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Thermally Induced-Noise Reduction Using an Electrostatic Force Feedback

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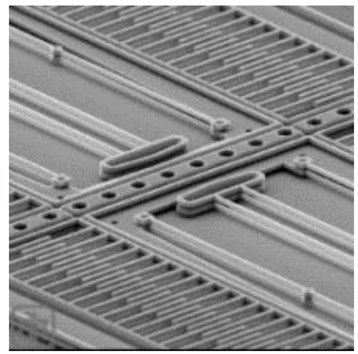
Introduction to MEMS

- MEMS gave versatile sensing solutions
  - Gyroscope
  - Accelerometer
  - Bio-Sensors



- MEMS have various advantages
  - Low cost and high performance
  - Small size

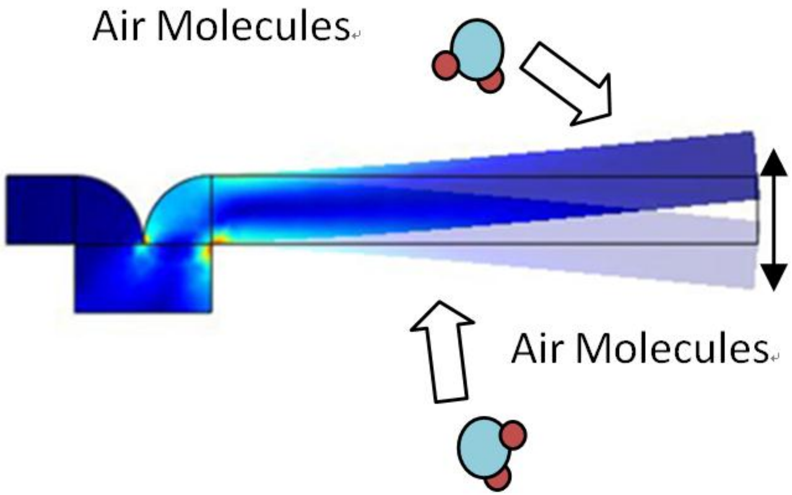
Thermal Noise in MEMS

- Thermal Agitation

  -Caused by temperature fluctuation

  -Inconsiderable in macro-scale

  -Becomes significant in micro-scale



Thermal Noise in MEMS

- Displacement of a mass-spring oscillator

$$\frac{1}{2}k\langle x^2\rangle = \frac{1}{2}K_BT$$ [1]

k= spring constant

x= mean-square displacement

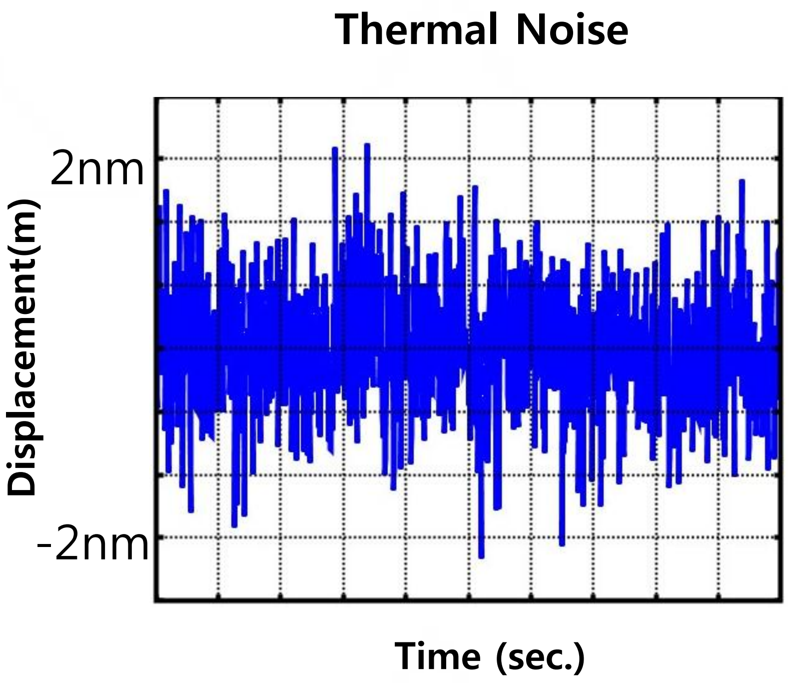
K_B=1.38e-23 J/K (Boltzmann's constant)

T= temperature

Thermal Noise in MEMS

Example) At T=300K, a micro cantilever with an effective stiffness of k=1e-3[N/m] will have an expected displacement amplitude <x> about ~2nm.

