# *What is the best displacement transducer for a seismic sensor?*

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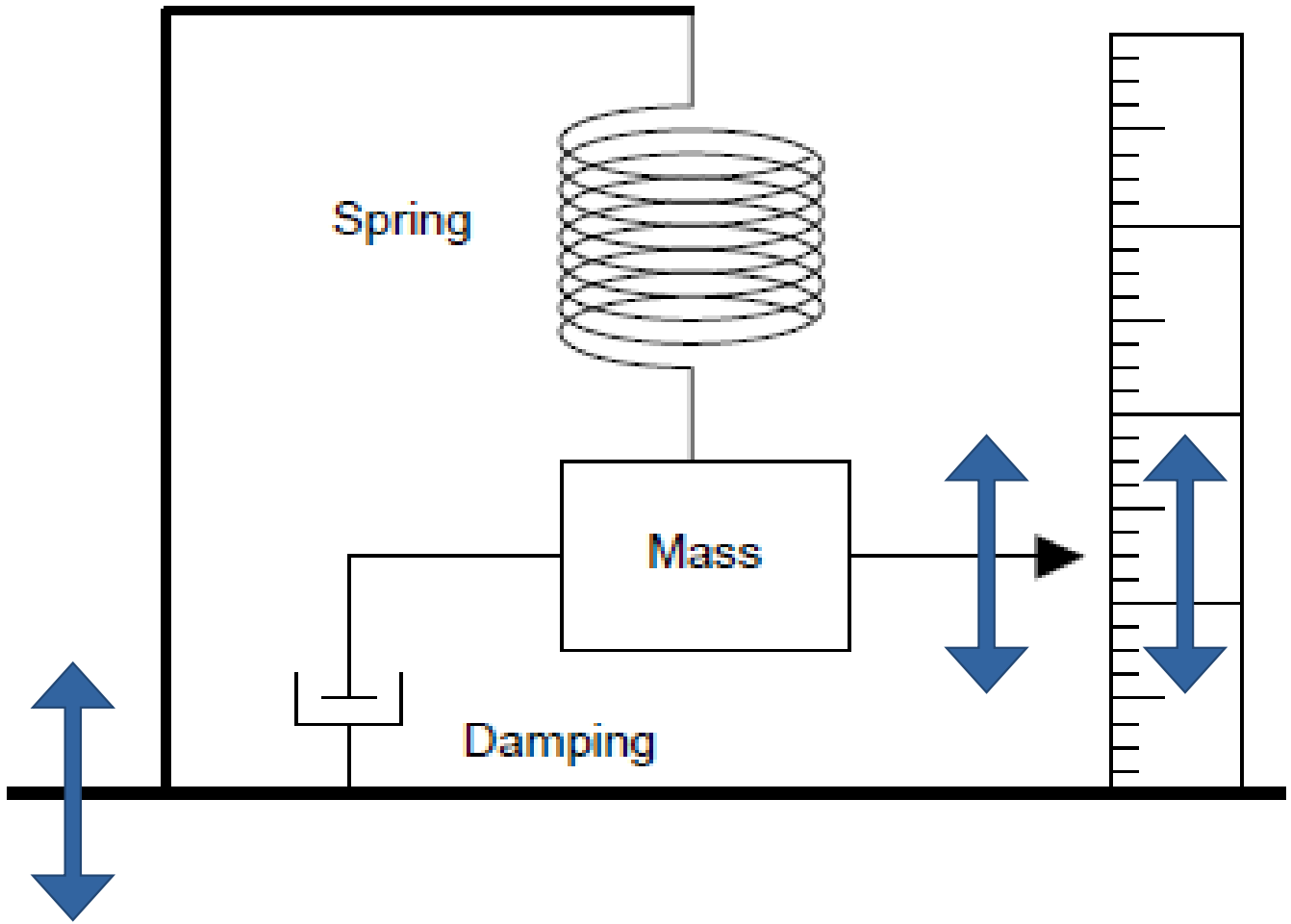
*Final PACMAN workshop, CERN, Geneva*

*21.3.2017*

# Content

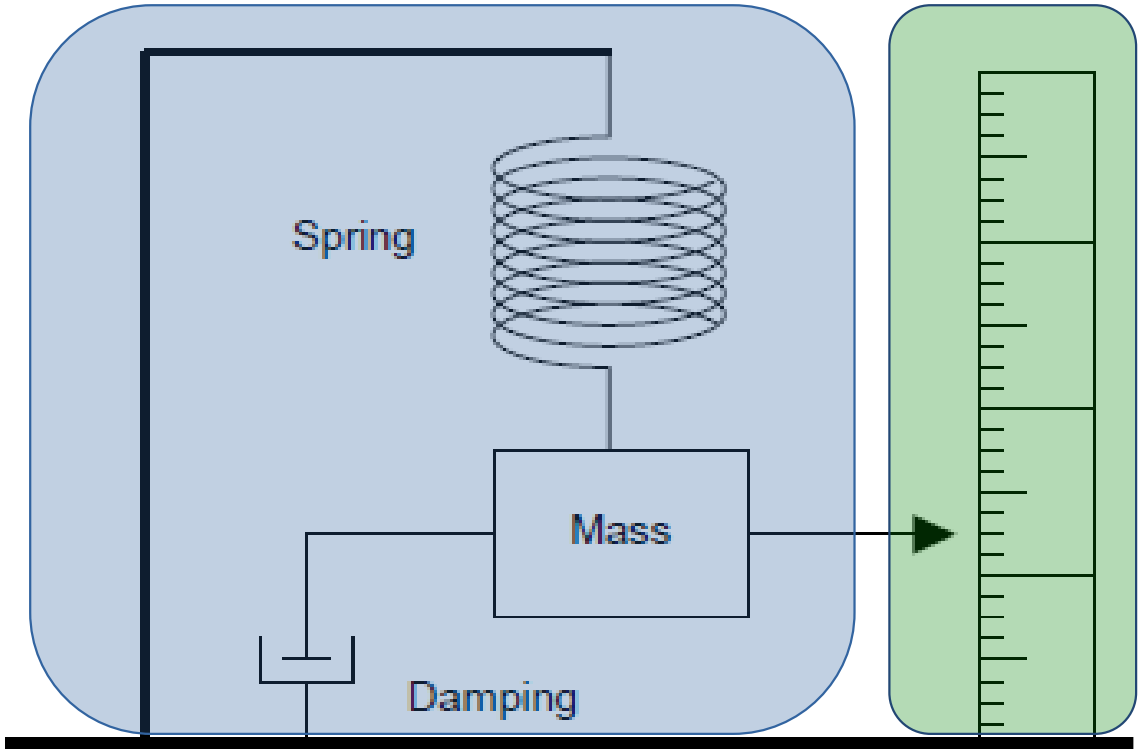
- Resolution comparison of displacement transducers.
- Seismic sensors resolution.
- Increasing resolution with multi-pass interferometer
- Resolution, resolution, resolution.

