Introduction to seismic sensors

(subject 3.2)

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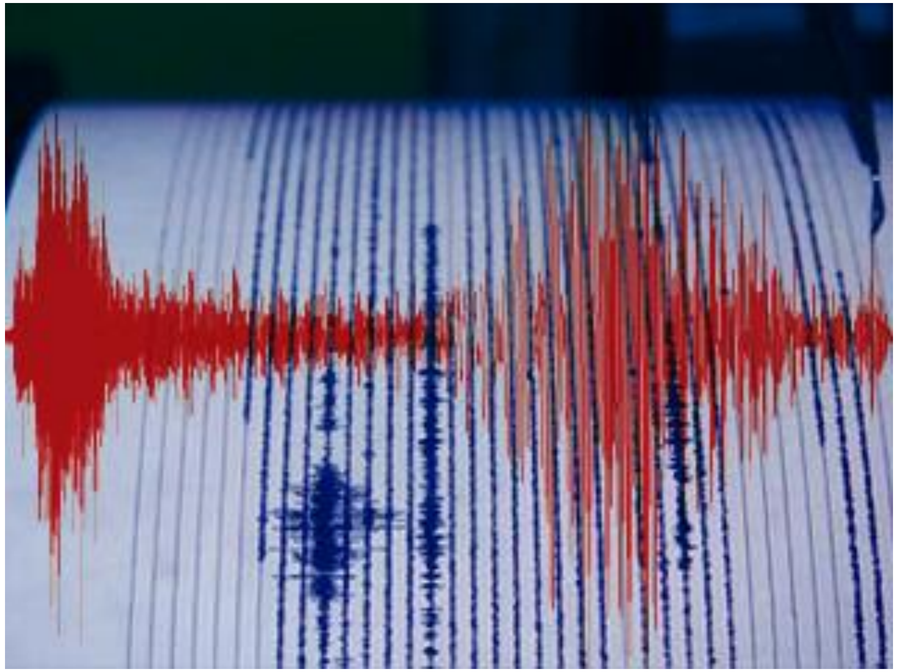
PACMAN meeting, CERN, 7 October 2014

What is seismic sensor?



Instrument which measures ground motion.

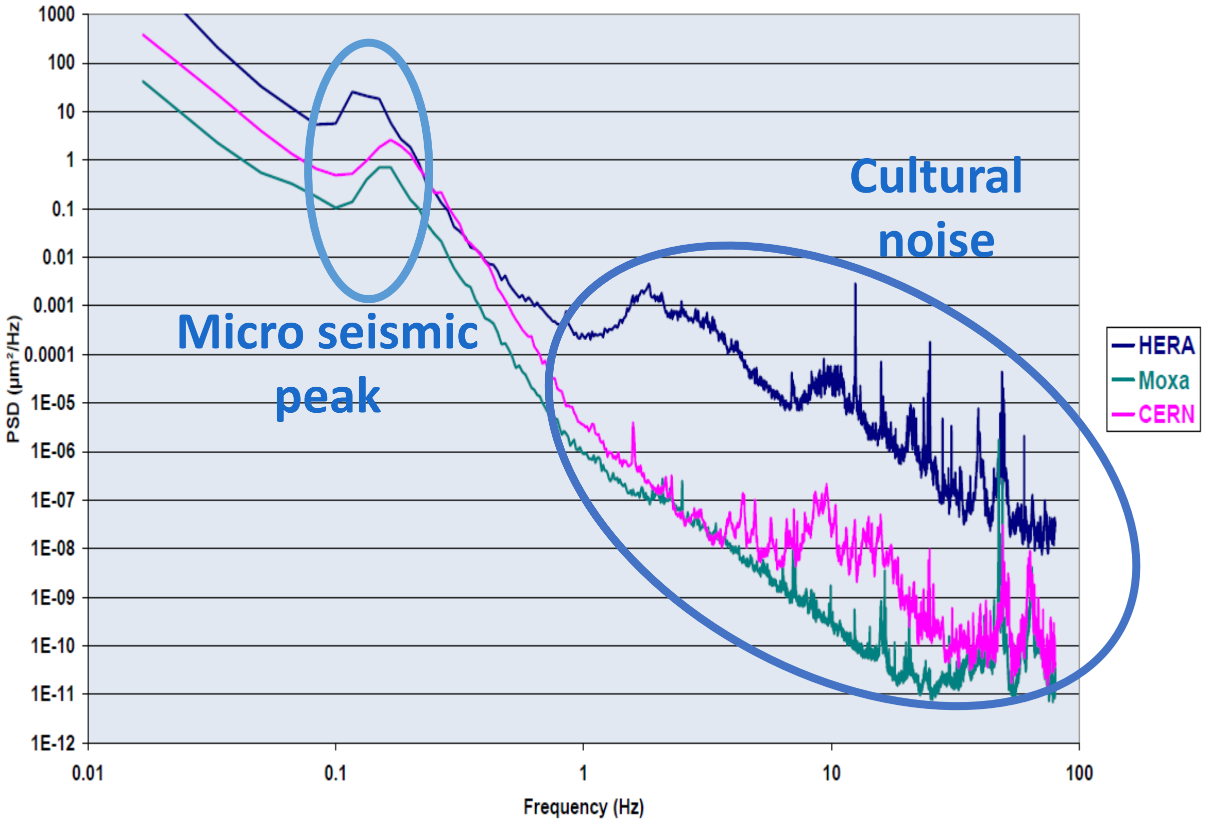
(Not only earthquakes!)