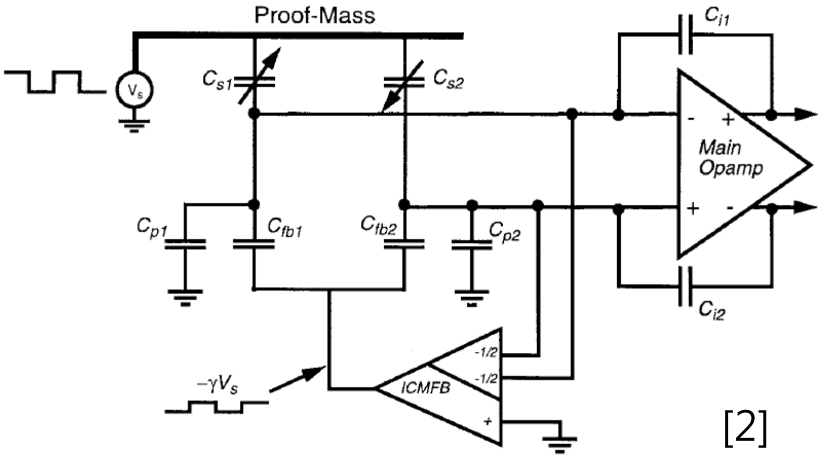
Not desirable for devices such as AFM which handles molecular scale measurements.



Electrostatic Force Feedback

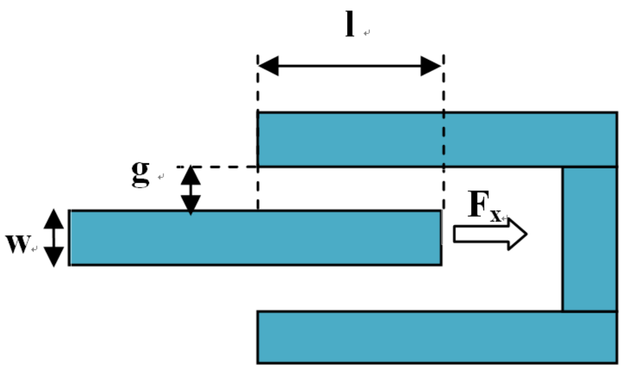
Previous usages of force feedback

- Extend sensor bandwidth beyond ω_o.[2]
- Nonlinearities in capacitive pickoff minimized[2]
- Decrease spring constant for high performance[2],[3]



[2]

Electrostatic Force Feedback



l	Overlap of the fingers
g	Gap between the fingers
w	Width of a finger
h	Thickness of the device
N	Number of fingers

Table 1. Important geometric variables for comb drive

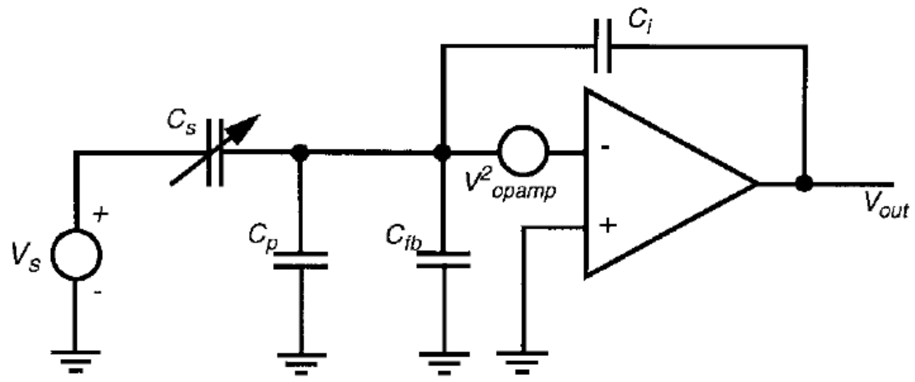
$$F_{electrostatic} = N\varepsilon_0 V^2 \frac{h}{g} \ [N]$$

