MEMS Capacitive Sensing for Motion Tracking
Functional Requirements List and Performance Specifications

Dave Brennan
Advisors Dr. Shastry and Dr. Timpe

Introduction:

The main motivation for the capacitive sensing project for Microelectromechanical systems (MEMS) motion tracking was for biomedical applications. MEMS are used in a wide application of devices today such as an accelerometer in a car for crash detection, or such as this project, a biosensor.

The MEMS device of this project contains cantilever beams that oscillate at a natural frequency.

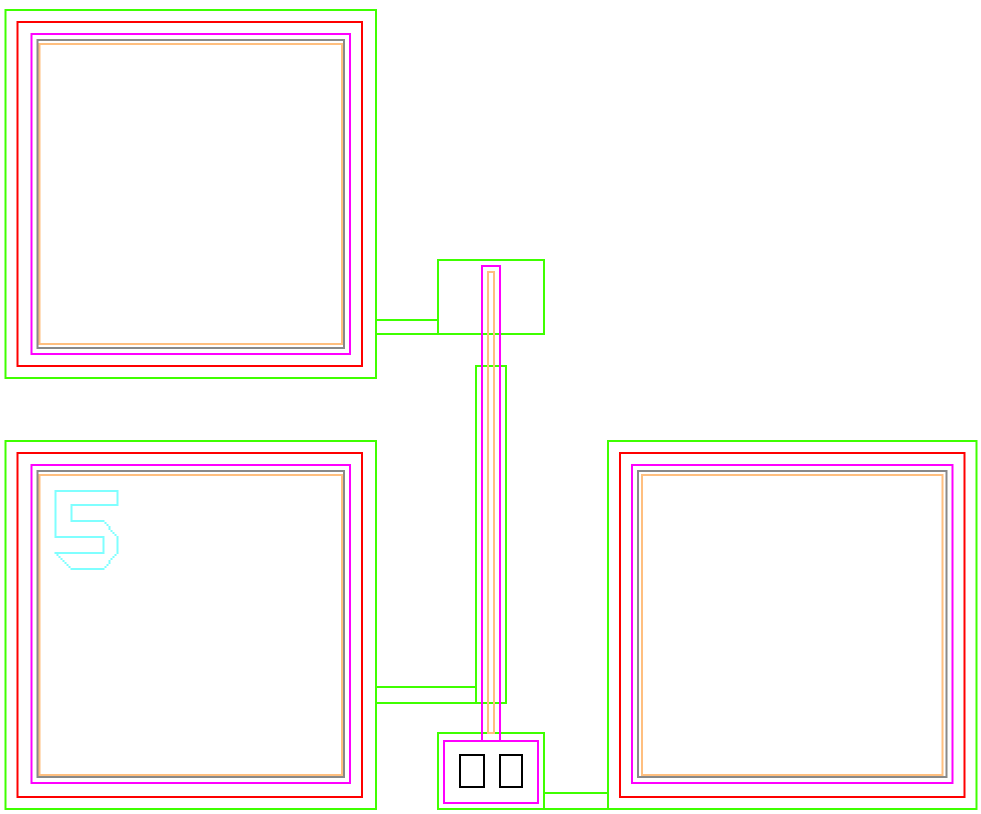


Fig 1 Cantilever Beam on MEMS chip

The natural frequency will change over time as mass is adsorbed on the cantilever beam since frequency is inversely proportional to mass shown in fig 2.

