uFluidics Amplifier and DSP

Michael Nolan

I. Amplifier

A. Specification

Because the signal from the uFluidics device is so small, an extremely low noise amplifier is needed to create a large enough signal that the DSP can detect it. From the initial COMSOL simulations, it appeared that the uFluidics pickup coil generated a voltage between 1 and 600nV. Since these voltages are approaching the limits of what can be measured without massive research budgets, a 100nV signal from the device was assumed. Next, for the signal to be input to the DSP, it needs to be centered around 1.5V (half of the supply voltage), and to have a relatively large swing of 200mV pk/pk. The 200mV swing gives enough room that if the signal is really 600mV or larger the amplifier will not saturate, but is also large enough to be easily detected by the DSP. This means the amplifier needs a gain of

$$\frac{200mV}{100nV} = 2 \cdot 10^6 V/V$$

Next, after some experimentation, it was determined that the DSP can reliably detect a signal that has twice the amplitude of the noise. Therefore, the amplifier's input noise needs to be less than 50nV pk/pk, and ideally should be less, to leave some room for the uFluidics signal to be smaller than calculated.

B. Component Selection

After some research, the AD8428 low noise instrumentation amplifier was selected as it had a very low input noise of 50nV, and multiple amplifiers could be paralleled to reduce the noise even further [1]. The AD8428 has a gain of 2000 V/V [2], so another amplifier is needed after the AD8428. The AD4528 op amp was selected for this task because of its low input offset voltage and low noise. The AD4528 was set up to have a gain of

$$\frac{2 \cdot 10^6}{2000} = 1000 \tag{1}$$

in a differential amplifier configuration to bring the total system gain to $2 \cdot 10^6$ and to introduce the 1.5V offset needed to feed the signal to the DSP.

C. Schematic

The amplifier uses two AD8428 instrumentation amplifiers to give an input noise of $\frac{50nV}{\sqrt{2}}$ [1]. Notice how both ICs are connected to the input, and have their `filt+` and `filt-` terminals connected, but only one has its output connected to the rest of the circuit as described in [1]. Next, the output of the AD8428 is connected to a high pass filter with a cutoff of $\frac{1}{2\pi 100uF*15k\Omega} = 0.1Hz$ to remove any DC voltage from the input offset voltage of the AD8428 or thermal effects from the uFluidics device. The filter then connects to an opamp differential amplifier with a gain of 1000, with a connection to the reference voltage V_{ref}. Finally, the reference voltage V_{ref} is generated by a resistor divider feeding an opamp voltage buffer.

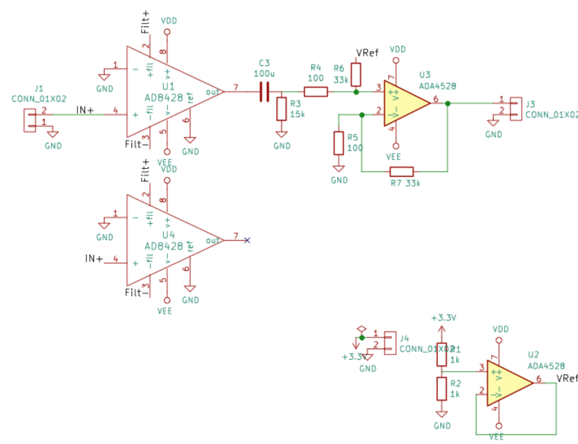

Fig. 1. Amplifier Schematic v1.0

II. Revision 1.1

A. Specification Changes

After presenting the amplifier to Dr. Thain, he pointed out that the amplifier didn't have any filtering to limit the bandwidth of the signal to the DSP, and that there would be problems with aliasing. Additionally, some newer simulations showed that the voltage spikes from the magnetic cells passing through would be much shorter than originally thought. Finally, the operating voltage of 5V(max) for the AD4528 op amp was not taken into account when designing the board, so the amplifier was presented with a voltage of 8V across it. Therefore the following changes needed to be made:

- Convert the ADA4528 power supply to single ended, and create a virtual ground as a reference.
- Add a low pass filter between the instrumentation amplifier and op amp.
- Change the existing high pass filter's cutoff frequency from 0.1Hz to 700Hz.

