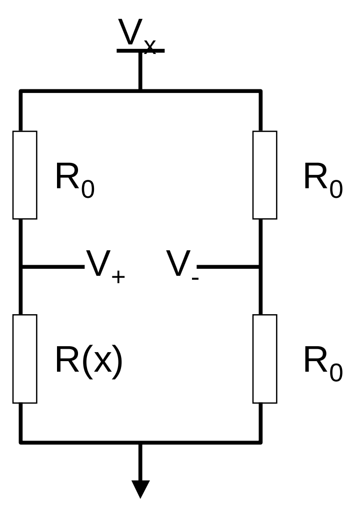
Sensors

- Resistive, Capacitive
- Strain gauges, piezoresistivity
- Simple XL, pressure sensor
- ADXL50
- Noise

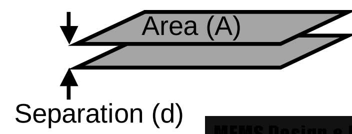
Resistive sensors

- $R(x) = R_0(1+\alpha x)$
  - E.g. TCR, gauge factor
- Generate thermal noise
- Wheatstone bridge minimizes sensitivity to
  - Nominal resistance value
  - Power supply variation
  - Other inputs
    - $R(x) = R_0(1+\alpha x)(1+\beta y)$



Capacitive sensors

- Typically used to measure displacement
- C ~= ε_0 A/d
- Can be used in Wheatstone bridge (with AC excitation)
- Sensitive to environmental coupling
  - Typically want amplifier very close
  - Typically need to shield other varying conductors
  - Definitely don’t want charge-trapping dielectrics nearby
- No intrinsic noise



Strain Sensors

- Shape change

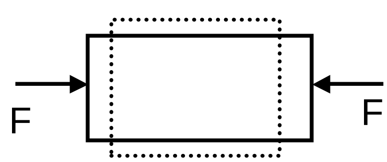
  $\delta L/L = \varepsilon$

  $\delta a/a = -\nu\varepsilon$ (Poisson’s ratio)

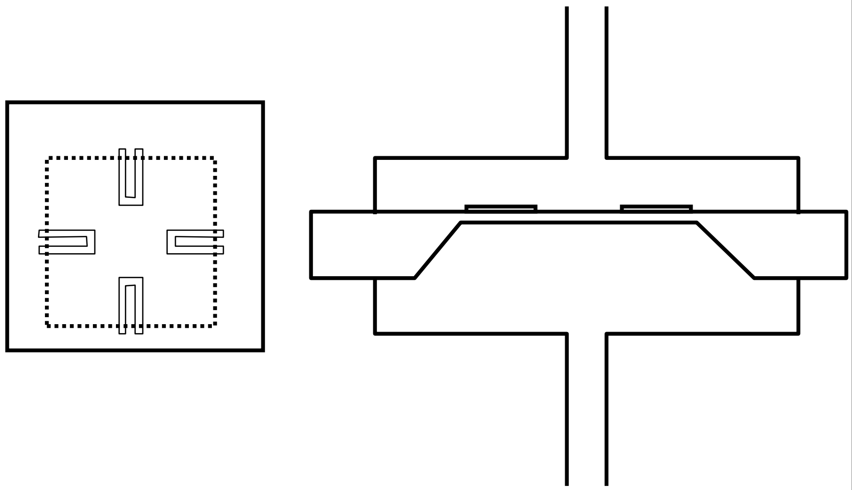
  - $R(a,b,L) = \rho\ L/A$
  - $R(\varepsilon) = R_0(1+(1+2\nu)\ \varepsilon\ )$
  - $R(\varepsilon) = R_0(1+G\ \varepsilon\ )$
- Piezoresistive

  $\rho(\varepsilon) = \rho_0(1+\ G_P\ \varepsilon\ )$

  - $R(\varepsilon) = R_0(1+(G_P+G)\ \varepsilon\ )$
  - G_P ~ -20, 30 (poly), ~100 (SCS)
- Piezoelectric
  - Strain generates charge, charge generates strain