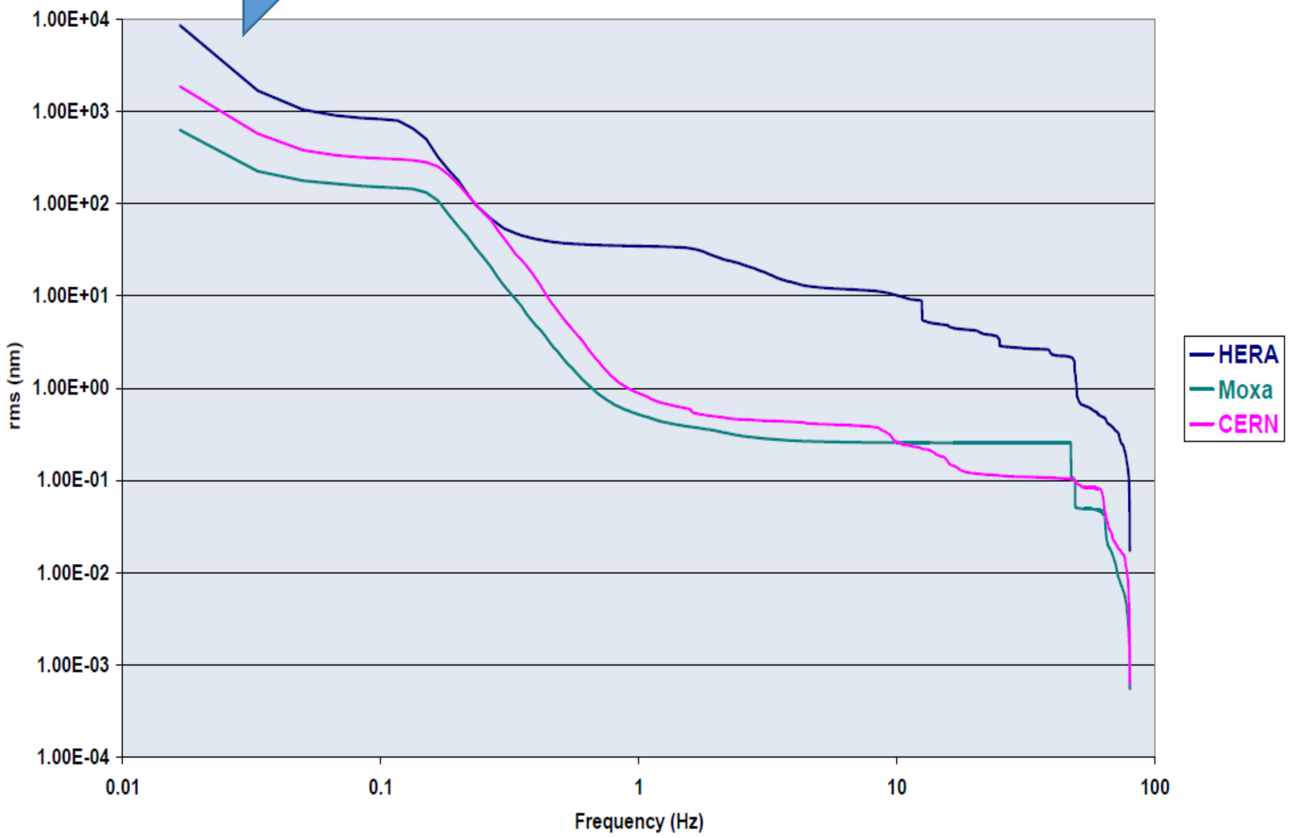
Ground Motion in frequency domain

Power Spectral Density – PSD of ground motion

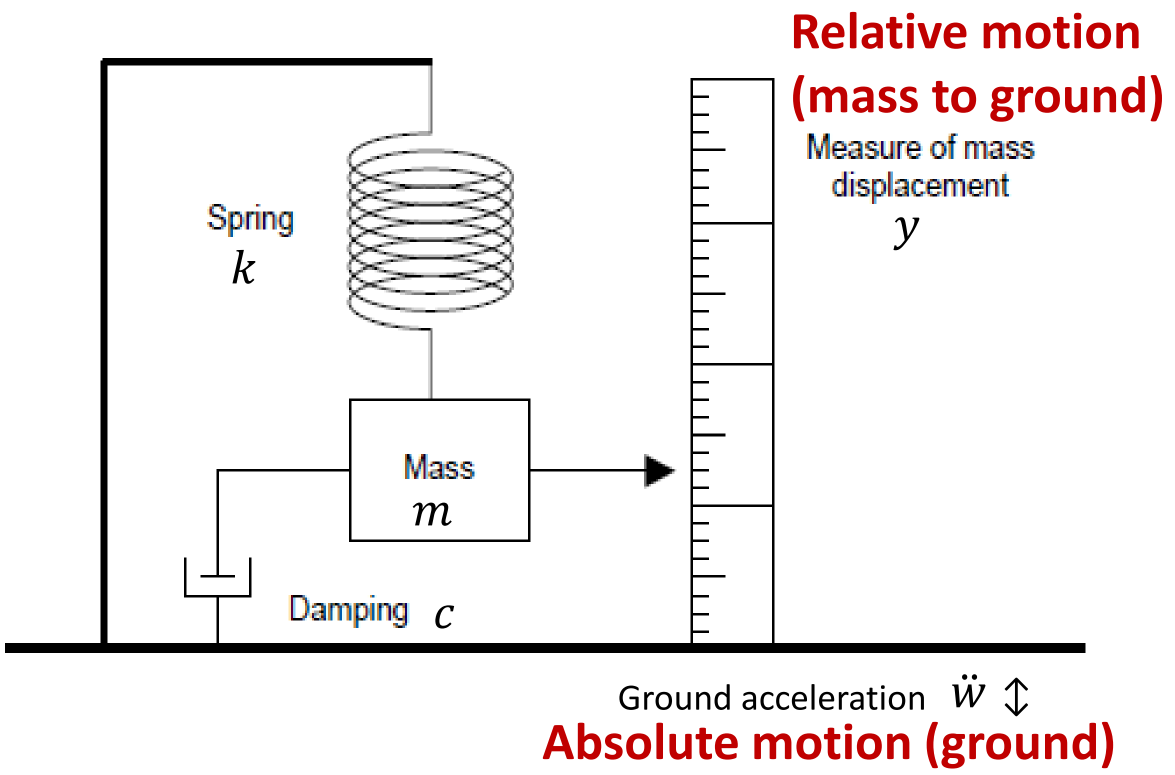
$$RMS\ motion = \sqrt{\int_{f_1}^{f_2} \left[\frac{Amp(f)}{\sqrt{Hz}}\right]^2 df}$$

