MEMS Capacitive Sensing for Motion Tracking

Senior Project Proposal

By

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Advisors

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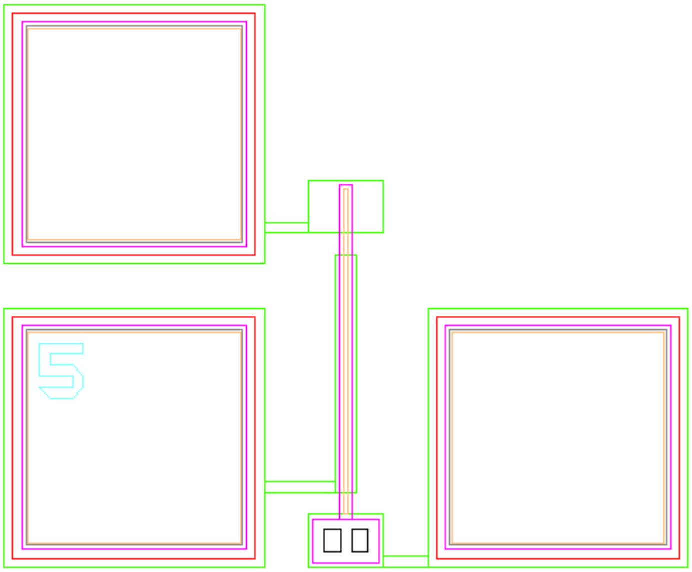
December 2011



I. Introduction

MEMS (Microelectromechanical systems in United States), are tiny micro machines (measured in microns) that are typically arranged on small chips (less than cm by cm) for various applications. They are primarily silicon based and manufactured using various etching techniques. Examples of MEMS applications are inkjet printer heads, airbag deployment sensors, and biomedical sensors (biosensor). The capacitive sensing aspect of the biosensor project will be the focus of this proposal. A plant sample will be introduced to the MEMS chip, and the goal will be to identify the mass adsorbed by the chip using capacitive sensing.

II Project Summary:

The ultimate goal of the Bradley Biosensor project using MEMS devices is that eventually unknown plant samples can be tested for possible biomedical applications. In order to accurately verify that plant samples are capable of aiding in treatment of diseases, the mass that reacts with the MEMS device must be known. Direct measurement of such a small amount of mass (millionths of a gram) is cumbersome, which is why capacitive sensing is utilized to indirectly find the mass adsorbed onto the MEMS device.

The order of capacitance that will need to be measured is incredibly low (fempto to atto farad range) which is anywhere on the order of one thousand to a million times out of the sensor range of the equipment available in lab. Fig 1 shows the relationship between oscillation distance and natural frequency. Max oscillation of a cantilever beam occurs at the natural frequency Wn, and using (1), by determining the capacitance of the MEMS device the oscillation distance can be found experimentally.

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

Where,

k: stiffness constant of cantilever beam (N/m)

m: mass (gram)

Wn=2(pi)(fn): natural frequency of oscillation of cantilever (rad/sec)

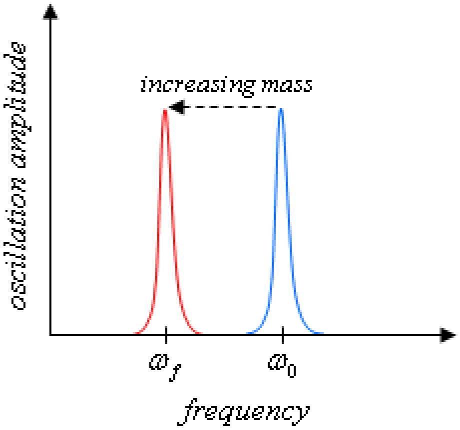


Fig. 1 Oscillation Amplitude vs. Natural Frequency

In Fig. 1, Wo is the natural frequency with no mass adsorbed by the MEMS cantilever, and Wf is the natural frequency after mass is adsorbed onto the cantilever.

This proposal will outline how the required specifications will be met to ensure accuracy and success for the MEMS capacitive sensing component of the Bradley biosensor project. The main goal of this project will be to accurately identify the natural frequency for various MEMS devices to eventually identify the mass.

