Lecture Outline

- Reading: Senturia, Chapter 1
- Lecture Topics:
  - Benefits of Miniaturization
  - Examples
    - GHz micromechanical resonators
    - Chip-scale atomic clock
    - Micro gas chromatograph

Benefits of Size Reduction: MEMS

- Benefits of size reduction clear for IC's in elect. domain
  - size reduction → speed, low power, complexity, economy
- MEMS: enables a similar concept, but...
  MEMS extends the benefits of size reduction beyond the electrical domain

Vibrating RF MEMS

Performance enhancements for application domains beyond those satisfied by electronics in the same general categories

- Speed
- Power Consumption
- Complexity
- Economy
- Robustness

- Frequency ↑, Thermal Time Const. ↓
- Actuation Energy ↓, Heating Power ↓
- Integration Density ↑, Functionality ↑
- Batch Fab. Pot. ↑ (esp. for packaging)
- g-Force Resilience ↑
Basic Concept: Scaling Guitar Strings

Frequ. Amplitude
Low Q
High Q
110 Hz Freq.
Vibrating “A” String (110 Hz)

Stiffness

Freq. Equation:

μMechanical Resonator

Metallized Electrode
Anchor
Polysilicon Clamped-Clamped Beam

Performance:

[Bannon 1996]

Frequency of a Stretched Wire

Frequency of a Clamped-Clamped Beam

Freq. Equation:

Frequency of a Clamped-Clamped Beam

[Press.=70mTorr]
**Basic Concept: Scaling Guitar Strings**

- **Guitar String**
- **μMechanical Resonator**

**Freq. Equation:**
\[ f_s = \frac{1}{2\pi} \sqrt{\frac{k_r}{m_r}} \]

- **Freq.**
- **Stiffness**
- **Mass**

**Performance:**
- **Lr = 40.8 μm**
- **mr = 10^-13 kg**
- **Wr = 8 μm, hr = 2 μm**
- **d = 1000 Å, Vp = 5 V**
- **Pn = -20 dBm**

- **μMechanical Filter Circuit**

**Micromechanical Filter Circuit**

- **Input**
- **Output**
- **Bridging Beam**
- **Coupling Beam**
- **Resonator**

**Design/Performance:**
- **R = 10 μm, t = 2.2 μm, d = 800 Å, Vp = 7 V**
- **fo = 1.51 GHz (2nd mode), Q = 11,555**
- **Pn = -5 dBm**
- **Rq = Rqo = 12 kΩ**

**3CC 3λ/4 Bridged μMechanical Filter**

- **Performance:**
  - \( f_s = 9 \text{Hz}, \, \text{BW} = 20 \text{kHz}, \, \text{PBW} = 0.2\% \)
  - I.L. = 2.79 dB, Stop. Rej. = 51 dB

- **Pn = -20 dBm**
- **μMechanical Disk Resonator**

- **Impedance-mismatched stem for reduced anchor dissipation**
- **Operated in the 2nd radial-contour mode**
- **Q ~ 11,555 (vacuum); Q ~ 10,100 (air)**
- **Below 20 μm diameter disk**

**1.51-GHz, Q=11,555 Nanocrystalline Diamond Disk μMechanical Resonator**

- **Polysilicon Stem**
- **CVD Diamond μMechanical Disk Resonator**
- **Ground Plane**

**Design/Performance:**
- **R = 10 μm, t = 2.2 μm, d = 800 Å, Vp = 7 V**
- **fo = 1.51 GHz (2nd mode), Q = 11,555**

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**163-MHz Differential Disk-Array Filter**

**Linear MEMS in Wireless Comms**

**Miniaturization of RF Front Ends**

**Multi-Band Wireless Handsets**

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**163-MHz Differential Disk-Array Filter**

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**Miniaturization of RF Front Ends**

**Multi-Band Wireless Handsets**
All High-Q Passives on a Single Chip

- Vibrating Resonator
  - 1.5-GHz, Q~12,000
  - 62-MHz, Q~161,000
- Optional RF Oscillator Ultra-High Q Tanks
- Low Freq. Reference Oscillator Ultra-High Q Tank
- CDMA RF Filters (869-894 MHz)
- GSM 900 RF Filter (935-960 MHz)
- PCS 1900 RF Filter (1930-1990 MHz)
- DCS 1800 RF Filter (1805-1880 MHz)
- CDMA-2000 RF Filters (1850-1990 MHz)
- WCDMA RF Filters (2110-2170 MHz)