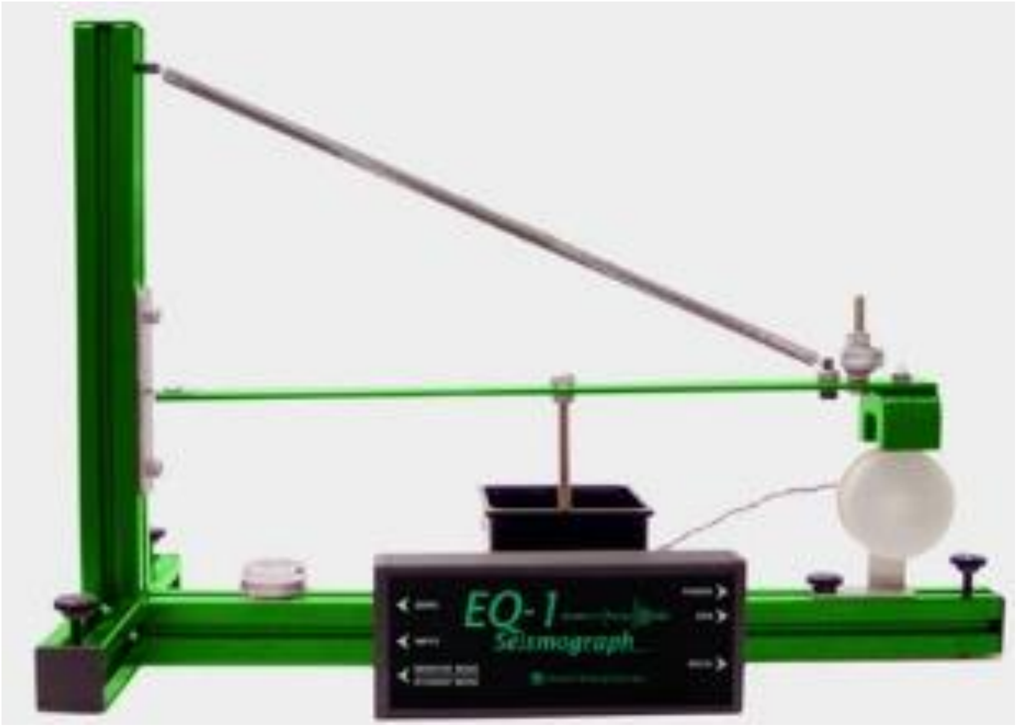
RMS of ground motion





How does seismic sensor work?





Dynamic described by 2nd Newton's law => Forced damped harmonic oscillator.

$$m\ddot{y} + c\dot{y} + ky = -m\ddot{w}$$

How does seismic sensor work?

Transfer functions:

Laplace transform

$$m\ddot{y} + c\dot{y} + ky = -m\ddot{w}$$

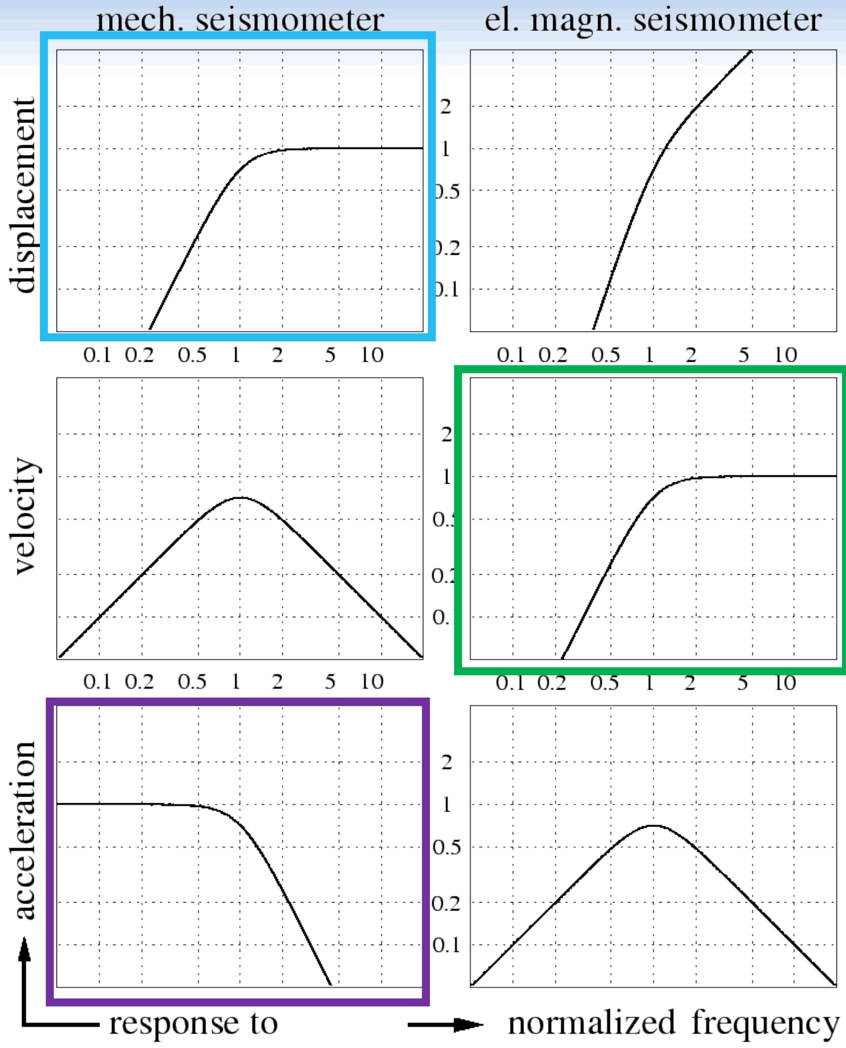
Natural frequency

$$\omega_0 = \sqrt{\frac{k}{m}}$$

$$T_{wy} = \frac{Y}{W} = \frac{relative\ displacement}{absolute\ displacement}$$

$$T_{\dot{w}\dot{y}} = \frac{\dot{Y}}{\dot{W}} = \frac{relative\ velocity}{absolute\ velocity}$$

$$T_{\ddot{w}y} = \frac{Y}{\ddot{W}} = \frac{relative\ displacement}{absolute\ acceleration}$$



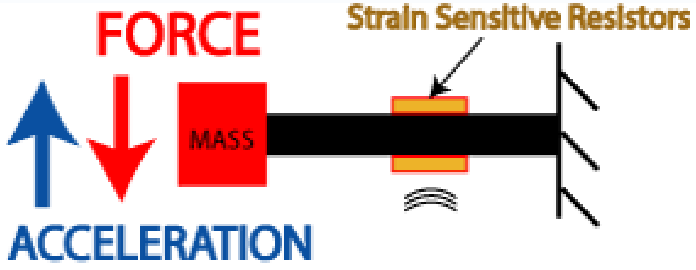
ω/ω_0

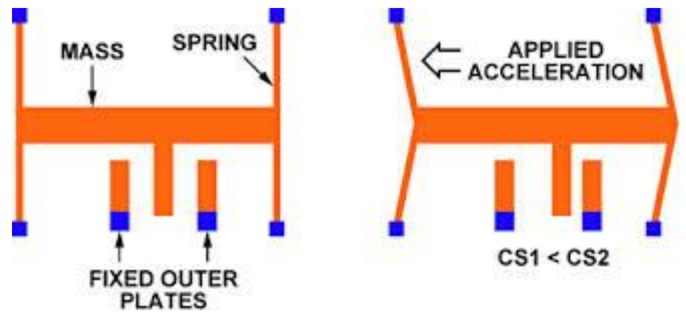
!! Information about absolute motion is in relative motion!!

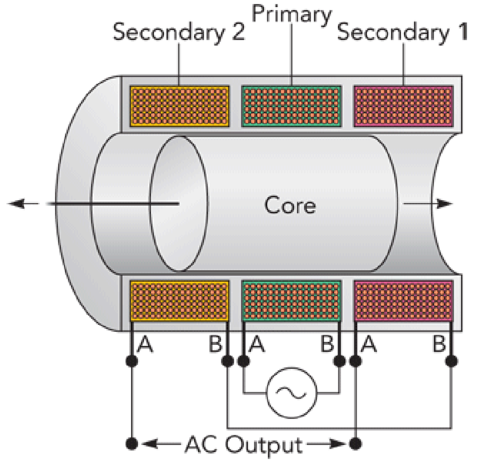
How we measure relative motion?

Using different types of transducers:

- **Pen** (mechanical seismometers - obsolete)
- **Resistive**
- **Capacitive**
- **Piezoelectric**
- **Optical** (Interferometers, encoders)
- **Inductive – coil + magnet**
- **Eddy current**
- **LVDT - Linear variable differential transformer**
- …







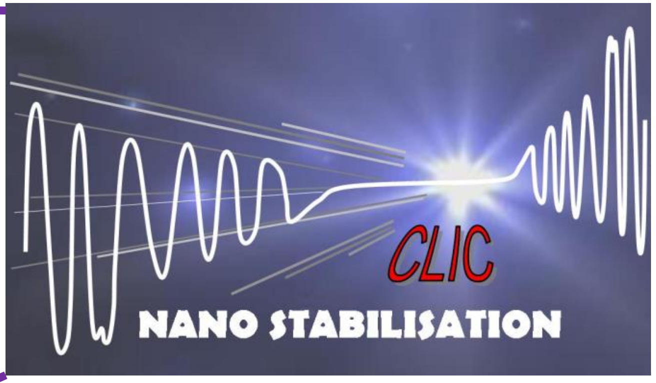
Seismic sensor parameters

- **Bandwidth** – f_{min} - f_{max}
- **Sensitivity *S*** – conversion factor from D,V,A to Volts
- **Self noise *N*** – determine resolution
- **Resolution *R* = *S*/*N*** – smallest measureable value
- **Dynamic range** – Max/Min measureable value
- **Active/passive** – need of power supply
- …