Simple piezoresistive pressure sensor



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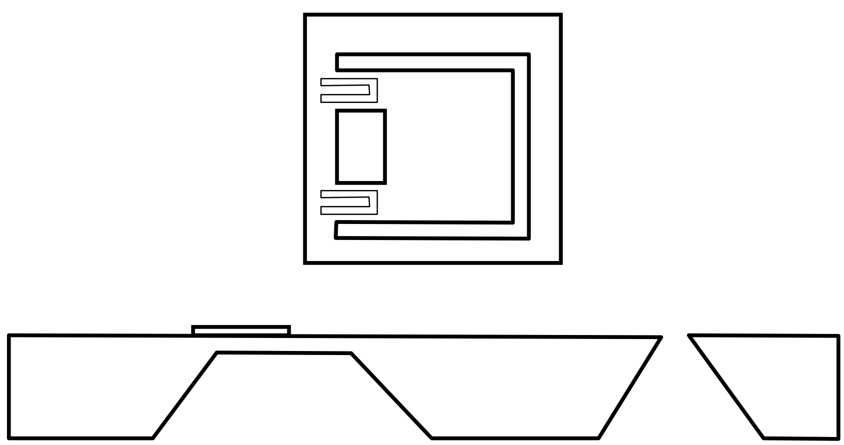
Simple piezoresistive accelerometer



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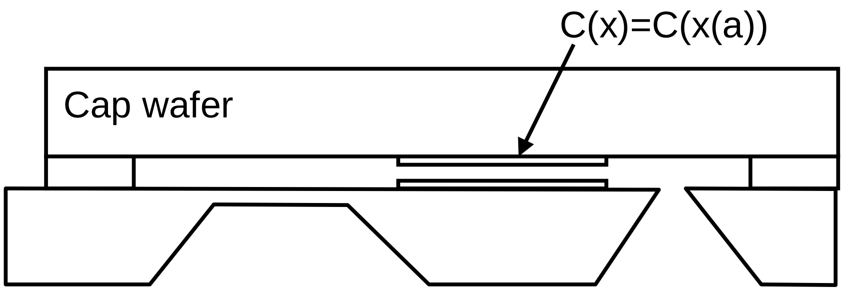
Simple capacitive accelerometer



- Cap wafer may be micromachined silicon, pyrex, …
- Serves as over-range protection, and damping
- Typically would have a bottom cap as well.

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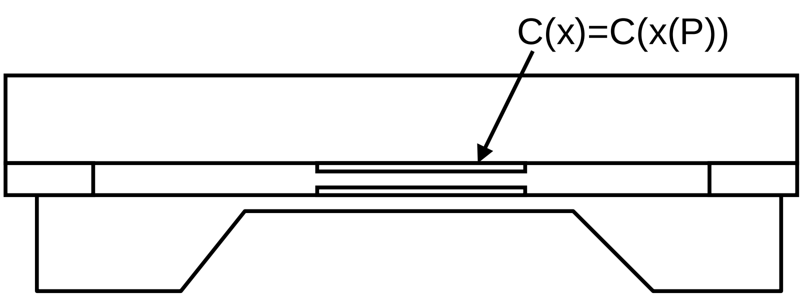
Simple capacitive pressure sensor



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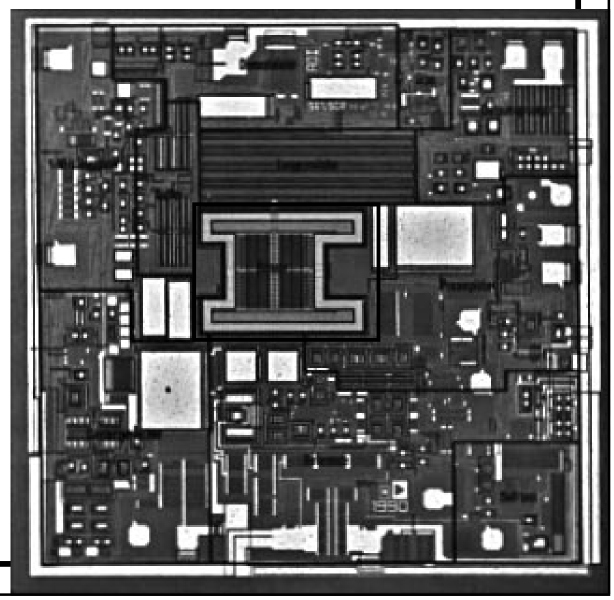
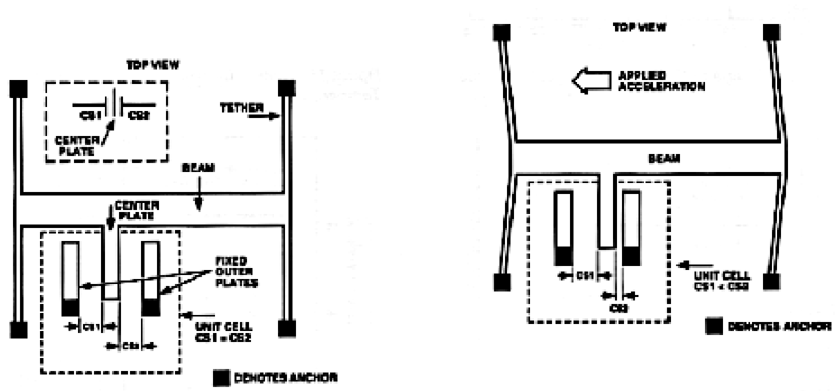
ADXL50 Accelerometer

- +-50g
- Polysilicon MEMS & BiCMOS
- 3x3mm die



ADXL50 Sensing Mechanism

- Balanced differential capacitor output
- Under acceleration, capacitor plates move changing capacitance and hence output voltage
- On-chip feedback circuit drives on-chip force-feedback to re-center capacitor plates.



