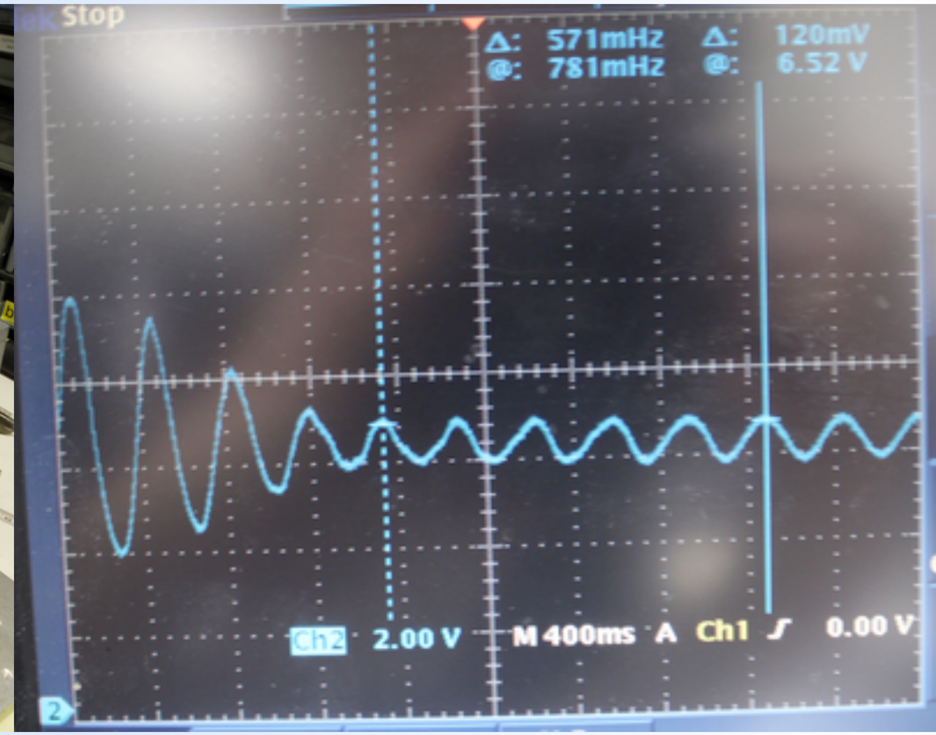
Diameter (mm)	Measured K' (Nm)	Comsol K' (Nm)
0.98	0.295	0.405
1.40	1.188	1.559
1.99	1.507	6.002