Velocity output bandwidth	*1 s – 100 Hz (Model CMG-6T-1), 10 s – 100 Hz (Standard) or 30 s – 100 Hz*
Velocity output sensitivity	*2 × 1200 V/m/s, (Standard) 2 × 2000 V/m/s or 2 × 1000 V/m/s*
Peak output	*±10 V (20 V peak-to-peak)*
Optional high gain sensitivity	*2 × 10000 V/m/s (adjustable)*
Lowest spurious resonance	*450 Hz*
Linearity	*> 90 dB*
Cross-axis rejection	*> 65 dB*
Electronics noise level	*–172 dB (rel. 1m2s-4Hz-1)*
Operating temperature	*–40 to +75 °C*
Temperature sensitivity	*< 0.6 V per 10 °C*
Mass recentring range	*±3 ° from horizontal*
Materials	*Hard anodised aluminium case Gold plated contacts O-ring seals throughout*
Case diameter	*154 mm*
Case height (with handle)	*207 mm*
Weight	*2.49 kg*
Power supply	*10 – 36 V DC*
Optional low power sensor	*5 V DC supply (output ±4.5 V)*
Current at 12 V DC	*38 mA*

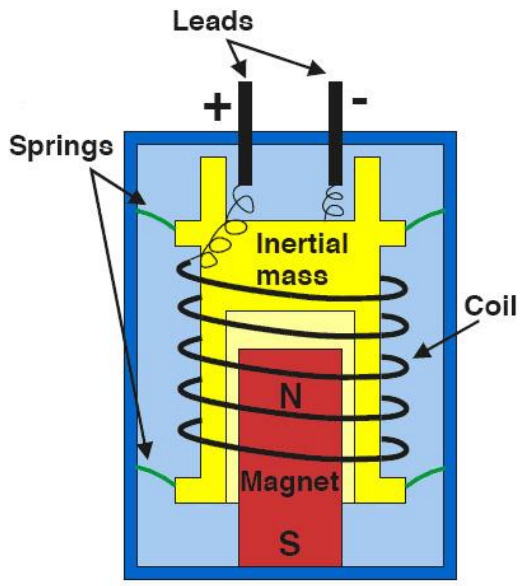
requirements on sensor

- Bandwidth = (0.1 – 100) Hz
- Resolution = ↑ Sensitivity and ↓ Self-noise
  - for R = 0.1um
  - for NANO STABILISATION R = 0.1nm
- Stray magnetic fields resistance
- Weight < few kg & compact size
- Temperature stability
- “Radiation resistance” => only for stabilisation
- Price ≈ 4000 sensors for CLIC
- …



Geophones

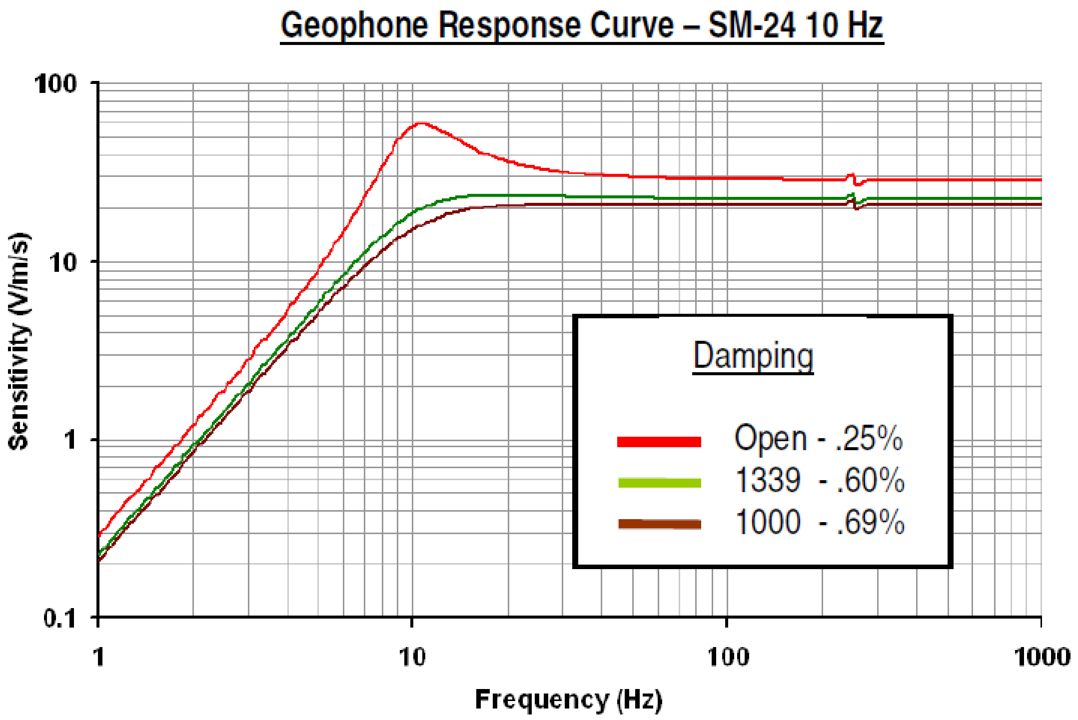
- **Output voltage proportional to ground velocity above natural frequency.**
- **Simple and compact solution**



