Optical Resonant Frequency Detection System for Mass-Sensing MEMS Resonators

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Introduction:

A newly proposed biomedical application for the combination of optical tweezers and micro-electro-mechanical systems (MEMS) resonators has promise for long-term mass monitoring of single cells. In cell trapping, a laser beam is focused through a microscope onto a cell to trap and position it on the resonator; a separate laser beam is incident onto the vibrating resonator and produces an optical deflection signal for frequency detection. The problem with using traditional optical trapping in this scheme is a decoupling between the cell trap and the resonating substrate, mitigating the cell's influence on the resonant frequency.

This can be remedied with the integration of photonic crystals. The MEMS resonator measures the cell mass by detecting the resonant frequency change of a resonant beam [1], and the photonic crystal optical tweezers are applied to improve the mass sensing capability of the MEMS resonator by fixing the cell position with low light intensity [2]. With the usage of photonic crystals on a MEMS resonator, the position of a cell can be finely controlled to enhance the ability of the resonator to monitor changes in cell mass over time by inducing shifts in the device's resonant frequency [1]. A detection circuit was necessary to measure these shifts. Being able to trap and measure the resonant frequency enables the manipulation and identification of living cells, parallel manipulation of DNA strands and nanoparticles, and identifying a cell's biophysical characteristics.

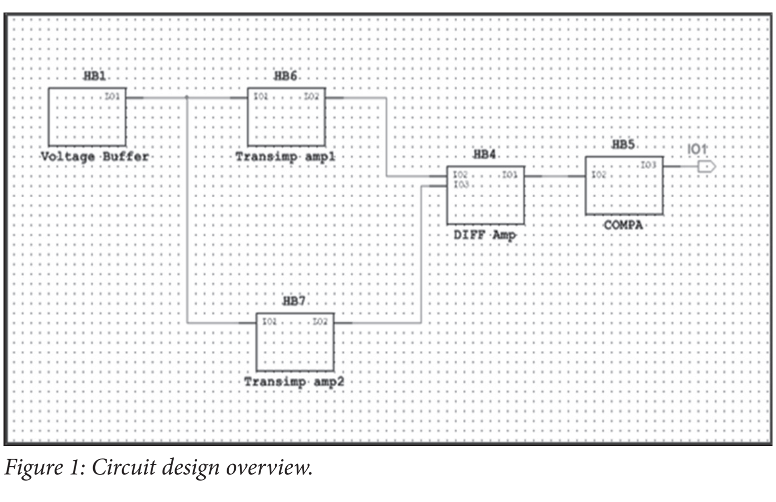

Figure 1: Circuit design overview.

Experimental Procedure:

Detection Circuit. The original detection circuit included two transimpedence amplifiers and a difference amplifier, serving the purpose of amplifying the signal produced by the optical deflection signal provided by a split photodiode. Figure 1 displays a general overview of the circuit. The circuit design software, Multisim, was used to establish an effective circuit schematic that would predict the behavior of the circuit to ensure a sinusoidal waveform as the output of the difference amplifier. In Multisim, the split photodiode was replaced with an AC current source at an initial frequency of 1 kHz. Through simulations, appropriate revisions to the circuit were conducted to provide an accurate layout to ensure the success of the circuit.

Originally the voltage ranges were from -2.5V to +2.5V, which was an issue considering an Arduino microcontroller would be programmed and combined with the circuit to calculate the resonant frequency. This was solved by inserting voltage dividers that would offset the voltage to an appropriate range of 0V to 5V. To counteract noise, a low pass filter was added (a 3.6 kΩ resistor and a 0.1 nF capacitor) with a cutoff frequency of approximately 420 KHz. A major issue was maintaining five volts throughout the circuit. To counter that, a voltage buffer was added, a unified power supply for the transimpedence amplifiers was established and the resistor values for the difference amplifier were modified.

A comparator was added to change the sinusoidal waveform into a square wave to make detection with the Arduino easier. One of the final steps using Multisim was increasing the frequency of the AC current source from 1 kHz to 300 kHz (split photodiode) to accurately reflect the frequency of the laser beam that will hit the split photodiode. That, however, changed the sinusoidal waveform from the difference amplifier to a triangular wave due to slew rate limits. This was remedied by lowering the gain (changing the resistor values from 100 kΩ to 10 kΩ) of the transimpedence amplifiers. During the assembly of the circuit, the comparator Vcc+ was changed from 5V to 10V, so that the oscilloscope can display the comparator signal.

Arduino Programming. With the usage of an Arduino microcontroller and programming software, the frequency of the vibrating resonator could then be measured by inputting the output of the comparator directly into the Arduino. The Arduino code was programmed to monitor overflow, count rising edges, enable the timer, temporarily store data and calculate the frequency after one hundred cycles.

Results and Conclusions:

With the laser beam collimated onto the split photodiode, the detection circuit was able to output an expected sinusoidal waveform (resonant frequency) from the difference amplifier and a square wave from the comparator, while maintaining a viable output voltage between the 0 to 5 volt range that allowed the Arduino microcontroller to calculate the resonant frequency. Figure 2 shows the output of the difference amplifier. Arduino code was tested using a signal from the function generator. With the proper adjustments to the code, the Arduino was able to calculate the frequency provided by the function generator. However, with a miniscule shift in the positioning of the laser beam onto the split photodiode, the expected frequency was compromised. While there are minor setbacks with the Arduino code and cell viability in terms of optical trapping of cells, there is great evidence that photonic crystal optical tweezers will not only be able to distinguish different types of cells, but also enable long-term biological mass studies.

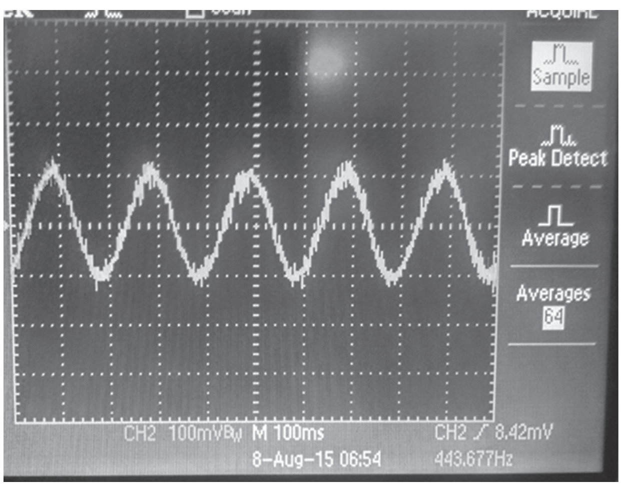

Figure 2: Signal output of difference amplifier. Output with a time base of 100 ms and a scale of 100 millivolts per division.

Future Work:

The next step in this process is to modify the Arduino code that will allow the accurate measuring of the resonant frequency regardless of the positioning of the collimated laser beam as it hits the split photodiode. With the modification of the detection circuit on the optical setup, the durability and efficiency of the circuit can be enhanced. The last major step would be to mount the detection circuit on the bio-sensing resonator, and calculate resonant frequency shifts using the optical deflection signal produced by living cells.

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References:

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[2] Peifeng Jing, Jingda Wu, and Lih Y. Lin, "Patterned Optical Trapping with Two-Dimensional Photonic Crystals", ACS Photonics, 1(5), 398-402, 2014.