B. Schematic

The major changes to the schematic shown in Figure 2 are as follows:

- The virtual ground made by the lower op amp is used in place of `GND` for the filter and the op amp feedback reference.

- The values for the RC high pass filter have been changed from $100\mu F$ to $100nF$ and $15k$ to $2k$, to create a cutoff frequency of 795Hz.
- The pads used to add the voltage offset in the original differential amplifier have been repurposed as a low pass filter with a cutoff frequency of $10k$. This is due to a lack of suitable capacitors between $100n$ and $1n$, and the need to keep the loading of the previous stage low.

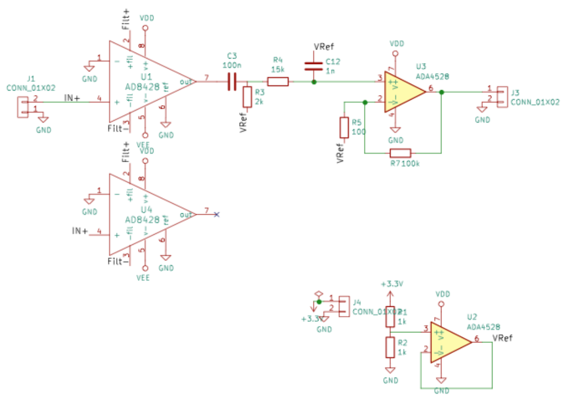

Fig. 2. Amplifier Schematic v1.1

C. Results

The amplifier was tested using a function generator generating a signal at 1kHz and a resistor divider made using a $9.1M$ and a 10Ω resistor. As seen in Figure 3, the input signal (blue) before going through the resistor divider is approximately 1.6V pk/pk. After voltage division, the input to the amplifier is about $1.7\mu V$. The voltage at the amplifier output (pink) is approximately 3.5V pk/pk, giving a total amplification of

$$\frac{3.5V}{1.7\mu V} = 1.99 \cdot 10^6 V/V$$

. This confirms that the amplifier is indeed working and is delivering the designed gain of 2 million.

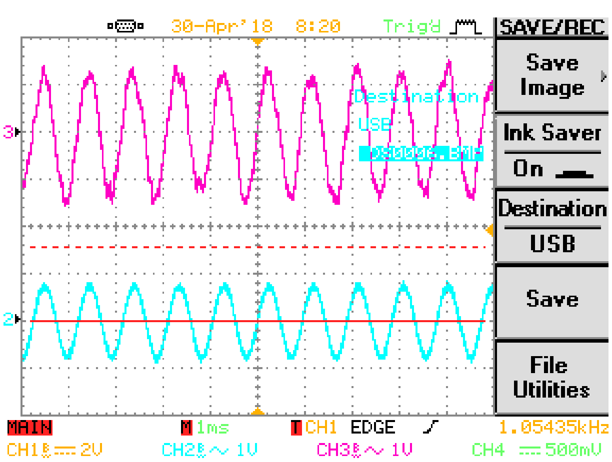

Fig. 3. Waveforms from revision 1.1

D. Noise Measurements

The noise of the amplifier has not been measured yet, but I have an appointment with Dr. Thain on Wednesday, May 2 to measure the noise with a spectrum analyzer.

III. Thermal Effects

A. Causes

One of the effects observed when testing the Keithley nanovoltmeter was a small voltage being generated across a thermal gradient. This voltage was determined to be caused by the Seebeck Effect, where a difference in temperature between two different metals causes a small voltage to be generated [3]. In our device, the seebeck effect is likely unavoidable, as there are multiple places where there are dissimilar metals connected to each other between the uFluidics coil and the amplifier IC.