requirements

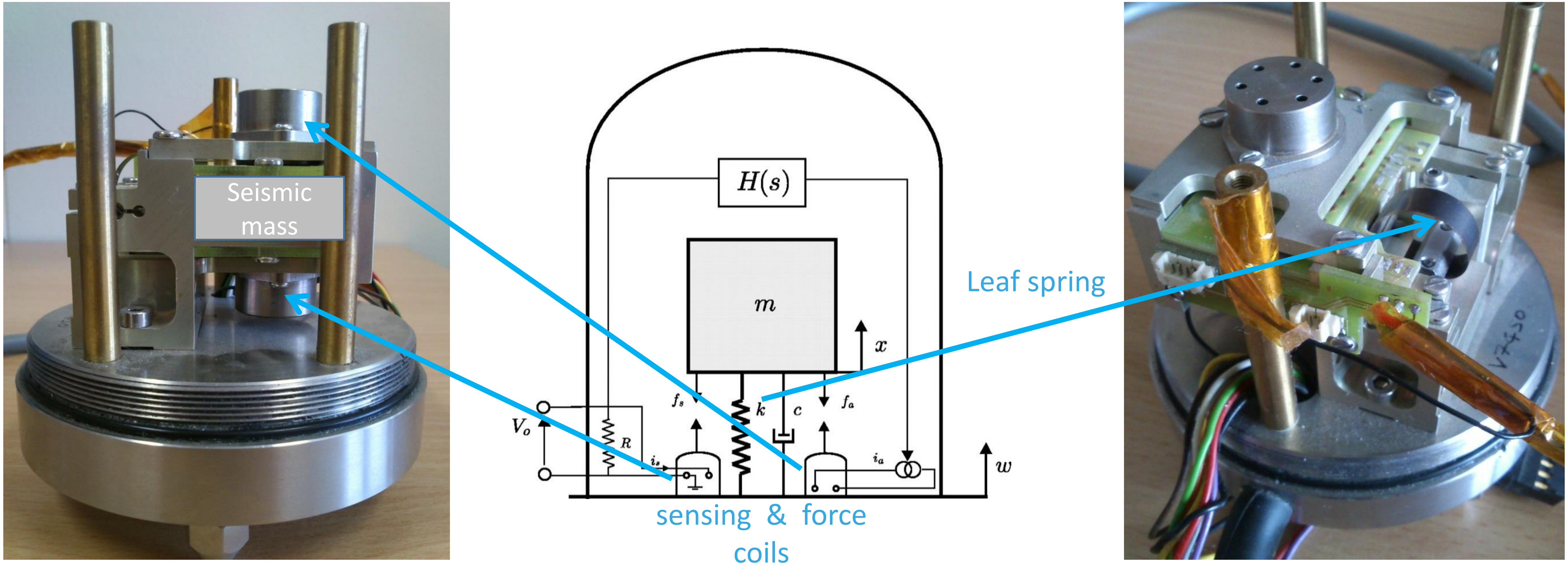
- ✓ Low noise
- ✓ Weight and size
- ✓ Price

- × Natural freq. > 10 Hz
- × Magnetic resistance



Geophones with feedback => seismometers

- **Utilise the feedback control of mass position to extend bandwidth to low frequencies.**



Geophones with feedback => seismometers

- **Output voltage is proportional to ground velocity in certain frequency bandwidth.**