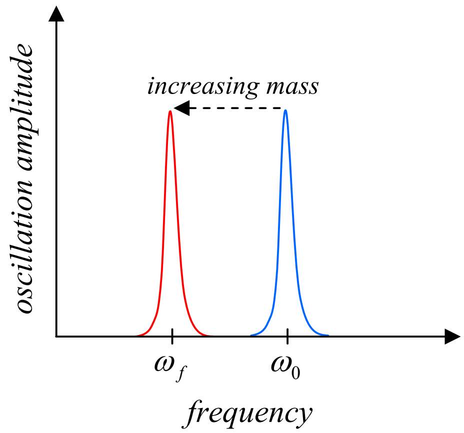


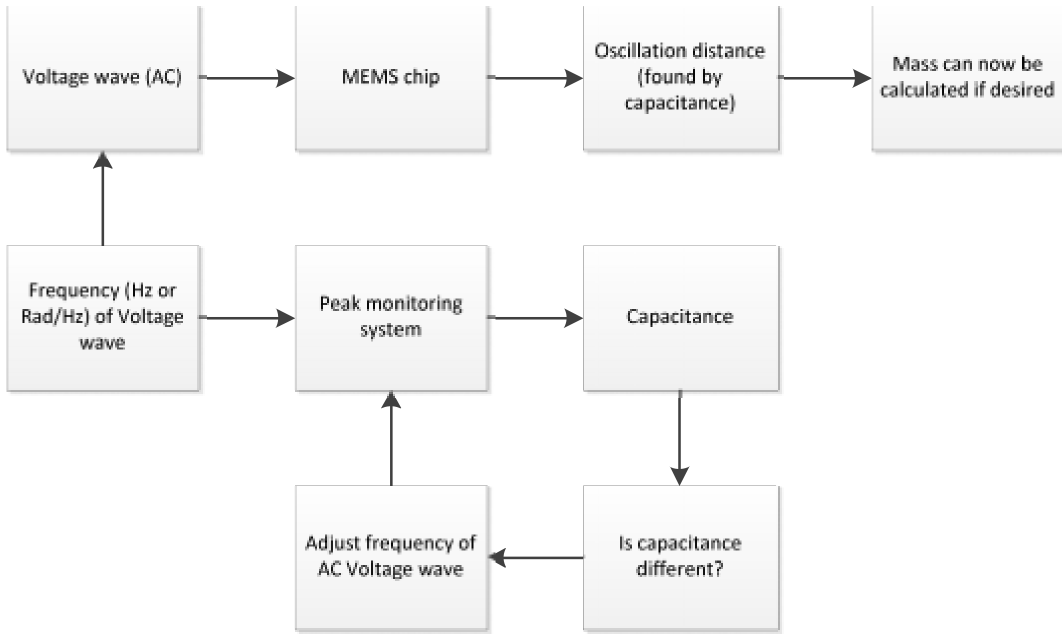
Fig 2 Oscillation amplitude vs. natural frequency

The formula relating natural frequency to mass is given by:

$$\omega_n = \sqrt{\frac{k}{m}} \text{ or } f_n = \frac{1}{2\pi} * \sqrt{\frac{k}{m}} \qquad 1)$$

Where m is the mass, k is the spring constant (design specification), and wn is the natural frequency given in Radian/Hertz and f is the natural frequency given in Hertz. Direct measurement of the mass collected on a microscopic cantilever beam is a challenging task (although this will be verified through biological techniques that are out of the scope of this project), so alternative methods are required.

The main challenge of this project is the capacitors are on a scale that is smaller than most electrical engineering applications acknowledge. For example, the parasitic capacitance of a breadboard is neglected when designing circuitry, but for applications in this project it could be even larger than the capacitance that is desired to be measured creating problems. Table 1 gives some sample MEMS specifications and their capacitances. The possibility of acquiring a capacitive sensor that can measure atto Farads is a possibility while using circuit analysis to determine the capacitance is another possibility. The main challenge of the project will involve identifying (accurately) the value of an unknown capacitance in the atto to fempto Farad range. This will be done with a combination of testing circuits, and probes. The following page contains the logic for the experimental procedure outlined above.



Specifications:

- Error in capacitance measurement less than 10%
- Feedback system continuous monitoring (updates every second, since the experiment takes such a long time high resolution shouldn't be required)
- Size of scope probes need to be roughly in the middle of the MEMS chip to make a proper contact
- Cantilever is elevated 3.5 microns above the substrate, however, the cantilever cannot get closer than .2 microns to the substrate otherwise it will become stuck to the substrate through adhesion
- Capacitance may vary between 5.01E-15 to 6.43E-17 F for non oscillating cantilevers, however when oscillating max capacitance value will occur at the .2 micron point above the substrate
- Values for max capacitance for various MEMS devices will be in the range of 5E-14 to 1.92E-15 F
- Since measuring in the Khz range, time increments will be in microseconds range to ensure long enough time for any calculations

- Sample Capacitance values for four different MEMS devices:

Epsilon (F/m)	Length (m)	Width (m)	Area (m^2)	Gap above substrate (m)	Capacitance (F)
8.85E-12					
First design	2.20E-05	6.00E-06	1.32E-10	1.50E-06	7.79E-16
Second design			4.35E-11	6.00E-06	6.42E-17
Third design			1.68E-10	2.95E-06	5.04E-16
Fourth design			1.13E-09	2.00E-06	5.01E-15

Inputs:

Amplitude of voltage wave (roughly in millivolts range), frequency of voltage wave (will need to be constantly adjusted to maintain peak of oscillation to find natural frequency)

Outputs:

Capacitance, oscillation distance, mass

Work Cited:

- Baltes, Henry, Oliver Brand, G. K. Fedder, C. Hierold, Jan G. Korvink, and O. Tabata. *Enabling Technology for MEMS and Nanodevices*. Weinheim: Wiley-VCH, 2004. Print.
- Elwenspoek, Miko, and Remco Wiegerink. *Mechanical Microsensors with 235 Figures*. Berlin: Springer, 2001. Print.
- Timpe, Shannon J., and Brian J. Doyle. *Design and Functionalization of a Microscale Biosensor for Natural Product Drug Discovery*. Tech. Print.