# How seismic sensor works?



# Main components of a seismic sensor.

- Mechanics – high pass filter.
- Relative motion transducer.

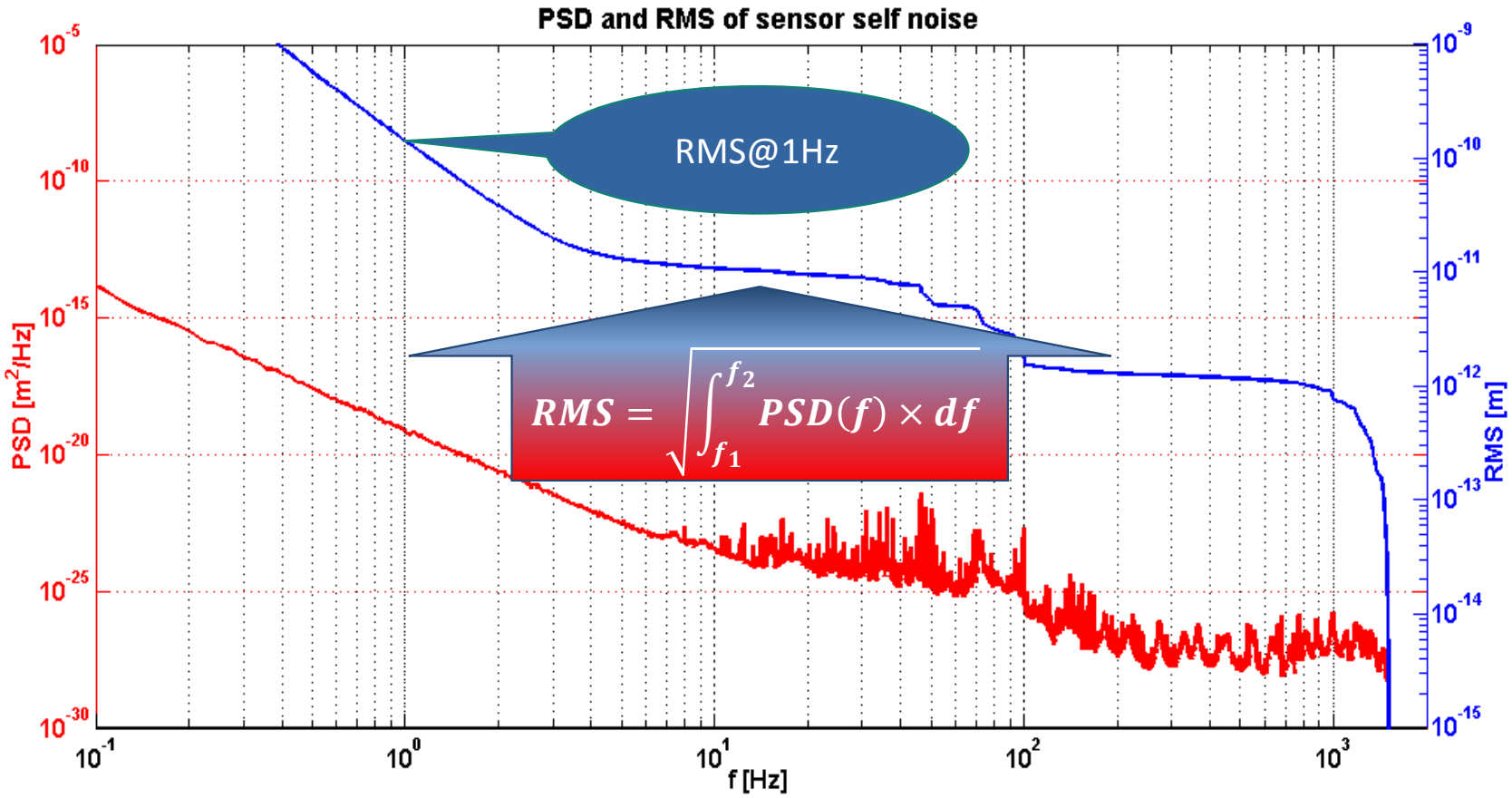


# PACMAN requirements.

- Bandwidth = 0.1 ~ 200 Hz
- Resolution ≤ 0.1nm RMS@1Hz
- Magnetic fields resistance
- (Radiation hard)

# What do we understand by resolution rms@1Hz ?

## RMS or “average” motion in the bandwidth of interest.



# How to improve resolution?

**Resolution=Noise/Sensitivity**

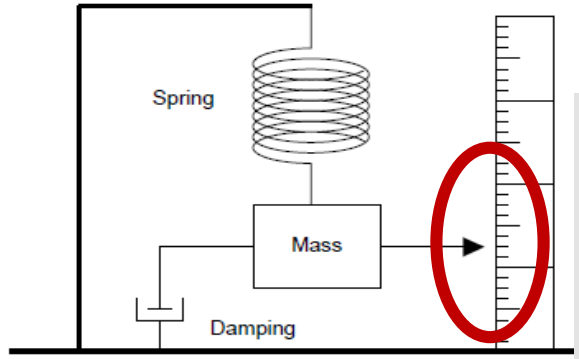
1. **Reduce noise e.g. by cooling the electronics.**
   - **Not the most feasible solution.**

2. **Increase sensor's sensitivity.**
   - **Implement high resolution displacement transducer.**

**SOTA interferometer**

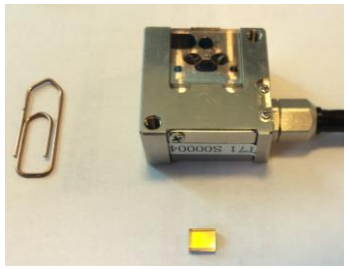
# How to improve resolution?