$$x = \frac{\varepsilon_0 h N}{g \cdot k_x} V^2 \ [m]$$

$$C = \frac{2\,N\,\varepsilon_0 h \cdot l}{g}$$

Electrostatic Force Feedback

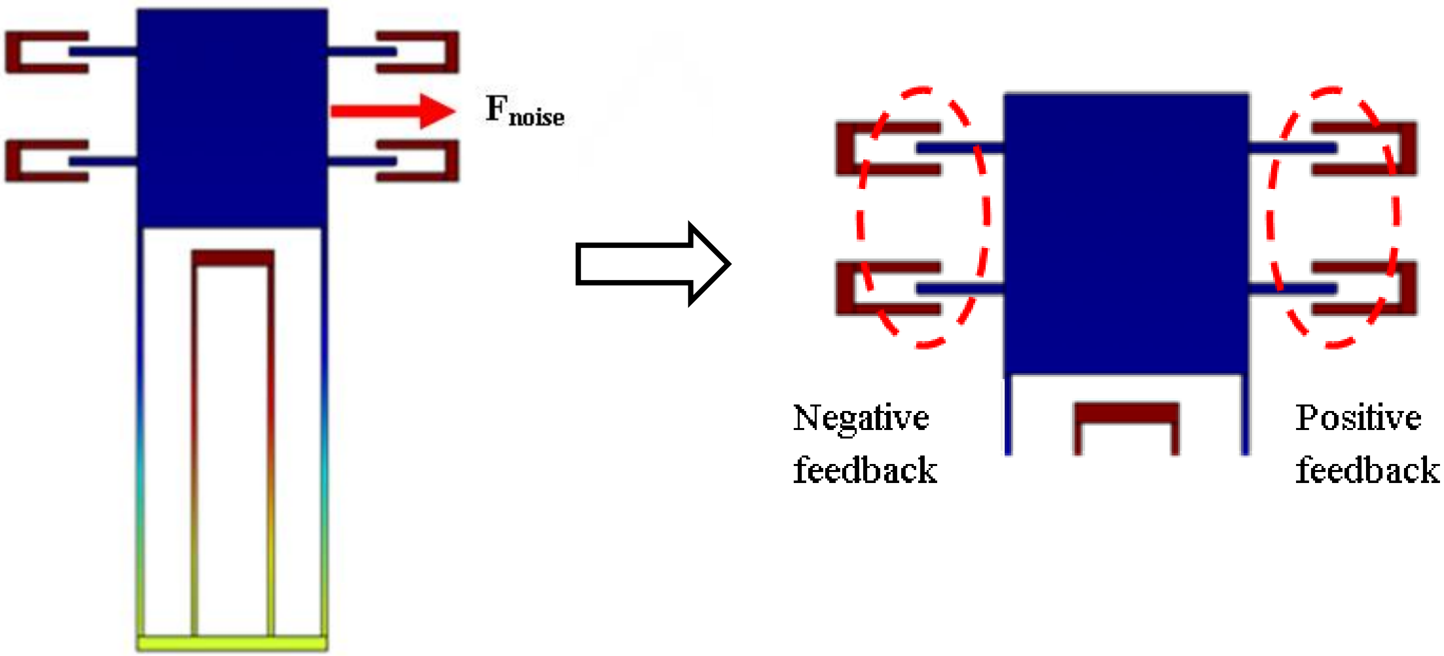
- Single-ended sensing interface
  - position measurement by applying Vs pulse at capa citive half bridge[2].
  - Capacitive imbalance cause different amount of cha rge flow[2].