B. Mitigation

However, the Seebeck Effect should not be much of a problem directly. The amplifier already includes a high pass filter to remove any voltage offset from the input amplifier's offset voltage, and the voltage from the seebeck effect will only add or subtract from this voltage. However, the Seebeck Effect has the capacity to introduce noise that the high pass filter cannot remove, and it is this aspect that must be mitigated. One of the ways that the Seebeck Effect could introduce noise is from rapid thermal fluctuations somewhere in the device. Therefore it may be adventageous to submerge all or part of the device in a thermally conductive fluid such as mineral oil to reduce this noise, even if it means introducing some voltage offset.

IV. DSP Portion

Because the uFluidics device generates an extremely weak signal, when the signal reaches the circuit to count the cells, it will have quite a lot of noise in it. In order to accurately count the cells, the signal will need to be processed in order to remove the noise and detect when a cell passes through the device.

A. DSP

The DSP for this project needed to

- Have a low cost
- Have an on board ADC
- Be more than able to process a 5ks/s signal (to allow for changes to processing algorithm)
- Have enough ram to process the above signal in batches of 1024 samples
- Be capable of driving a display or other peripherals to present results

After some searching, a dsPIC33f was determined to be able to fufill the above requirements, and the dsPIC33FJ128GP802 was selected as it had more than enough ram and processing power for our use. Additionally, a less powerful DSP from the same product line could be used in the final product after determining exactly how much ram and processing power are needed.

B. Processing

According to [4], the optimal way to separate a known signal from white noise is to use correlation. Via COMSOL simulation and via a crude prototype involving dropping a straw through a coil, the signal of interest would have a shape similar to Figure 4

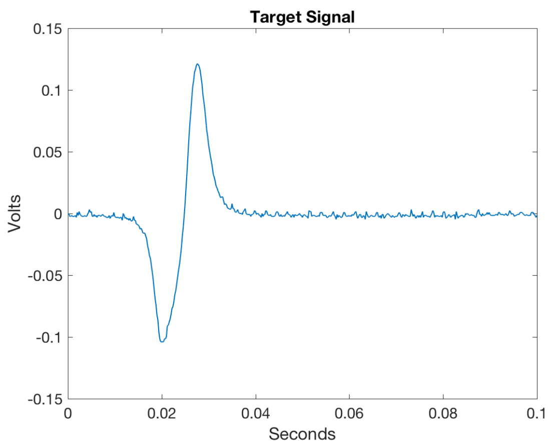

Fig. 4. Signal from prototype device

Therefore we should correlate our input signal with this signal to maximize the separation from noise. To make sure this technique would suit our needs, a script was created in MATLAB to illustrate the effects of the correlation.

First, the signal in Figure 4. was modified by adding some noise, and appears in Figure 5 Next, the signal was correlated

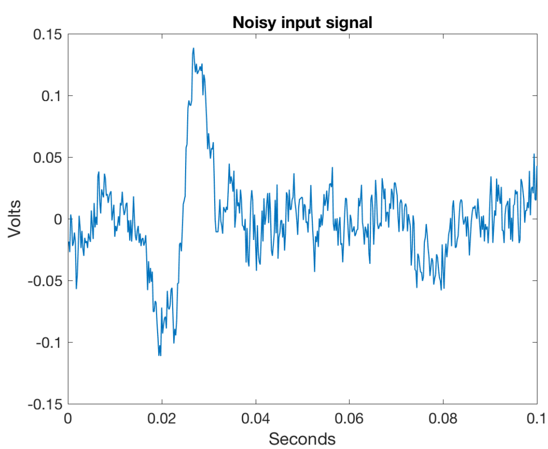

Fig. 5. Signal with simulated noise

with the signal in Figure 6, and the resulting signal appears in Figure 7.