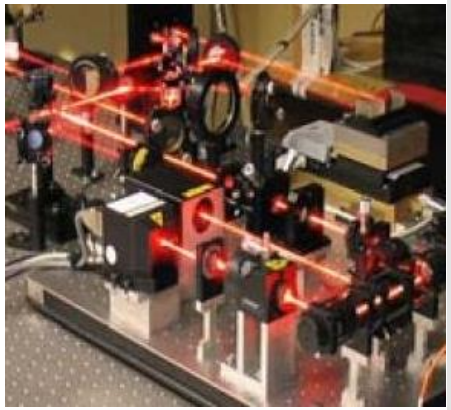
- **High resolution transducers for displacement measurement**




- Options:
  - Resistive, Capacitive, LVDT, Optical encoders, Piezoelectric, Eddy current, Interferometers, …

- After applying following requirements:
  - Contactless
  - Sub-nanometer resolution
  - Magnetic field resistance





# How to improve resolution?

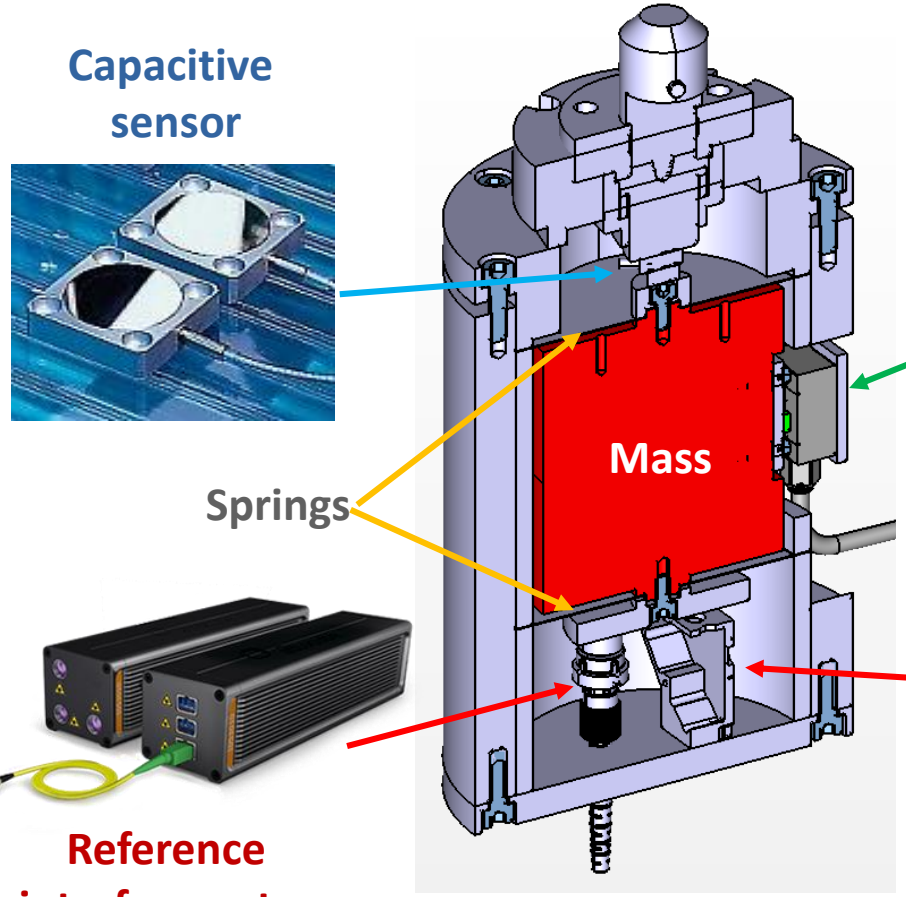
**All technologies implemented before but because results are influenced by:**

- Ambien environment (temperature, humidity, air refraction index, …)
- Mechanical design
- Data acquisition hardware
- Signal processing algorithm

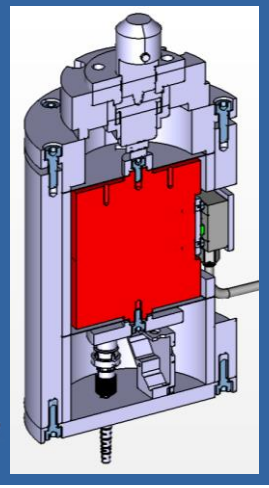
**Comparison is very difficult and unclear.**

# Direct comparison = no data ambiguity

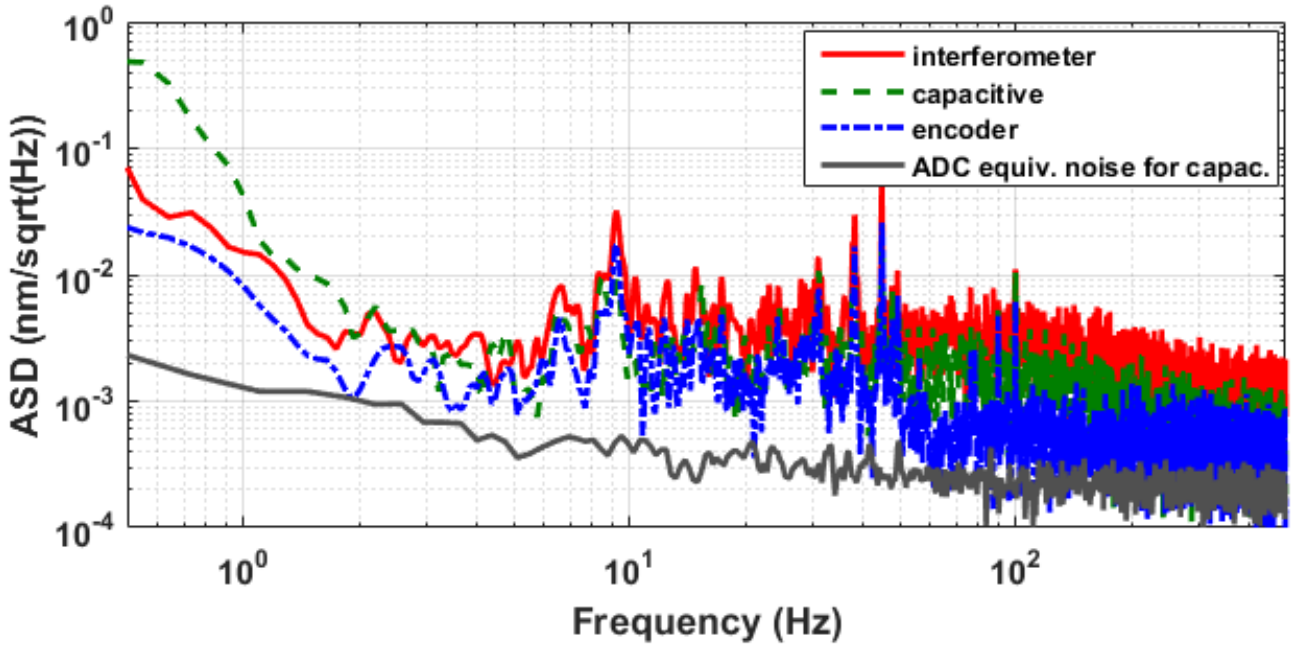
Implementation of displacement transducers into the same mechanical body