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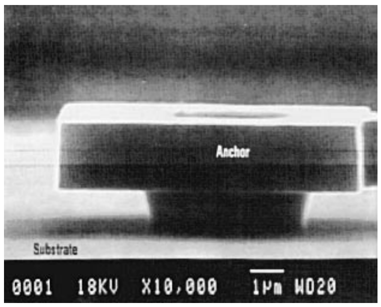
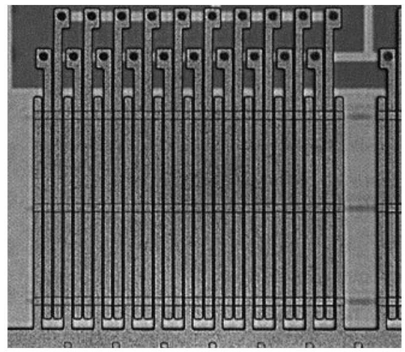
Analog Devices Polysilicon MEMS





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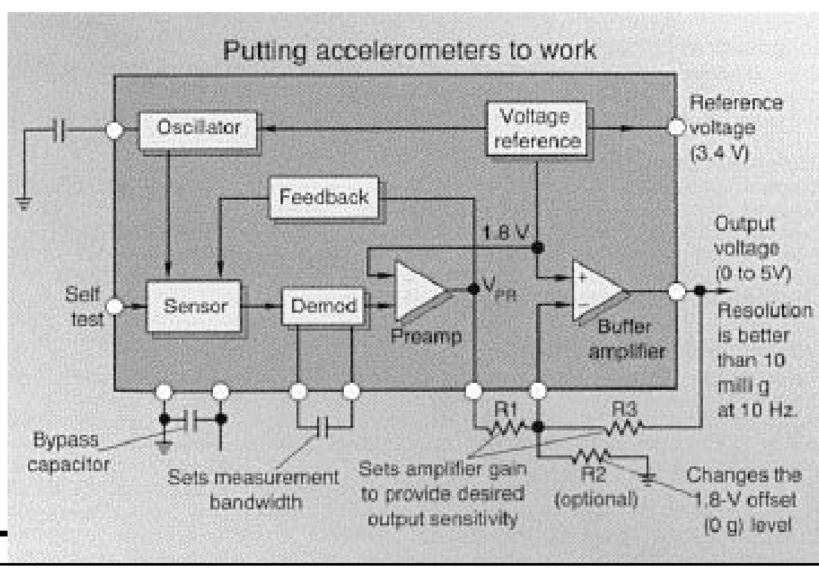
ADXL50 – block diagram



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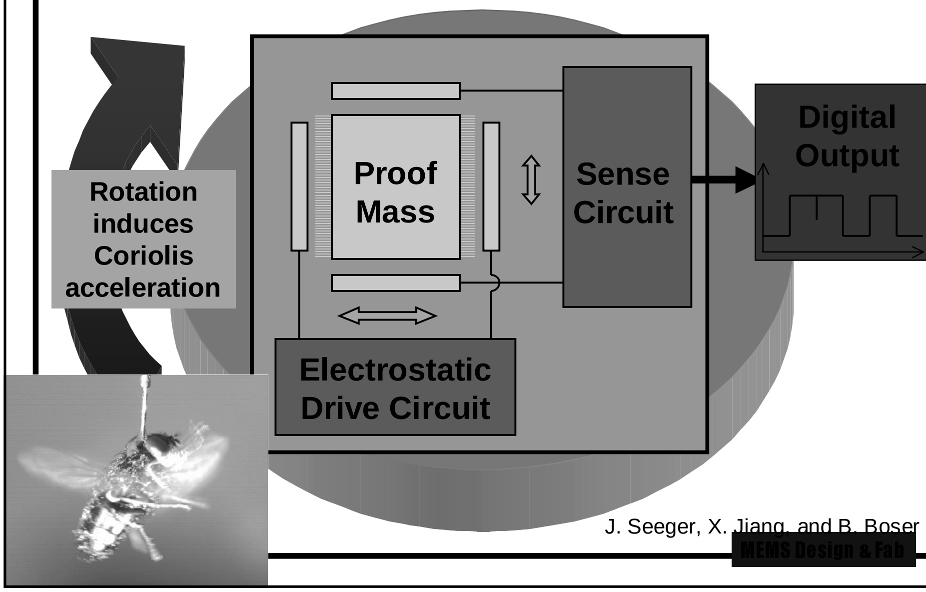
MEMS Gyroscope Chip