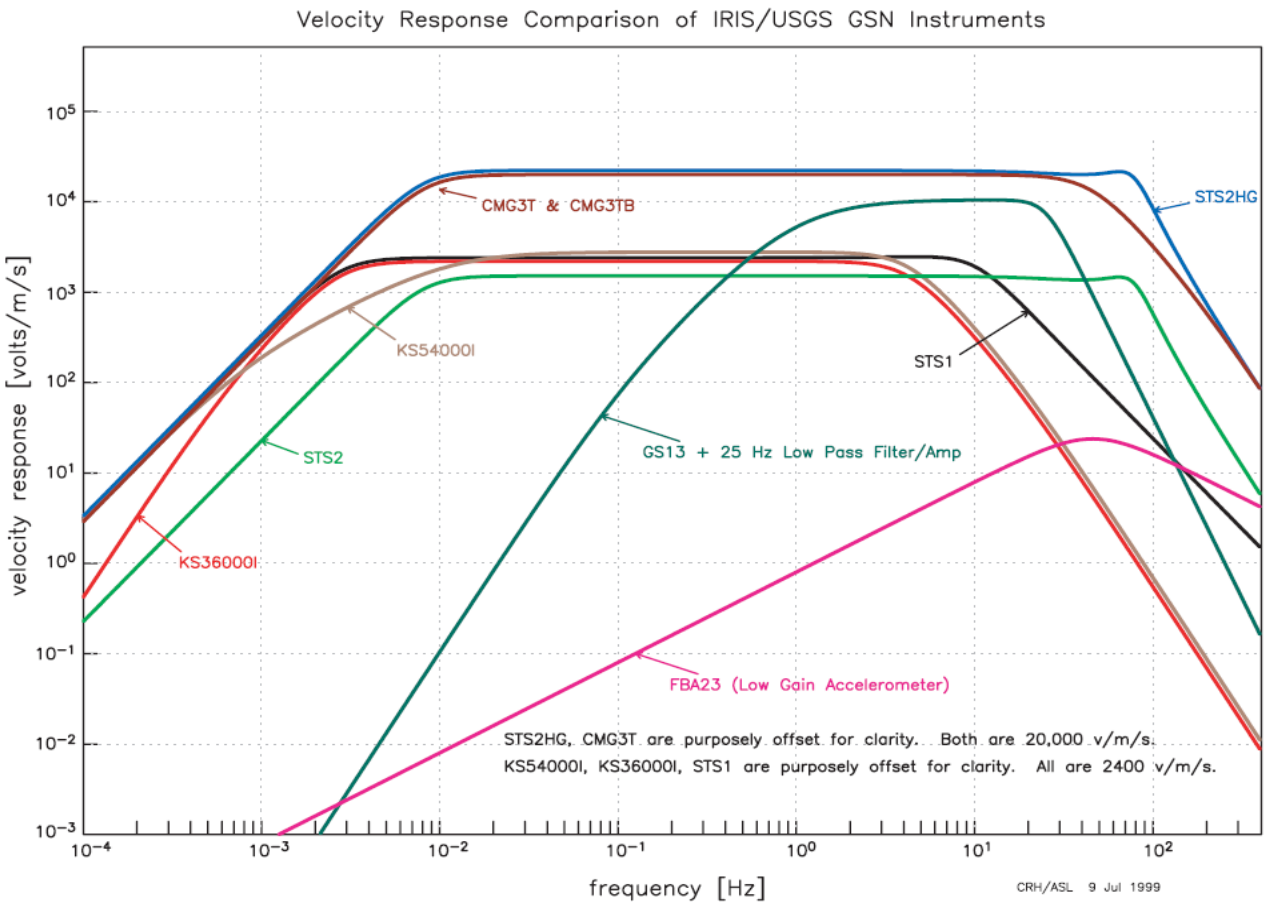


Figure 3. Frequency response of representative seismometers. Figure courtesy of R. Hutt, USGS/ASL.

requirements

- ✓ Very low noise
- ✓ Resolution
- ✓ Broad bandwidth
- • Weight and size
- × Magnetic resistance
- × Price

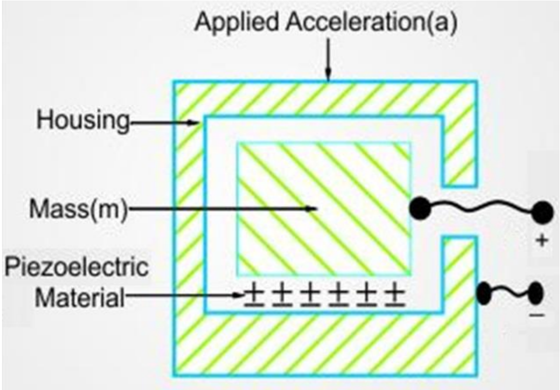
Accelerometers

- **Output voltage proportional to ground acceleration below natural frequency.**
- **Different types:**
  - **Piezoelectric, piezoresistive, capacitive, Force Balanced (FBA)**
- **Possibility of utilizing MEMS**
  - + size and price reduction
  - - high self noise

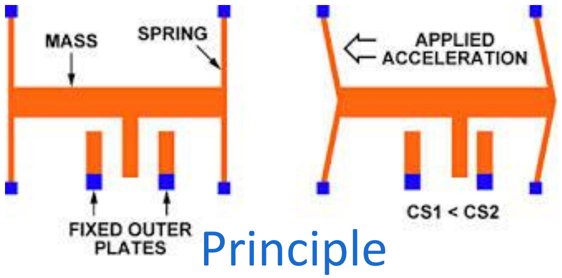
requirements

- ✓ Bandwidth
- ✓ Magnetic resistance
- • Price
- × Higher noise at lower freq.
- × Resolution

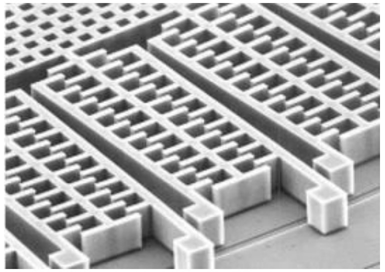
Piezoelectric



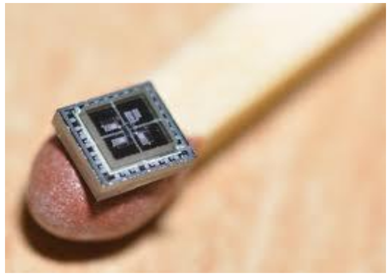
MEMS capacitive acc.