# Measurement of transducers resolution.



## Mass locked – no relative motion.

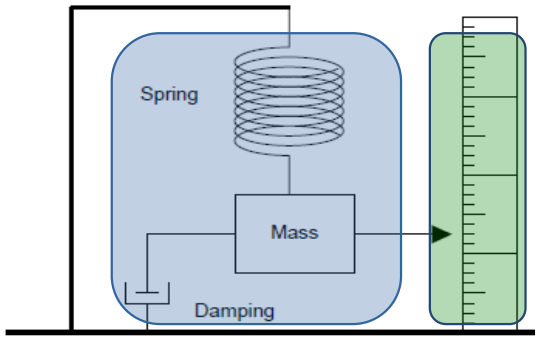


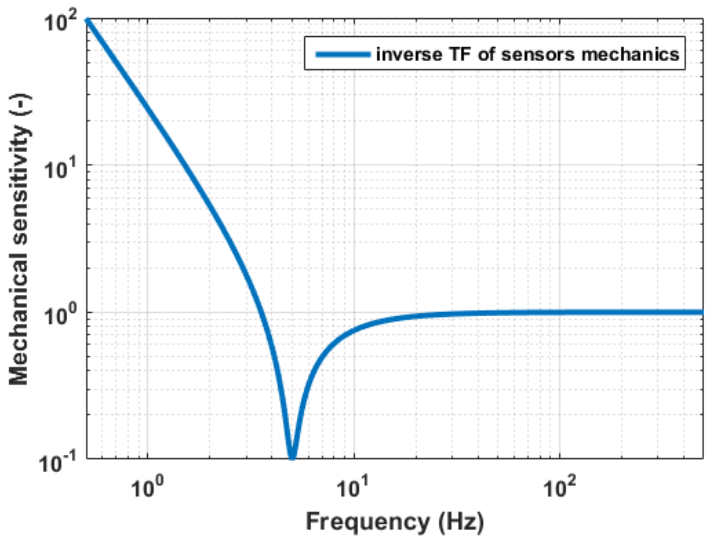

| Transducer | Interfero-meter | Encoder | Capacitive |
|---|---|---|---|
| RMS resolution (pm) | 69.3 | 28.8 | 39.8 |
| Resolution specified by producers (pm) | 44 | 18.2 | 22 |

# Transducers vs. seismic sensor resolution.

**Two main components of seismic sensor:**

- **Mechanics – high pass filter ($TF^{-1}$)**
- **Displacement transducer**

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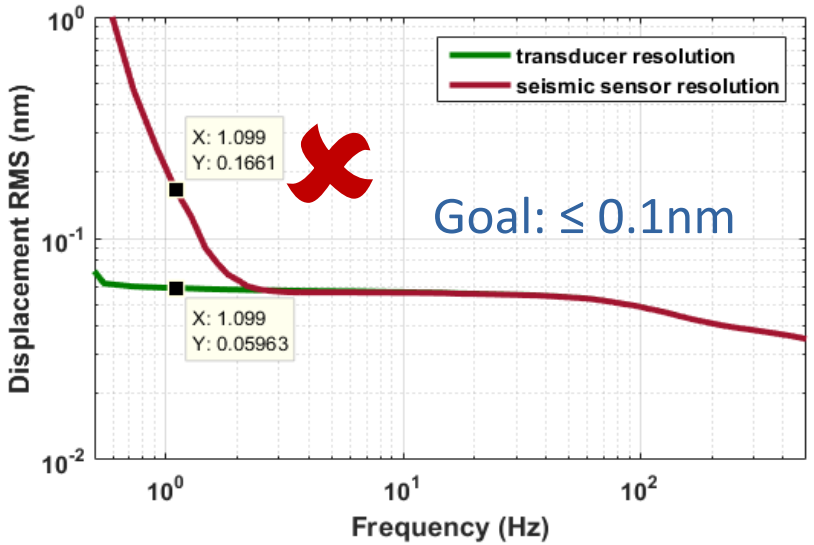
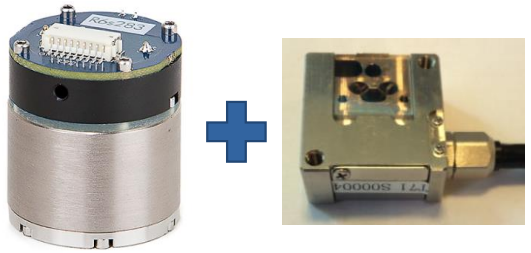


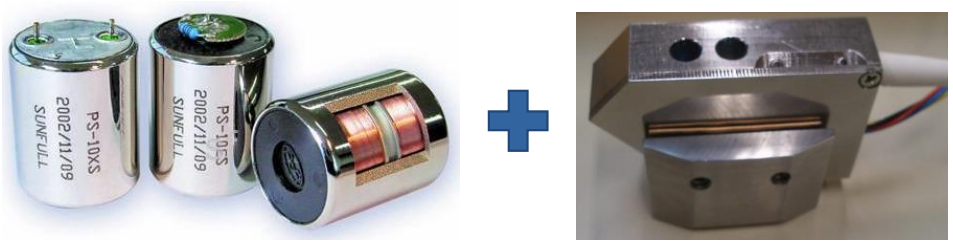

# How to achieve required resolution for seismic sensor?

1. **Use encoder in a feedback configuration.**



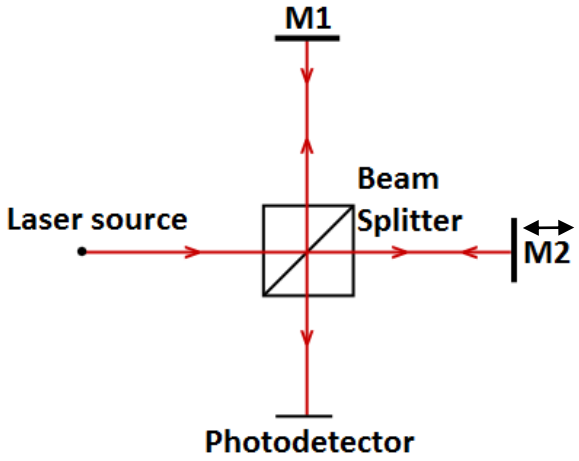
- **Voice coil actuator - not ideal for magnetic environment.**

