MEMS Gravimeter

Presentation
ENV-548

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Agenda

- Gravimetry
- Existing Tools
- MEMS Gravimeter - How does it work?
- Advantages & Disadvantages
- Applications

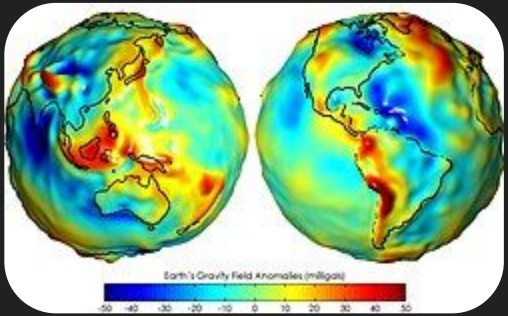
Background - Gravimetry

Gravimetry: measurement of the strength of the gravitational field => **small variations around 9.81m/s^2**

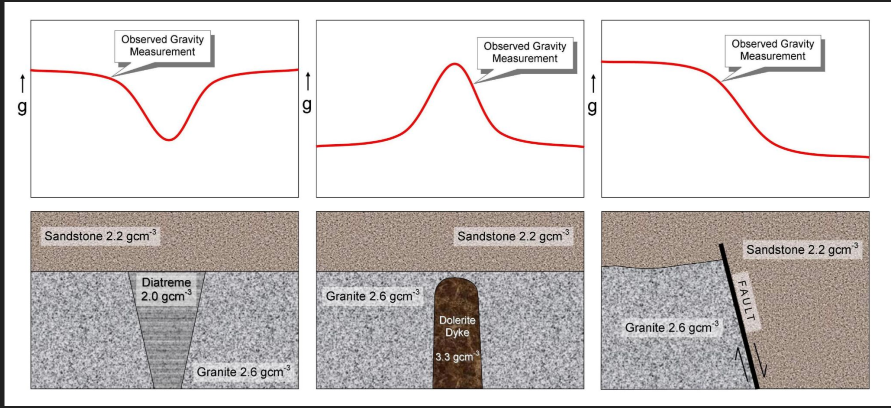
Unit: Gallileo [Gal] = 1 cm/s^2 = 10^{-2}m/s^2 **=>** g = 980 Gal

Applications:

- Volcano and aquifer monitoring
- Voids detection
- Gas and oil exploration.



Earth’s gravity measured by NASA [src]



Change in gravity based on terrain [src]

Types of Gravimeters

Absolute gravimeter:

- Test mass (macro- or microscopic e.g. prism or group of atoms) **fall** in a vacuum chamber
- Laser interferometer tracks fall
- Superconducting masses **suspended** in a magnetic field
- Mass cooled down to minimize the random accelerations from thermal noise

Relative gravimeter:

- **Spring-mounted mass** → measure stretch or compression using either light-based or capacitive-based method

GWR Superconducting Gravimeter [src]

Existing Gravimeters

Example: A10 Portable Absolute Gravity Meter

- **Type** - Absolute
- **Dimensions** - N/A
- **Weight** - 105 kg
- **Power Consumption** - 200 W
- **Precision** - 10 µGal
- **Price** - “Request a quote”

A10 Portable Absolute Gravity Meter [src]

Existing Gravimeters

Example: Scintrex CG-6 (relative gravimeter)

- **Type** - Relative
- **Dimensions** - 21.5 x 21 x 24 cm
- **Weight** - 5.5kg
- **Power Consumption** - 5.2W
- **Precision** - 0.1μGal
- **Price** - $ 100’000

Disadvantages of Existing Solutions

- Large
- Heavy
- Energy-intensive
- Delicate handling
- Long manufacturing leadtimes

Scintrex CG-6 [src]

MEMS Gravimeters (Relative Gravimeter)

1. **Inertial Transducer**

   Acceleration (a) → displacement (z) of proof-mass

   $$a = 4\pi^2 f^2 z$$

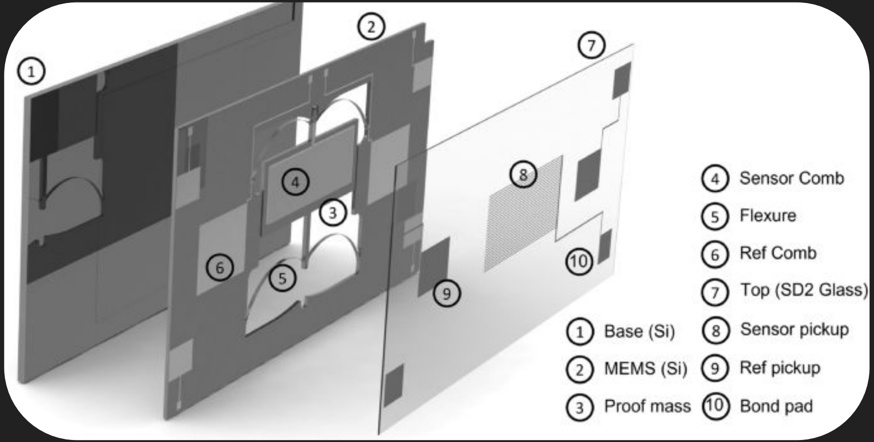
   f : fundamental resonant frequency

2. **Displacement Transducer**

   displacement → electrical signal

   a. Light-Based

   b. Capacitive



Wee-g Sensor Layers [src]