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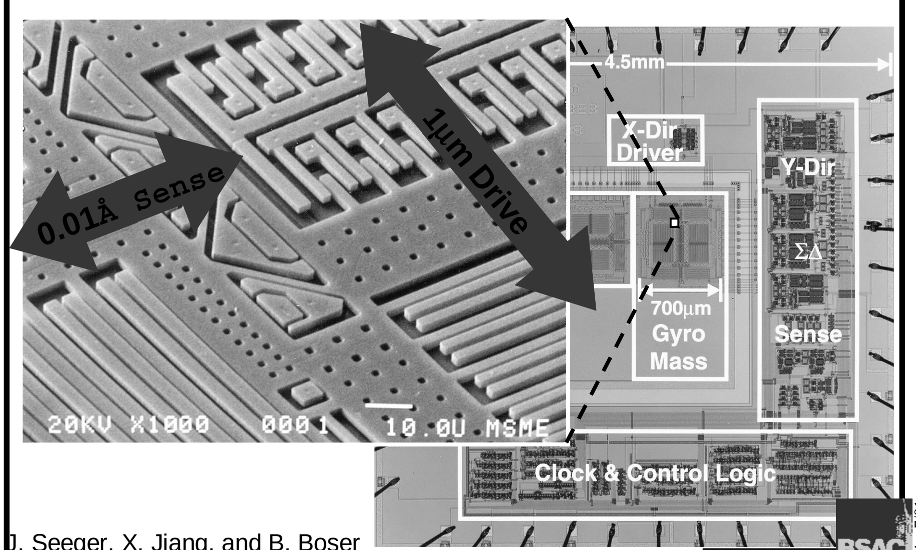
MEMS Gyroscope Chip



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Thermal Noise

- Fundamental limitation to sensor performance due to thermal noise
- "White" noise, Johnson noise, Brownian motion all the same
  - Not the same as flicker, popcorn, 1/f noise
- Equipartition theorem (energy perspective)
  - every energy storage mode will have ½ k_BT of energy
- Nyquist (power perspective):
  - Every dissipator will contribute $P_N = 4\ k_BT\ B$
  - B = bandwidth of interest in Hz

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Equipartition

- $\frac{1}{2} k_BT = 4\times10^{-21}$ J @ room temperature (300K)
- $\frac{1}{2} C V^2 = \frac{1}{2} k_BT$
  - C=1pF → V_n = 60uV (RMS value)
- $\frac{1}{2} k x^2 = \frac{1}{2} k_BT$
  - K = 1N/m → x_n = 0.06nm
- $\frac{1}{2} m v^2 = \frac{1}{2} k_BT$
  - m = 10^{-9} kg (~100um cube) → $v_n = 2\times10^{-6}$ m/s

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Nyquist

- $P_N = 4\ k_B T\ B$
- In a resistor
  - $P_N = V_N^2/R = 4\ k_B T\ B$
  - V_N = sqrt(4 k_BT R B)
  - = sqrt (4 k_BT R) sqrt(B)
  - If R = 1kZ then
  - V_N = 4nV/sqrt(Hz) sqrt(B)

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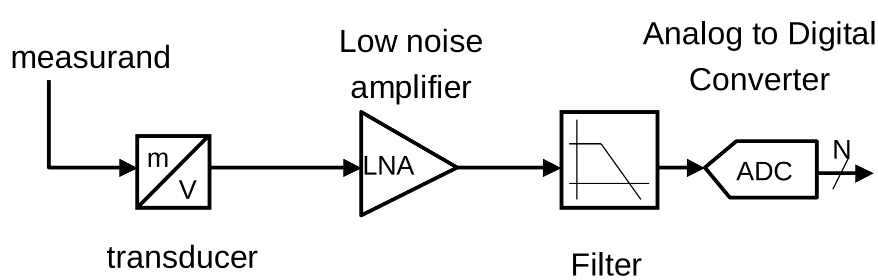
Sensor and interface electronics



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Summary

- Resistive and capacitive sensors most common
- Sensing, amplification, filtering, feedback on the same chip ~$2
- Minimum detectable signal limited by thermal noise

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