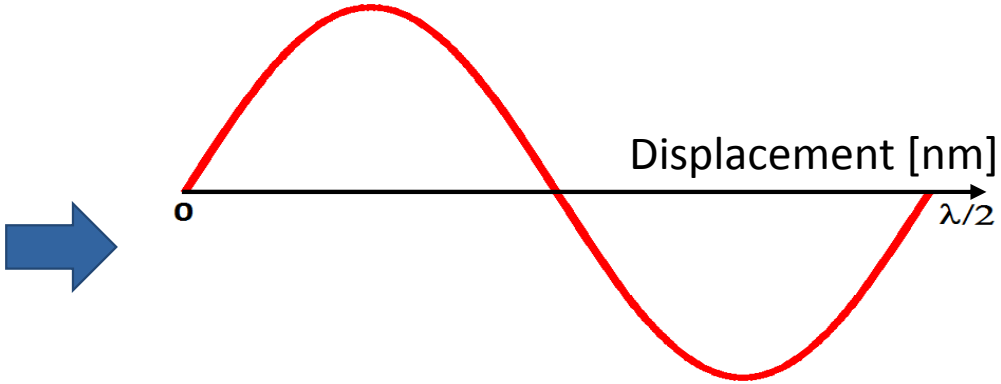
2. **Increase transducer resolution even further.**
   - **Multi-pass interferometer - feasibility study.**