Notice how Figure 7 has several small bumps where the target signal matched weakly with the noise, and also the very large negative spike from where the target signal was lined up with the pulse in the input signal. Unfortunately, the signal from the uFluidics device can be either positive or negative, so further processing is needed. To force both polarities to be positive, the signal in Figure 7 is squared, which also has the effect of reducing the relative amplitude of the spikes from

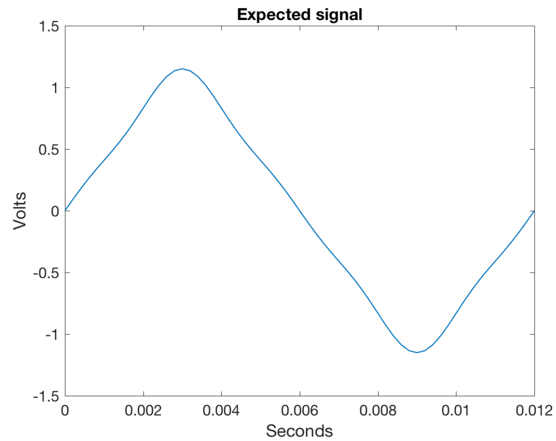

Fig. 6. Correlation target signal

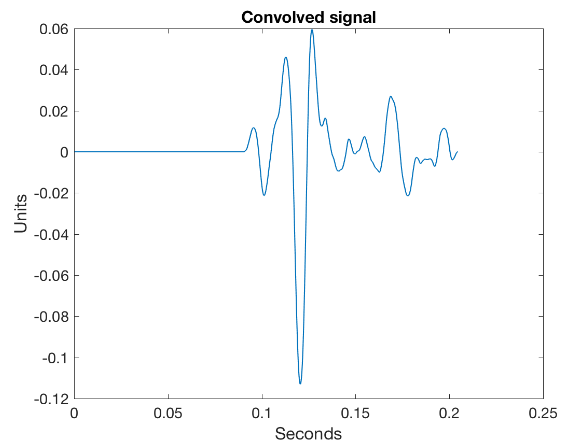

Fig. 7. Result of correlation

the noise compared with the desired spike. Finally, the number of spikes above a threshold value are counted, and the result appears in Figure 8.

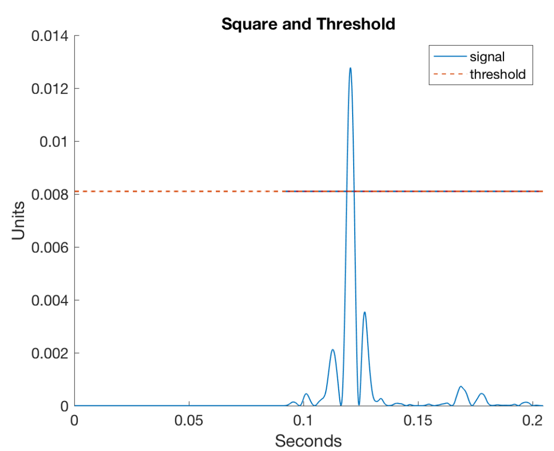

Fig. 8. Squared signal with threshold

C. Software

The DSP was programmed in C, with some functions, such as squaring and thresholding, written in assembly. The processing is as above, with some additional considerations for continuous processing. 256 samples are read from the ADC and fed into a buffer, along with the previous 256 samples. Then, those 512 samples are correlated with the signal from Fig. 6, and the resulting signal is placed into another buffer. Each sample in the buffer is squared, and then the 256 samples starting at sample number $256 - 61 = 195$ (256 - samples from the previous sample period, 61 - number of samples in the target signal) are fed to the threshold counting function, which counts the number of times the signal crosses the threshold value going positive. The threshold is only run on these samples so that a cell that generates a signal between the two aquisition periods will still get counted.

References

[1] M. Gerstenhaber, R. Johnson, and S. Hunt, “No pain high gain: Building a low-noise instrumentation amplifier with nanovolt sensitivity.”
[2] “Ad8428 datasheet.” Online, Feb 2017.
[3] Caltech Materials Science, “Brief history of thermoelectrics.” Online.
[4] S. Smith, *The Scientist and Engineer’s Guide to Digital Signal Processing*. California Technical Pub, 1997.