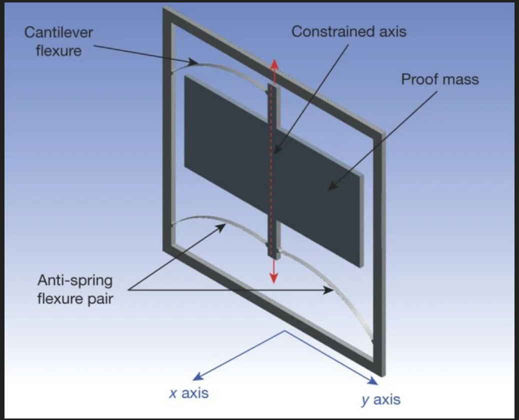
Transducers structure

Inertial Transducer:

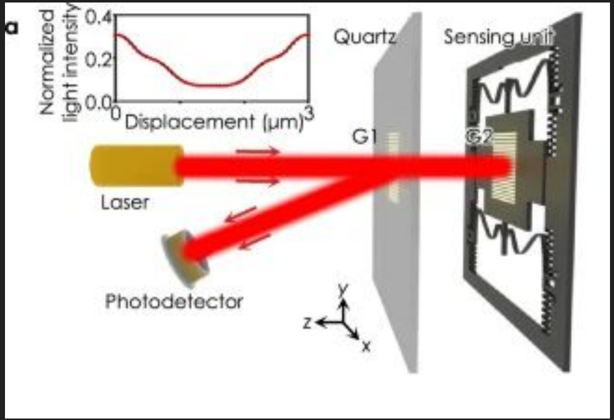
A proof mass is suspended using springs.

Displacement Transducer:

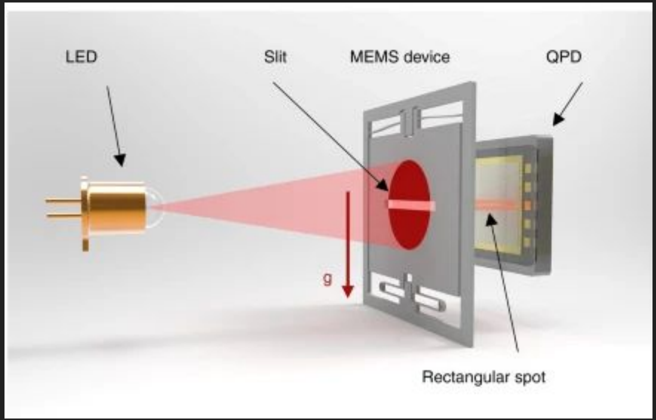
We pick up the displacement using either capacitive combs or light based techniques



Proof mass MEMS structure [src]



Optical grating-based displacement measurement unit [src]



Optical Slit-based displacement measurement unit [src]

Displacement Transducer

Light-Based

- \+ High-sensitivity: sub-picometer precision
- \- Requires additional off-chip components
- \- Less common

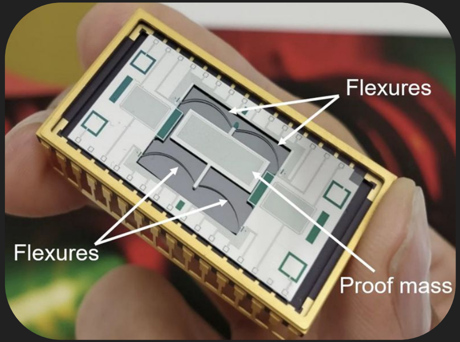
Capacitive

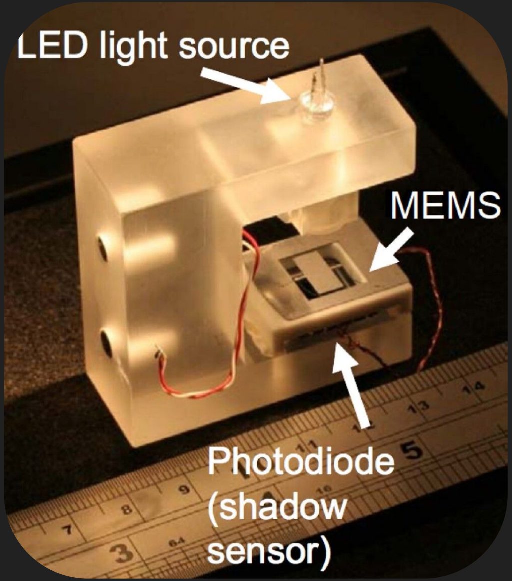
- \+ Stand-alone
- \+ Established technique
- \- Sensitive to noise: capacitive and electronic (1/f noise)
- \- Precision: tens of picometers

Example of MEMS Gravimeter

Example: Wee-g

- **Type** - Relative
- **Weight** - 5kg
- **Sensor Dimensions** - $12mm^2$
- **Casing Dimensions** - 30x30cm
- **Price** - “Request a quote”





Wee-g [1, 2, 3]

Advantages & Disadvantages

Advantages

- Cheaper than traditional Gravimeters
- Smaller => more portable
- Easier to produce in large quantities

Disadvantages

- Not widespread => still expensive
- Lower Dynamic Range
- Lower Robustness
- Susceptible to Environmental Factors
- Calibration requires a commercial gravimeter.

Challenges

- Mechanisms behind the high drift rates are not well understood.

  (150-270μGal/day compared to ~13μGal/day for the Scintrex CG-6)
- Active temperature compensation increases the overall size.
- Postfabrication tuning of the resonant frequency :
  - Increase it when handling the device to improve it's robustness.
  - Decrease it when measuring to improve it's sensitivity.

Applications

- Low-cost, singlepoint or array-based, time-lapse and continuous monitoring gravity surveys.
- Drone-based deployments (need for sub-Hz isolation, low power electronics) [src]
- Geophysical applications