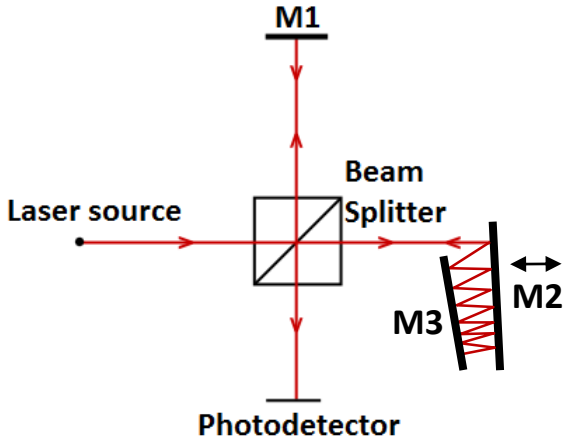


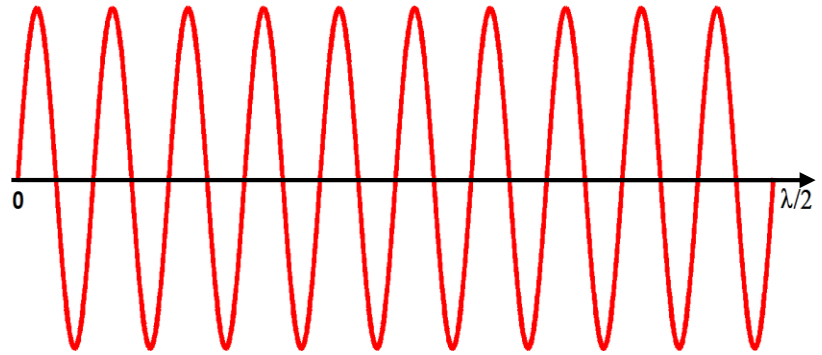
# Multi-pass Michelson interferometer

## Working principle of multi-pass Michelson interferometer

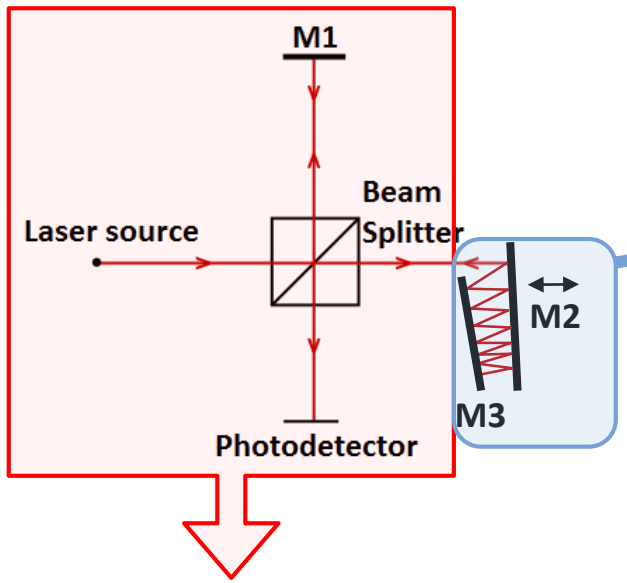


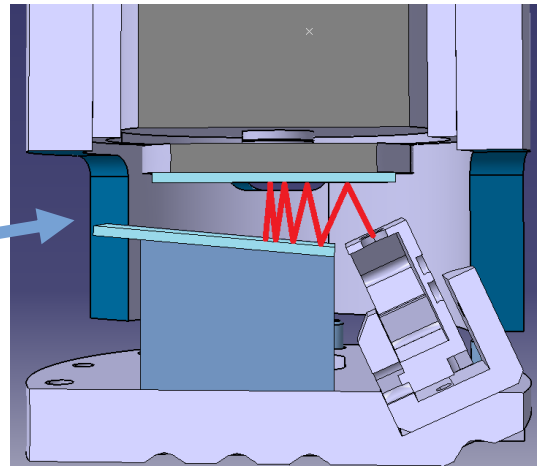



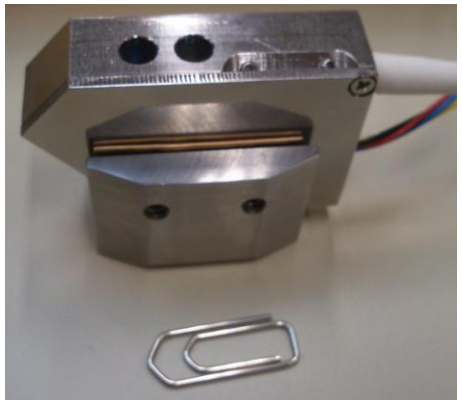



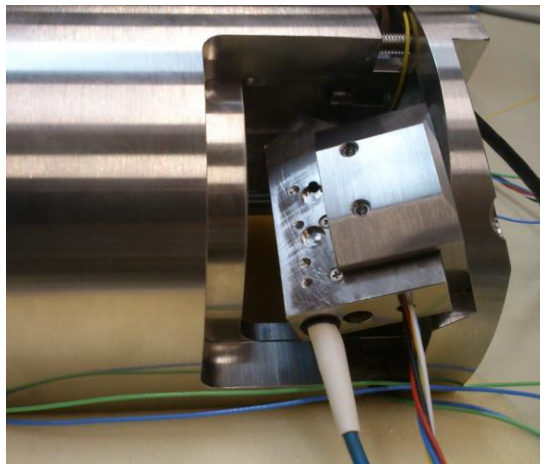



# Implementation of multi-pass Michelson interferometer into seismic sensor.

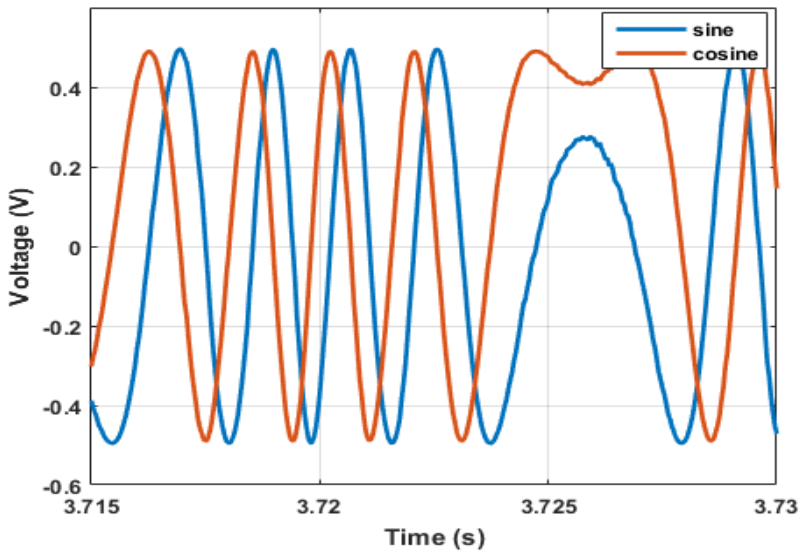


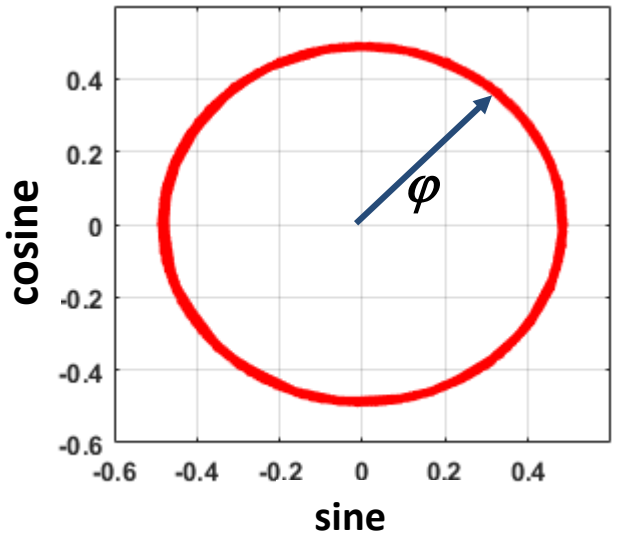







# Obtaining displacement from quadrature signal.



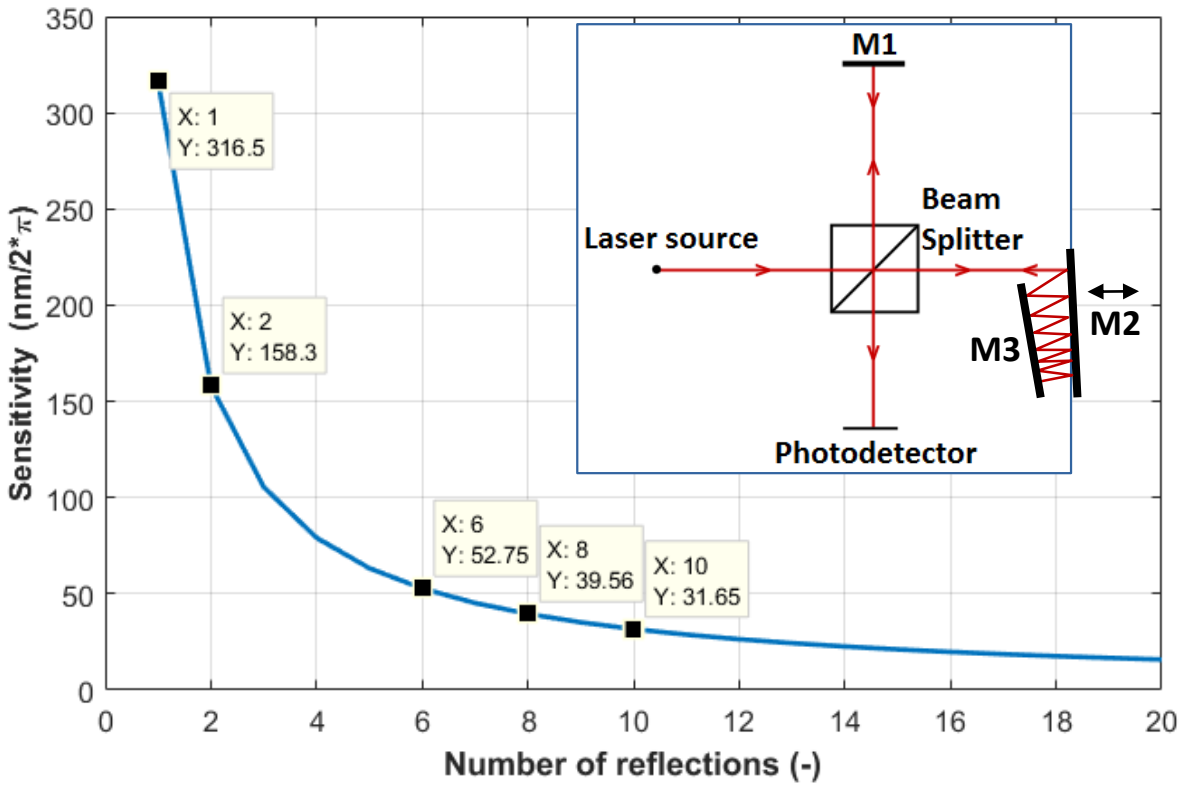




$$displacement = \varphi \times sensitivity$$

$$[nm/2\pi]$$

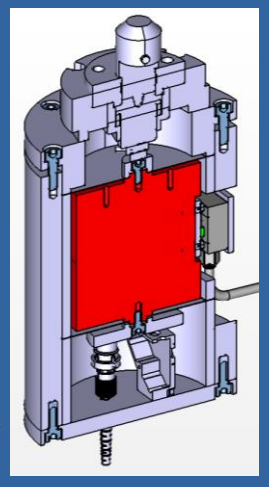
# Increasing sensitivity with number of reflections.

$$S = \frac{\lambda/2}{N}$$




| Transducer | Encoder | attocube | Michelson interferometer | Multi-pass interf. N=8 |
|---|---|---|---|---|
| Sensitivity [nm/2π] | 250 | 200 | 316,5 | 39,6 |