Differences probably due to clamping of the rod

Experimental test

- Measure the resonant frequency of the three rods



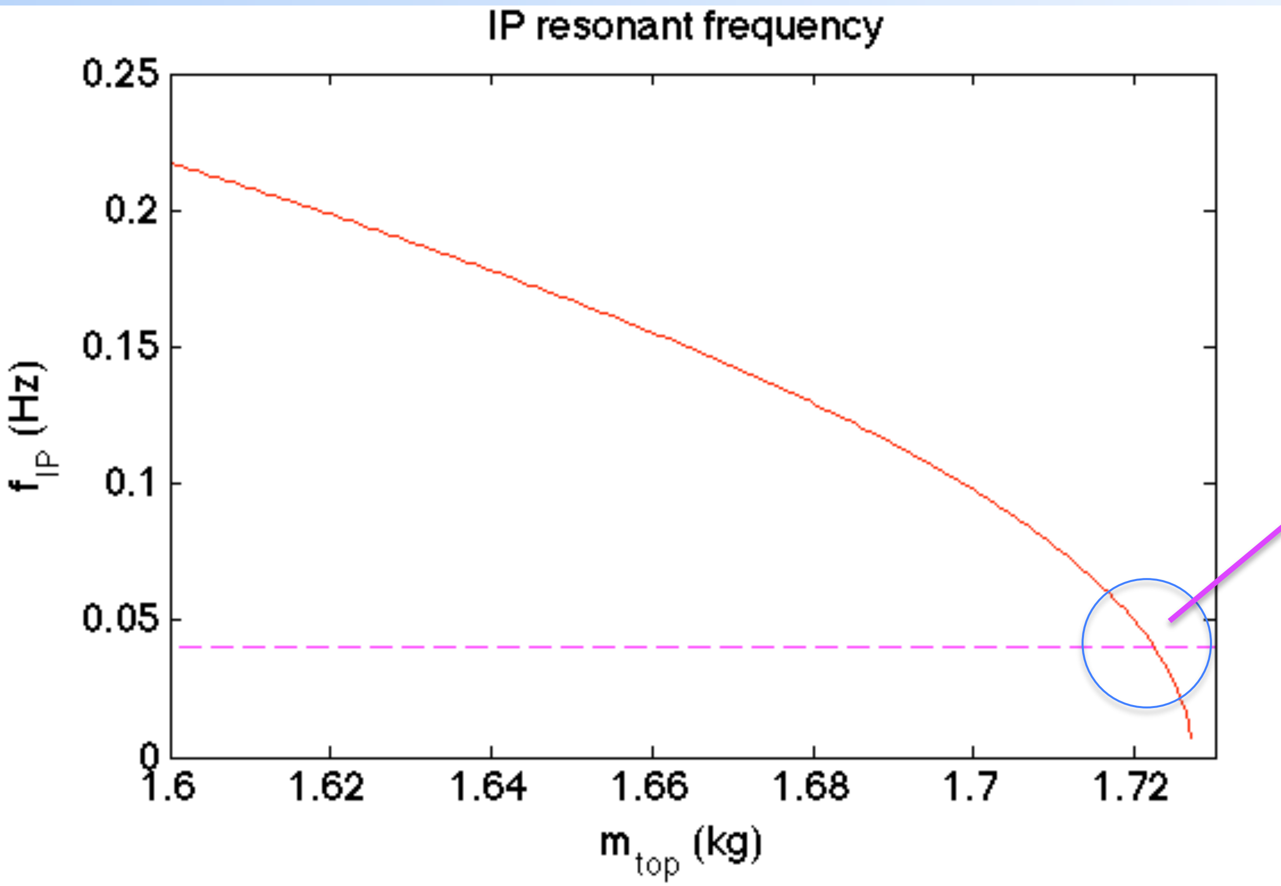


- Calculate the resonant frequency from analytical expression using K'_{Comsol} and $K'_{measured}$

- Results: confirmation of measurements with $K'_{measured}$

Final parameters for the IP

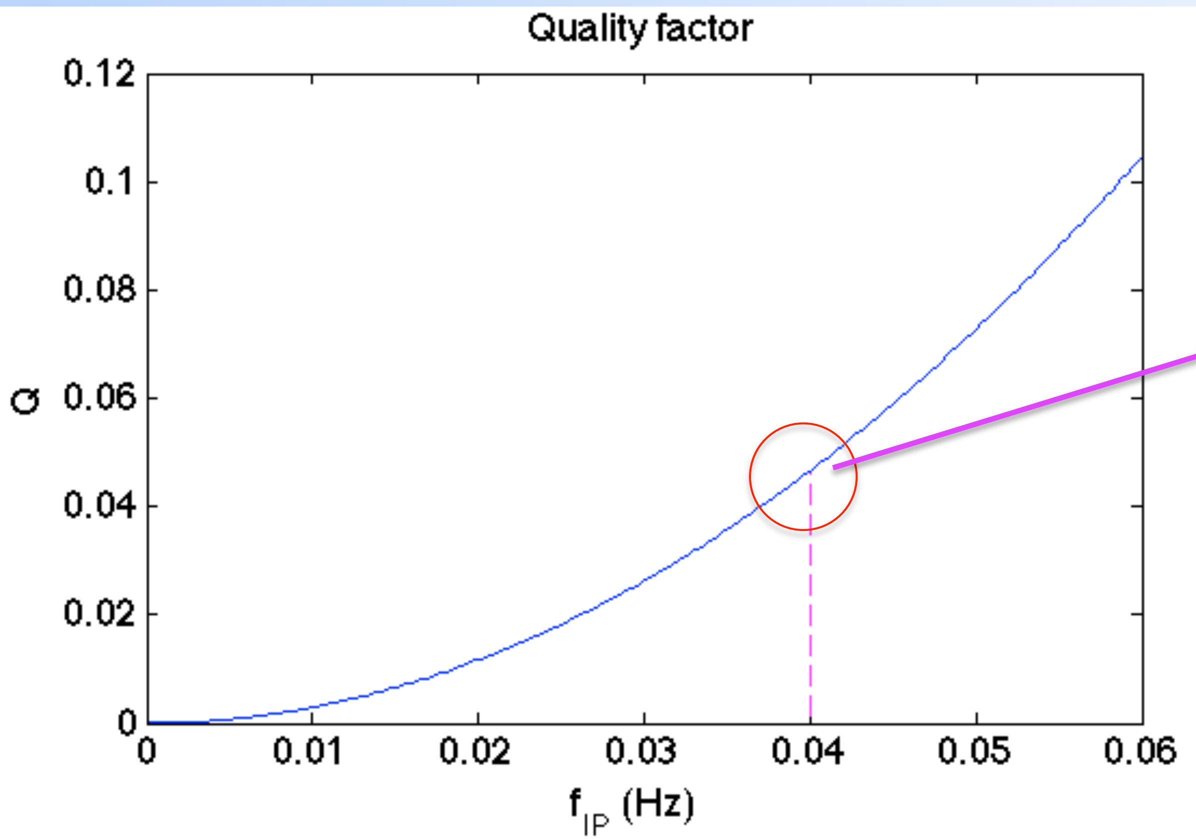
- Use of measured K' to determine the mass on top of final IP to reach 40 mHz
- Can't use 0.98 mm diameter rod (buckling) → use 1.4 mm diameter rod



40 mHz reached for a mass on top of ≈1.72 kg

Quality factor

- Main dissipation mechanism: structural damping → $k \rightarrow k(1+i\phi(\omega))$
- IP quality factor: $Q_{IP} \approx \frac{1}{\phi}\frac{\omega_0^2}{\omega_0^2 + g/l}$
- Measure Q → Deduce ϕ for final IP → Calculate Q_{IP} at 40mHz



- $\Phi = 0.055$
- Quality factor at 40 mHz ≈ 0.047
- Overdamped but in the real IP there is no clamping.

Future work

- Eigen-frequency study on Comsol
- Build a prototype of the IP and measure resonant frequency
- Build the final IP

Acknowledgments

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