We need a different amplifier

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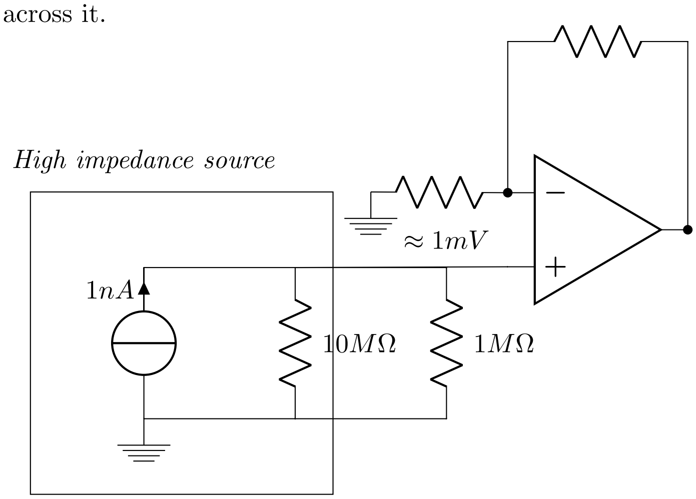
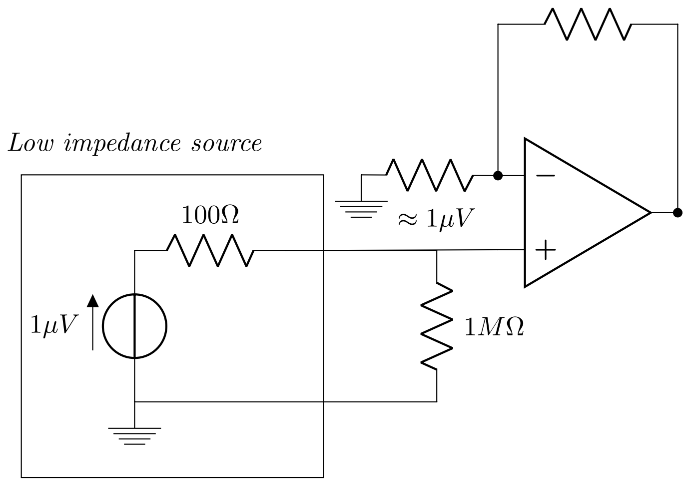
1 Problem

The current uCurrent style amplifier will not provide good data from the uFluidics coil because the uCurrent relies on the source having a very high output impedance, whereas the uFluidics coil has a low output impedance. Illustrated below, the high impedance source converts a $1nA$ current into $1mV$ and feeds it to the op amp to be amplified. Because the sense resistor has a significantly lower impedance than the impedance of the current source, most of the current flows through the sense resistor and generates a comparatively large voltage across it.



In contrast, in the circuit below, the sense resistor has a much higher impedance than that of the source, so the source puts almost it's full voltage across the sense resistor. However, since the source voltage is small, the voltage would require far more amplification to get to the level of the above example. The source below could be transformed to a current source in parallel with the 100Ω resistor similar to the above circuit, but since the source impedance is much lower than the sense resistor, only a very small amount of current will flow through the sense resitor, generating only a very small voltage across it.



How do we know that the coil has a low impedance? Intuitively, it makes sense because it's simply a coil of wire, and it makes sense that the impedance would be small (infinitely small, in the case of perfectly conductive wire. This agrees with faraday's law of induction, where

$$V = -N\frac{d\Phi}{dt}$$

meaning that the coil is a voltage source (low impedance). Finally, this is confirmed by experiment, when I hooked up a prototype uCurrent to the straw coil and saw very little signal (indicating that the signal was a low impedance voltage source).

2 Solution

Since this is the case, how much amplification do we need? The ADC on the microcontroller has 12 bits of resolution, or 4096 different values. The ADC linearly assigns these values to voltages between 0 and 3.3V, so we want the resting voltage to be around 1.5V, and a decent amount of swing when a cell passes through, say 400mV pk/pk. And from the COMSOL simulation the maximum voltage produced was around 600nV. So we need amplification of

$$\frac{400mV}{600nV} = 660,000 = 116dB$$

We'll likely need to cascade op amps to keep the feedback resistors within a reasonable value. Additionally, 600nV is low enough that it approaches the thermal noise from the op amp itself, so the op amps will need to be selected for exceptionally low noise, especially low frequency noise since the cells will be traveling fairly slowly.

3 Op Amp Selection

The op amps used for this amplifier need to have the following characteristics

- <300nV 0.1-10Hz noise
- Very Low 1/f noise
- <1uV input offset voltage

The 0.1-10Hz noise needs to be minimized because that is where the signal will be. The 1/f noise is less important, because it is more relevant at higher frequencies, but should still be taken into account. The input offset voltage will add a DC offset to each amplifier stage, and needs to be taken into account to make sure each amplifier stage stays in the middle of its input/output voltage range (so no clipping).
Most of the op amps in this category are ultra high precision, chopper stabilized op amps. Some op amps that will likely work:

Part	0.1-10Hz noise nV	1/f noise $nV/\sqrt{Hz}$	offset voltage μV
MAX44243	117	9.0	1-5
MAX44252	123	5.9	3-6
LT1028	90	1.0	20-80
OPA827	250	4.0	75-150
LT6018	30	1.2	7-50
LT1037	130	4.5	20-60
AD797	50	2.5	10-40
AD4528	97	5.6	0.3-2.5