Principle



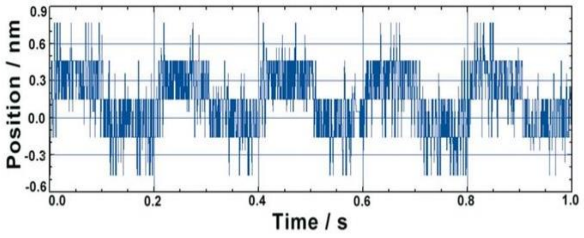
MEMS realisation

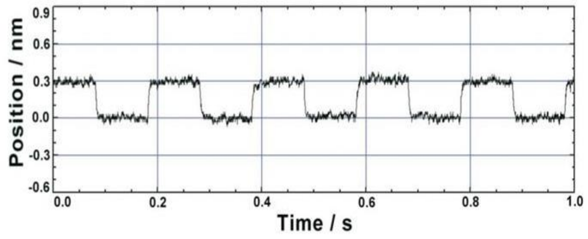


Final product

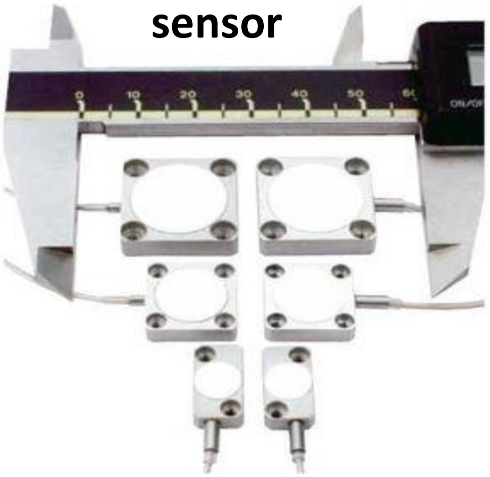
Noise in seismic sensors

Interferometer



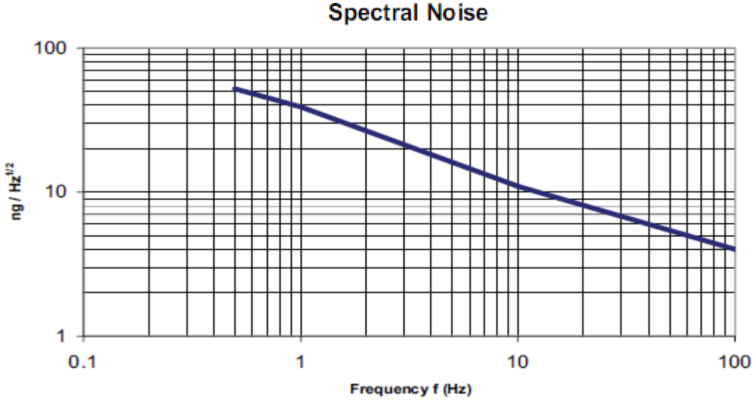


Capacitive sensor



- **Sources of noise:**
  - **Thermomechanical (Brownian) noise**
    - Molecular collisions with mass
  - **Thermoelectrical (Johnson) noise**
    - Random thermal excitation of charge carriers
  - **Schottky noise**
    - Random movement of charge across potential barriers
  - **Flicker *1/f* noise**
    - Impurities in semiconductors
  - **Discretisation noise**
    - ADC converters

Producer	Model	Noise [$um*s^{-2}/Hz^{1/2}$]
Endevco	87	0.9 @1Hz 0.25 @10Hz 0.1 @100Hz bb rms <4um*s^{-2}
Wilcoxon	731A	0.3 @2Hz 0.1 @10Hz 0.04 @100Hz
Brüel & Kjær	8340	14.7 @0.1Hz 14.7 @55Hz
PCB	393B31	0.6 @1Hz 0.1 @10Hz 0.04 @100Hz
COLIBRYS	SF1600S.A	3 in 0.1-100Hz BW
Metrozet	TSA-100S	rms 0.22@1Hz rms 0.2@10Hz rms 0.7@10Hz



Classification of seismic sensors

Output voltage proportional to:

- Displacement
- Velocity:
  - geophones
  - feedback geophones = seismometers
- Acceleration:
  - Accelerometers
  - Force Balanced Accelerometers (FBA)

By type of sensing transducer:

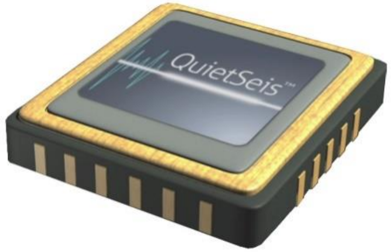
- Capacitive
- Inductive
- Piezoelectric
- Optical
- …

Other classifications:

- Bandwidth
  - Short period, Long period, Broad band, Very BB
- Signal intensity
  - Strong motion, High sensitivity

Few sensors and their producers

Producer	type of sensors
GURALP	Seismometers
ion (Sensor Nederland B.V.)	geophones
Sercel (Mark Products)	geophones
Kinemetrics (Streckeisen)	Seismometers + FBA
Nanometrics	Seismometers
REFTEK	Seismometers
Lennartz electronic	Seismometers
Metrozet	Seismometers + FBA
Eentec	FDBCK MET geophones + FBA
SINUS	Piezo-velocity sensor
GeoSIG	geophones + FBA
Endevco	accelerometers
Wilcoxon	accelerometers
DYTRAN	accelerometers
DJB Instruments	accelerometers
MMF	accelerometers
Brüel & Kjær	accelerometers
PCB	accelerometers
COLIBRYS	accelerometers
R-sensors	MET geophones + acc
METTECH	MET
GEOTECH INSTRUMENTS	Seismometers

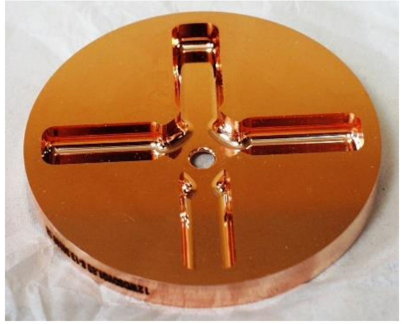


Secondments

- **Development of the seismic sensor for stabilisation of the Final Focus (of CLIC)**
- **Equivalent of 7 months**

  (already started)
- **Their measuring and control system**

- **High precision mechanic manufacturer**



- **3 months starting in March 2015**
- **Project:**
  - **Measurement and adjustment techniques for precision applications**

Thank you for your attention!