Single-ended representation for op-amp thermal noise analysis. [2]

Modeling in COMSOL

- MEMS> 2D-Plane Stress & Electrostatics

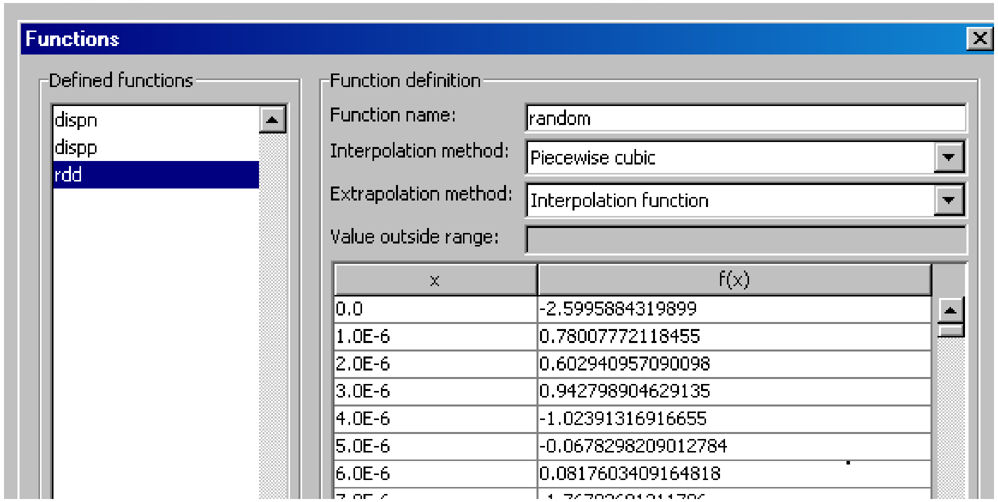


Modeling in COMSOL

- Modeling Random Noise

  Option > Functions >New > File

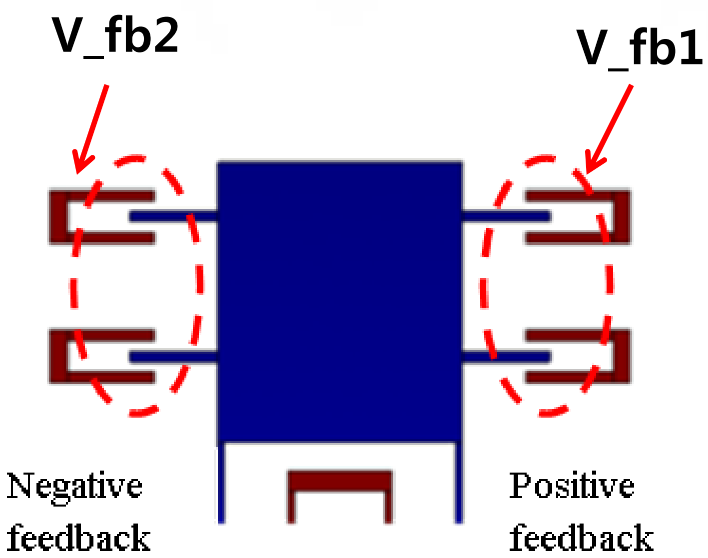
Random arrays of numbers were created using MATLAB.



