

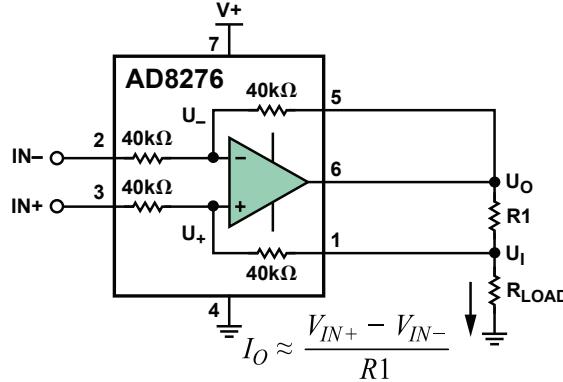
Suggested circuits for voltage-controlled current source for iontophoresis

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1 Option 1: AD8276 unity-gain difference amplifier and single resistor

We can try using a Howland current pump. The following schematic is taken from a document written by Analog Devices, and the datasheet for the IC is at this link.



Setting $R = 40 \text{ k}\Omega$ and $V_{IN-} = 0$, we get the following nodal equations:

$$\begin{aligned} \frac{U_-}{R} + \frac{U_- - U_0}{R} &= 0 \\ \frac{U_+ - V_{IN+}}{R} + \frac{U_+ - U_1}{R} &= 0 \\ \frac{U_1}{R_L} + \frac{U_1 - U_+}{R} + \frac{U_1 - U_0}{R_1} &= 0 \end{aligned}$$

Assuming $U_- = U_+ = U$,

$$\begin{aligned} \frac{U}{R} + \frac{U - U_0}{R} &= 0 \\ \frac{U - V_{IN+}}{R} + \frac{U - U_1}{R} &= 0 \\ \frac{U_1}{R_L} + \frac{U_1 - U}{R} + \frac{U_1 - U_0}{R_1} &= 0 \end{aligned}$$

Working out the arithmetic, we get

$$U_1 = V_{IN+} \cdot \frac{(R_L \parallel 2R)}{(R_1 \parallel 2R)}$$

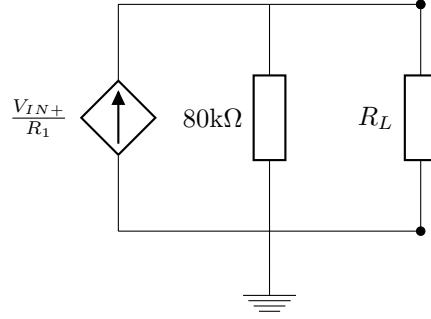
and

$$I_{\text{load}} = \frac{V_{IN+}}{(2R \parallel R_1)} \cdot \frac{2R}{R_L + 2R}$$

If we assume that $2R \gg R_1$ and $2R \gg R_L$ (this last assumption may be a bit shaky, because I don't exactly know the DC impedance of skin, and the impedance will also have a dependence on the area of the electrodes), we get

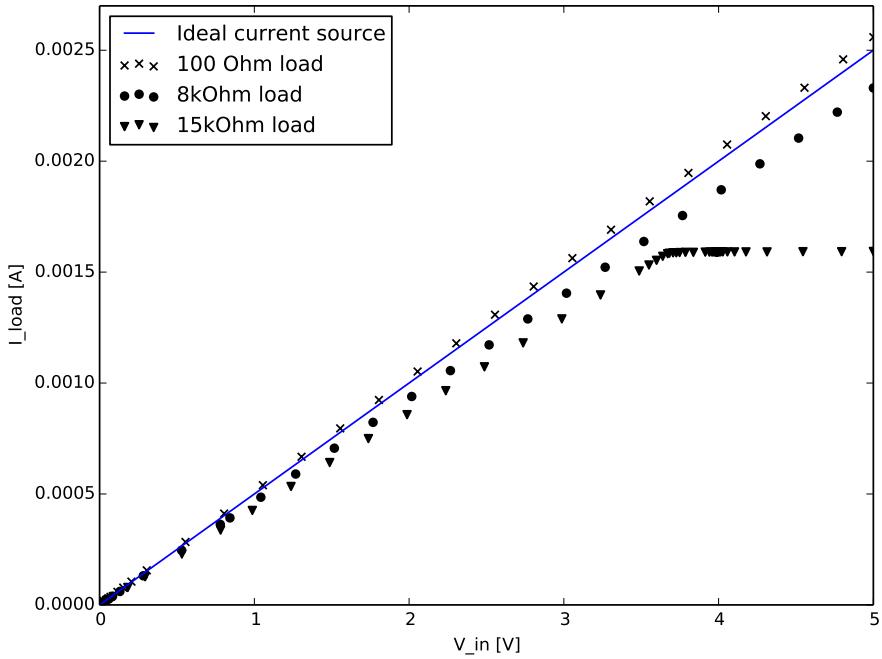
$$I_{\text{load}} = \frac{V_{IN+}}{R_1}$$

Using the equations and only making the assumption $2R \gg R_1$, I can find the output impedance, which is approximately $2R = 80\text{k}\Omega$, and therefore we can model the circuit approximately as the following:



Depending on what the impedance of skin is, this may or may not be acceptable. If skin ends up having a much higher impedance than this circuit allows, then we may need to use a different IC.

Using $R_1 = 2\text{k}\Omega$, $V_{DD} = 30\text{V}$, the complete circuit was simulated in HSPICE, with different load resistances.