# Multi-pass interferometer resolution.



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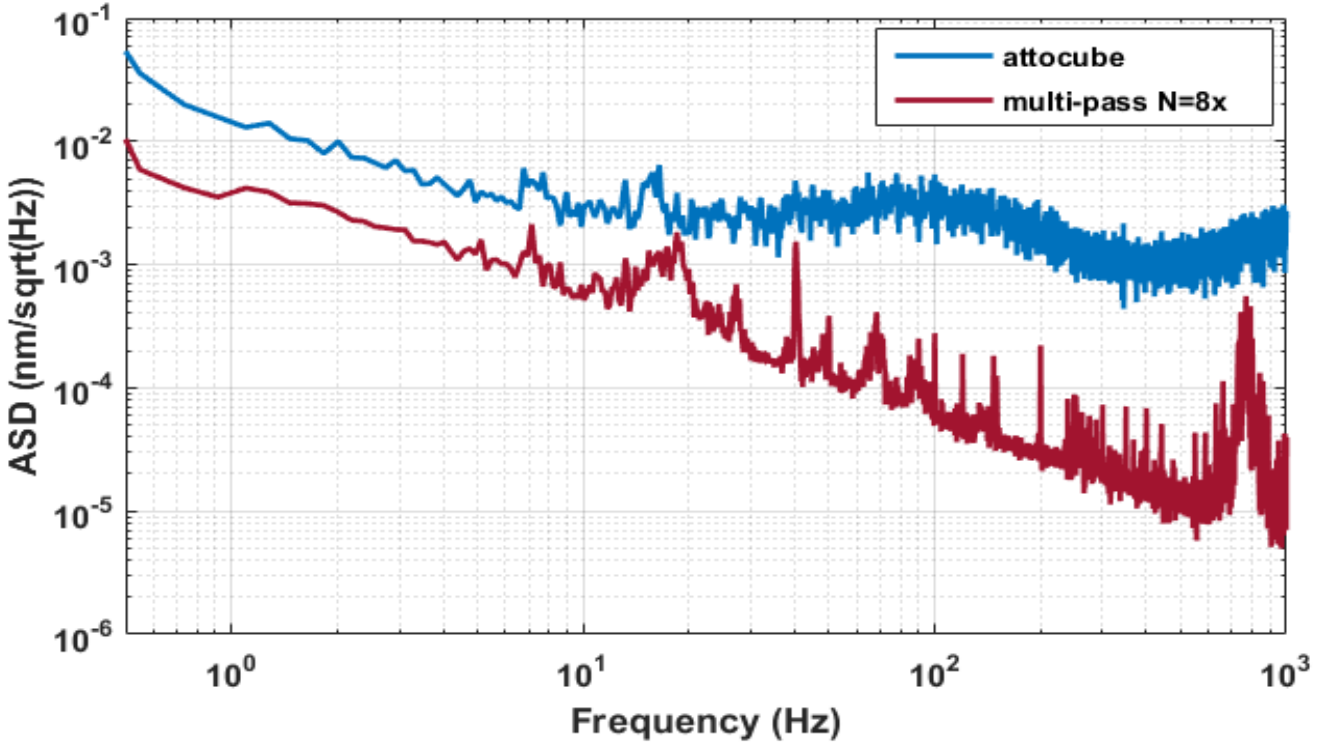


| Transducer | attocube | Multi-pass 8x |
|---|---|---|
| RMS resolution (pm) | 59.6 | 6.5 |

# Seismic sensor resolution.

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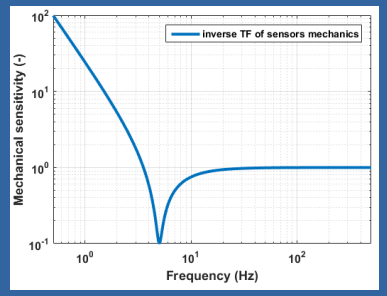
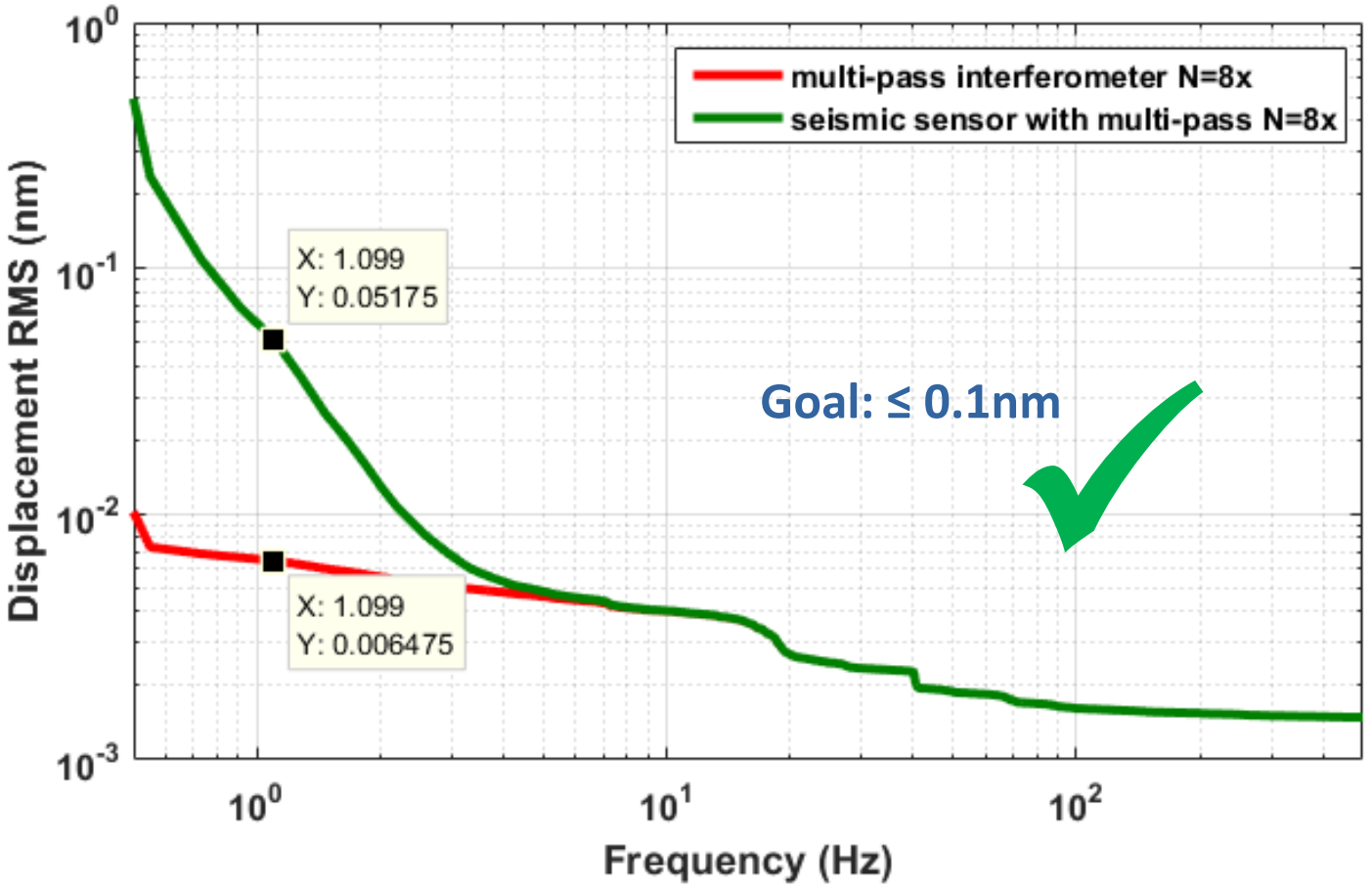
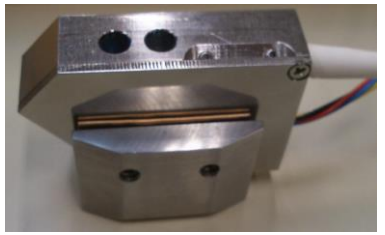