Global Expression > F_{noise} = (amplitude) * random(t)

Modeling in COMSOL

- Feedback Voltage Expression



$$F_x = F_{Electrostatic}$$

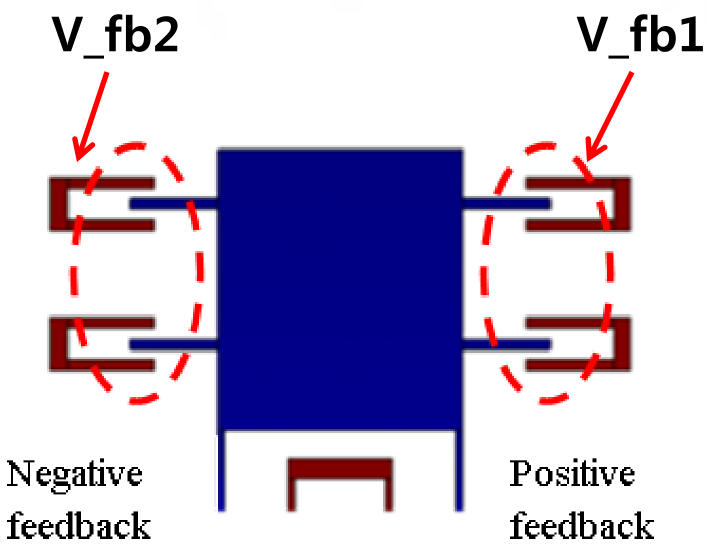
$$x \cdot k_x = N\varepsilon_0 V^2 \frac{h}{g}$$

$$V\_fb1 = \sqrt{\frac{g \cdot k_x}{\varepsilon_0 hN} \cdot \frac{d(disp_n)}{dt}}$$

$$V\_fb2 = \sqrt{\frac{g \cdot k_x}{\varepsilon_0 hN} \cdot \frac{d(disp_p)}{dt}}$$

Modeling in COMSOL

- Feedback Voltage Expression



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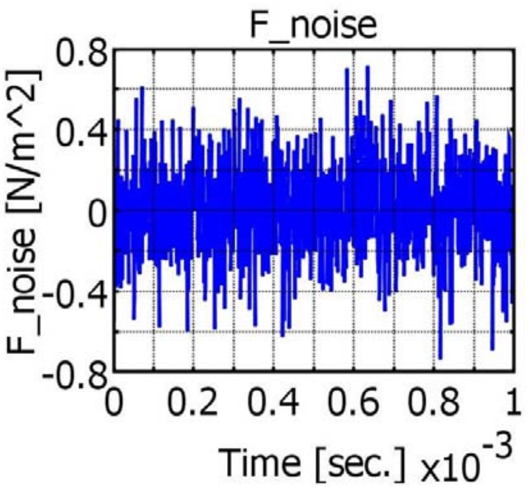
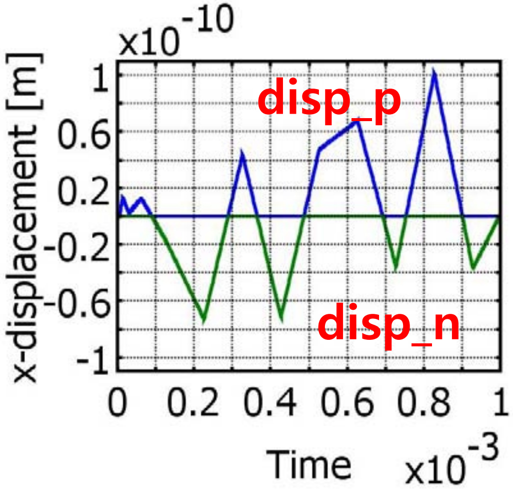
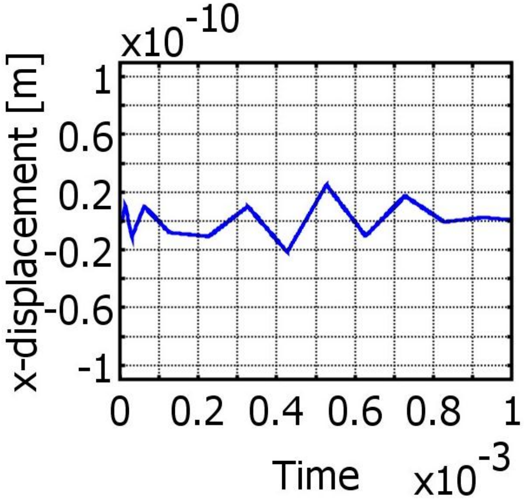
Modeling in COMSOL