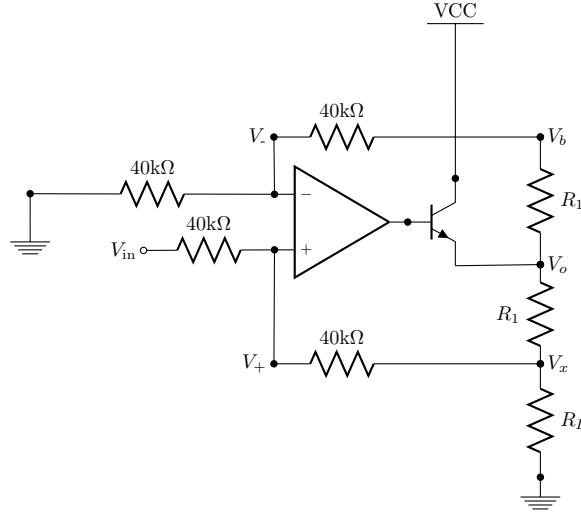


For large loads (i.e. around $10\text{k}\Omega$ and larger), HSPICE shows that the current gets clipped, for large values of current. This is mainly because of the upper bound imposed by V_{DD} .

In summary:

- V_{in} will most likely be supplied by a DAC.
- Very simple voltage-controlled current source, requiring only a single inexpensive (about \$1 or so) IC, and a single resistor
- Load is connected to ground at one end
- If we need more current, or if skin impedance is high, this particular IC is rated up to 36V V_{DD}
- We may want to go with a different IC if skin impedance is excessively high
- It would probably be a good idea to use a unity-gain difference amplifier rather than going the DIY op-amp + resistor approach. The circuit is essentially a Howland current pump, and according to this TI document the Howland current pump has a strong dependence on resistor variability. The datasheet for the IC claims that the resistors are precisely laser-trimmed, so this should help a lot with variability.

2 Option 2: AD8276 unity-gain difference amplifier with boost transistor



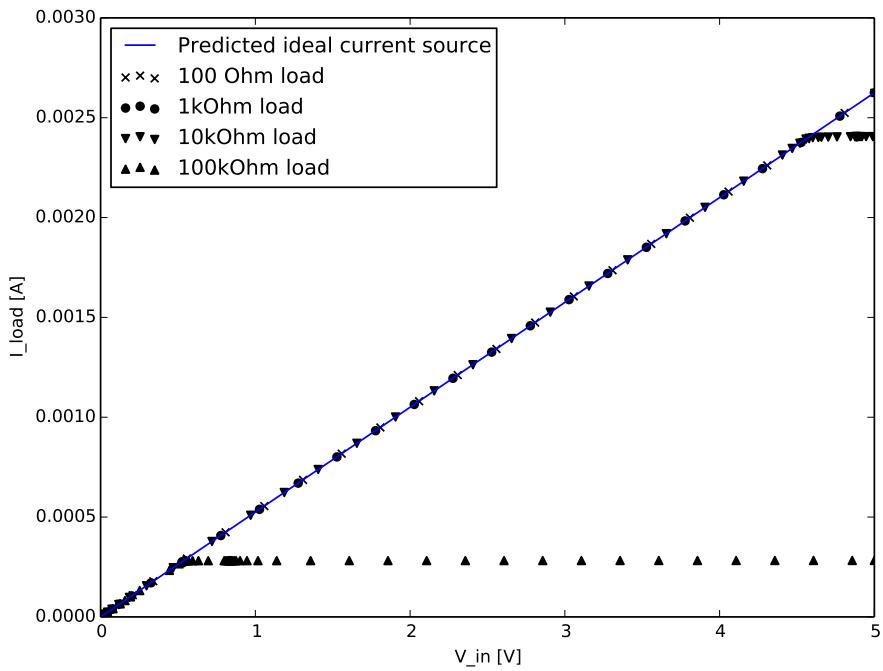
Note that the $R = 40\text{k}\Omega$ resistors and the op-amp are internal to the AD8276. In this circuit, V_{DD} is the same as before, 30V, and the AD8276 positive and negative supplies are 30V and 0V respectively. This circuit can be solved very simply, using a similar approach to that given previously. The nodal equations are

$$\begin{aligned} \frac{V_-}{R} + \frac{V_- - V_b}{R} &= 0 \\ \frac{V_+ - V_{in}}{R} + \frac{V_+ - V_x}{R} &= 0 \\ \frac{V_b - V_-}{R} + \frac{V_b - V_o}{R_1} &= 0 \\ \frac{V_x - V_+}{R} + \frac{V_x - V_o}{R_1} + \frac{V_x}{R_L} &= 0 \end{aligned}$$

and working out the arithmetic, assuming that $V_+ = V_-$, gives

$$I_L = \frac{V_{in}}{(R_1 \parallel R)}$$

where $R = 40\text{k}\Omega$. With these assumptions the circuit is something very close to an ideal current source. HSPICE simulations were then run for $R_1 = 2\text{k}\Omega$, and varying values of R_L . The results are shown below.



The clipping is brought upon by the upper limit imposed by V_{DD} .

In summary:

- V_{in} will most likely be supplied by a DAC.
- Closer to an ideal current source than the original circuit
- Load still grounded on one end.
- A bit more complicated than the original circuit, requiring an extra resistor and a BJT
- Analog Devices claims that if the two resistors with value R_1 mismatch, there may be some sort of error. Since these resistors are external, we might need high precision resistors/trimmable resistors if we were to build this circuit.