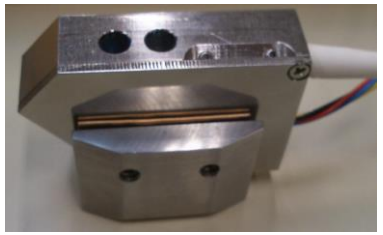



# Possible applications.

1. **PACMAN (CLIC) and also other research projects.**

2. **Industry: Use multi-pass interferometer in a feedback configuration.**



# Room for improvement.

1. Use better alignment system.


2. Improve collimation of light into fibre.

3. Use better optimized mirrors.

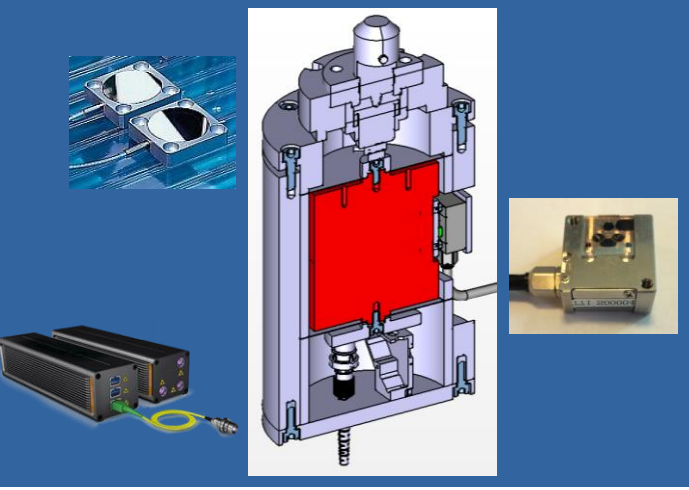
4. Save money by moving to a telecommunication wavelength where components are cheaper.

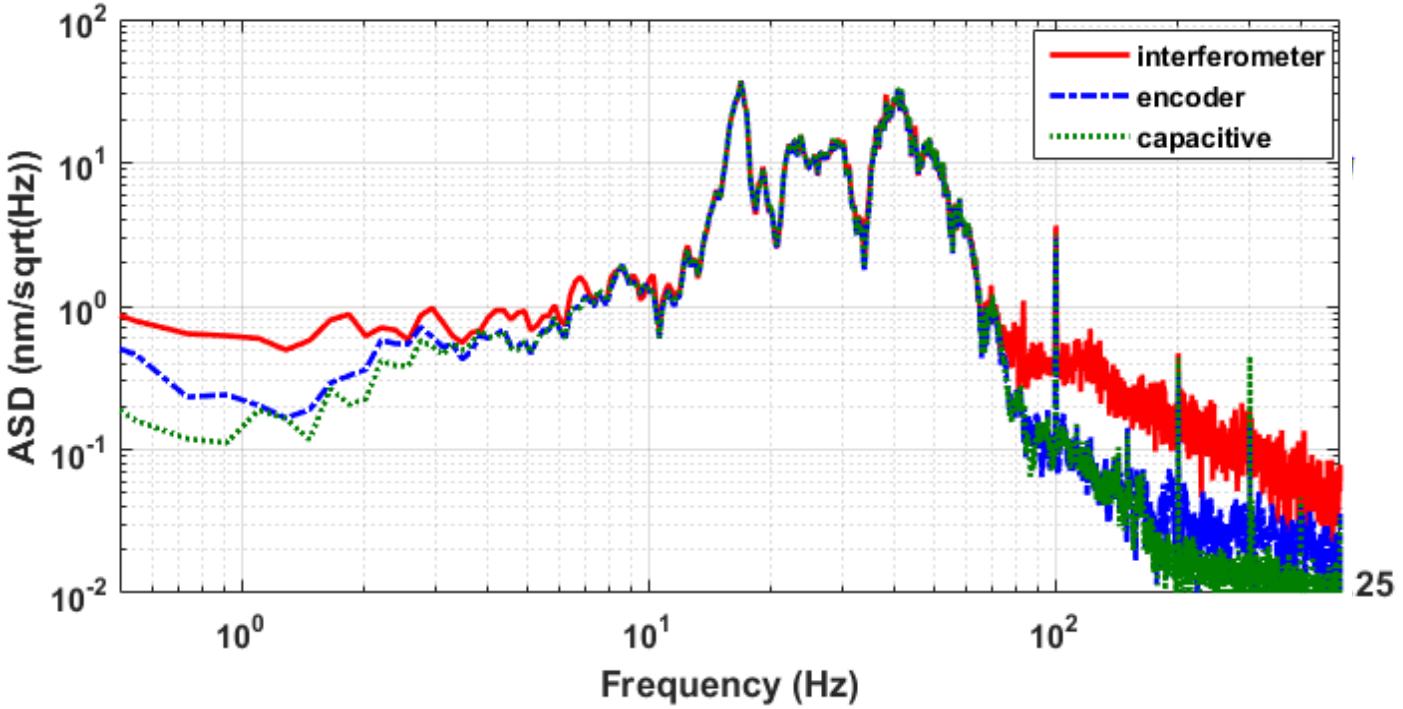
# Conclusions

- Three sub-nanometer displacement transducers were integrated into the same mechanical body and their resolutions were measured.
- Optical encoder had the best resolution but still not sufficient when combined with mechanics of a sensor.
- Multi-pass Michelson interferometer was implemented into the sensor in order to increase resolution even further.
- Sufficient resolution was achieved with 8 reflections and concept was proven to be feasible.

# Thank you for your attention!

# Measurement of transducers sensitivity.






| Transducer | Interfero-meter | Encoder | Capacitive |
|---|---|---|---|
| RMS of ambient vibration excitation (nm) | 221.29 | 221.46 | 223.82 |