- Summary of Simulation





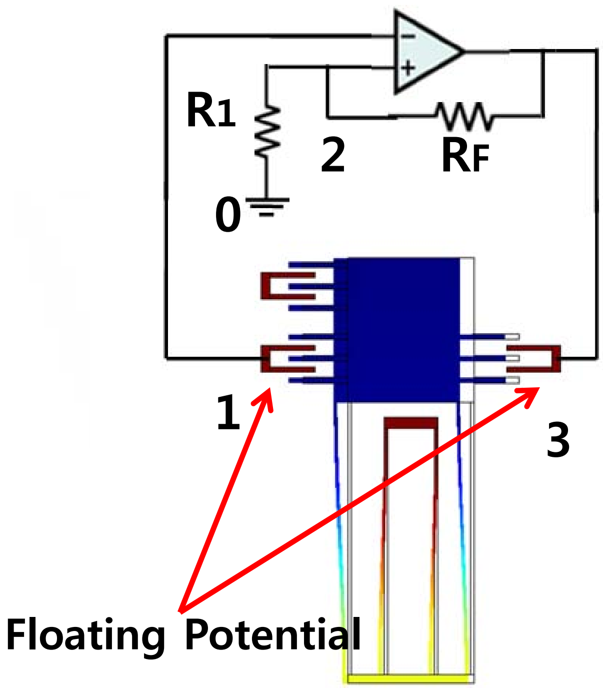


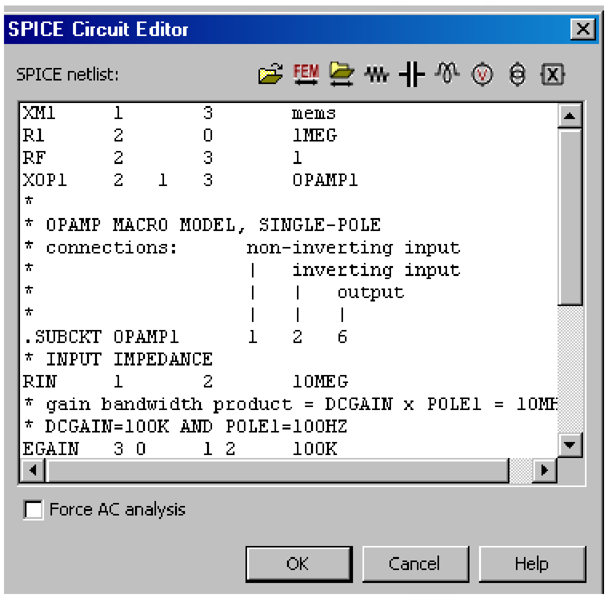
① Apply Noise > ② Obtain disp. > ③ Apply Feedback V

Challenges in COMSOL

- Modeling sensing interface with SPICE

Physics > SPICE Circuit Editor





Conclusion

- Electrostatic force feedback reduces the amplitude of noise induced displacement
- More careful modeling necessary for mor e significant reduction
  - Randomized noise
  - Realistic Geometry
  - Sensing Interface

References

[1] T.B. Gabrielson, "Mechanical-Thermal Noise in Micromachined Acoustic and Vibration Sensors", IEEE Transactions on Electron Devices, Vol.40, 5 May 1993, pp. 903-909

[2]M. Lemkin, B. E. Boser, "A Three Axis Micromachined Accelerometer with a CMOS Position-Sense Interface and Digital Offset-Trim Electronics", IEEE J. Solid-State Circuits 34(4) (1999) 465 456.

[3] M. Handtmann, R. Aigner, A. Meckes, G. K. M. Watchutka. "Sensitivity Enhancement of MEMS Inertial Sensors Using Negative Springs and Active Control", Sensors and Actuators A 97-98(2002) 153-160.

[4] http://pakogom.files.wordpress.com/2008/06/main_accelerometer20080609.png

[5] http://mems.sandia.org