III. System Block Diagram

The block diagram for the procedure for analyzing the capacitance is shown in Fig. 2. Automation of this procedure will be completed if time permits, but human measurement will suffice for determination of the natural frequency of the MEMS chip. The procedures for determining natural frequency are given in the following:

1. Set up MEMS chip with plant sample(s) ready to be adsorbed onto the cantilever beam
2. Place plant biomass on MEMS chip
3. Connect to MEMS chip with probes (will be done in advanced microwave engineering laboratory)
4. Apply small sinusoidal signal to make the cantilever beam oscillate
5. Determine maximum capacitance (this implies maximum amplitude of oscillation)
6. Keep track of the natural frequency as matter is adsorbed onto the cantilever beam, adjusting the frequency of the AC voltage input
   accordingly

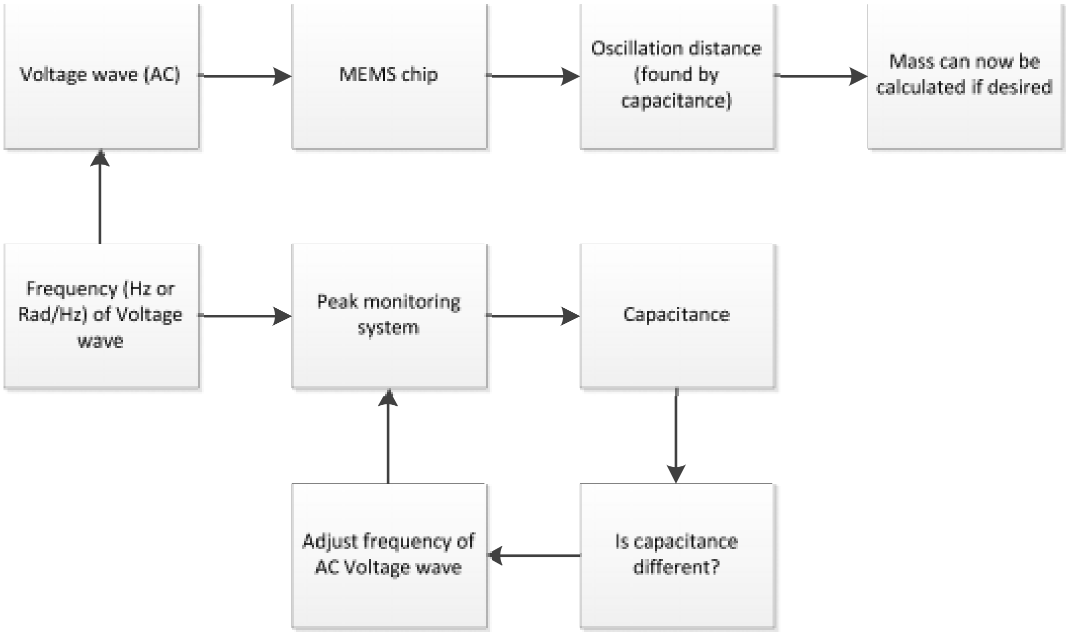


Fig 2 System Block Diagram

Inputs to the system include the voltage wave (amplitude in the millivolts range, frequency in the KHz range), and the biomass that is added to change the natural frequency of the cantilever beam. After measuring the capacitance we can determine oscillation distance which will indirectly tell us the mass of biomass adsorbed onto the beam.

IV. Measurement of Capacitance

The LCR meter in laboratory will measure down to the two pico Farad range, which is well above the value of capacitance we will be working with. The implementation to measure capacitance will be done using bridge circuitry. The parasitic capacitance of the MEMS device will be roughly around the same magnitude as our desired capacitance, but we can effectively “tune” the parasitic capacitance out with impedance cancelations, or isolating the desired capacitance.

V. Schedule of tasks (December through May)

- Winter break - Simulate various bridge circuits and try to predict the ideal configuration
- Winter break - Use Orcad to identify time constants of circuits with independent energy storage devices
- Winter break – conduct literature searches on capacitive sensing and small capacitance measurement
- Weeks 1-2 Build bridge network and verify unknown capacitors using system ID and compare vs. LCR meter results
- Weeks 3-4 Make connections in microwave laboratory to prepare for accurate measurements later on
- Weeks 5-10 Connect and make test measurements on MEMS chip in microwave laboratory, apply biomass and track natural frequency
- Week 11 Prepare for presentation at Bradley University Student Scholarship Expo
- Week 12 Prepare senior project presentation
- Week 13 Prepare senior project report
- Week 14 Deliver Senior Project Oral Presentation

VI. Equipment list

The following are necessary components of the capacitive sensing project:

1) MEMS chip(s)
2) Orcad for simulation purposes
3) Biomass

4) Function generator
5) Probe tip(s) for making connections in the microwave laboratory
6) Assorted sizes of resisters/capacitors for the Wheatstone Bridge

Specifications:

- Error in capacitance measurement less than 10%
- Scope probes need to be securely and accurately attached to MEMS device to ensure measurement of the correct device
- 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 (roughly an order of magnitude higher than non oscillating cantilevers)
- 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 sampling time

References

1) 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.
2) Elwenspoek, Miko, and Remco Wiegerink. *Mechanical Microsensors with 235 Figures*. Berlin: Springer, 2001. Print.
3) Timpe, Shannon J., and Brian J. Doyle. *Design and Functionalization of a Microscale Biosensor for Natural Product Drug Discovery*. Tech. Print.