
Operational Amplifiers

ECE 321: Electronics II

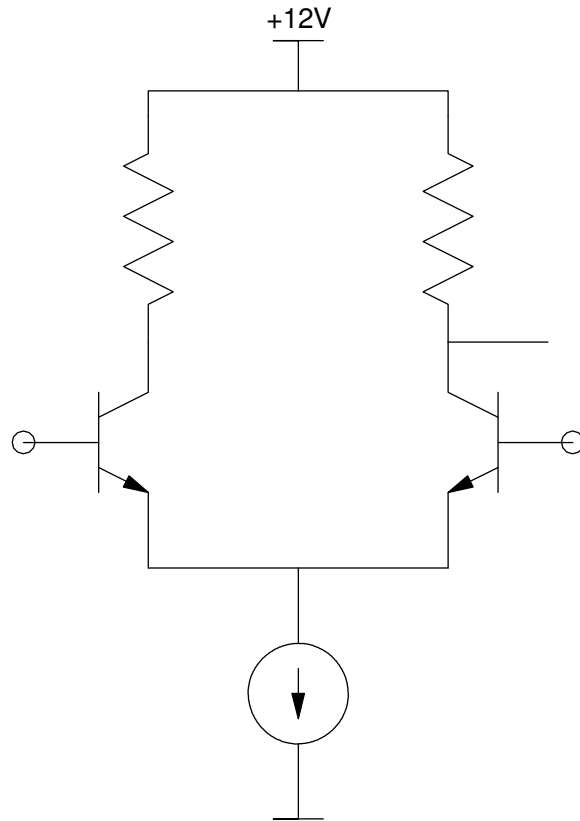
Lecture #1

Please visit [Bison Academy](#) for corresponding lecture notes, homework sets, and solutions

Operational Amplifiers

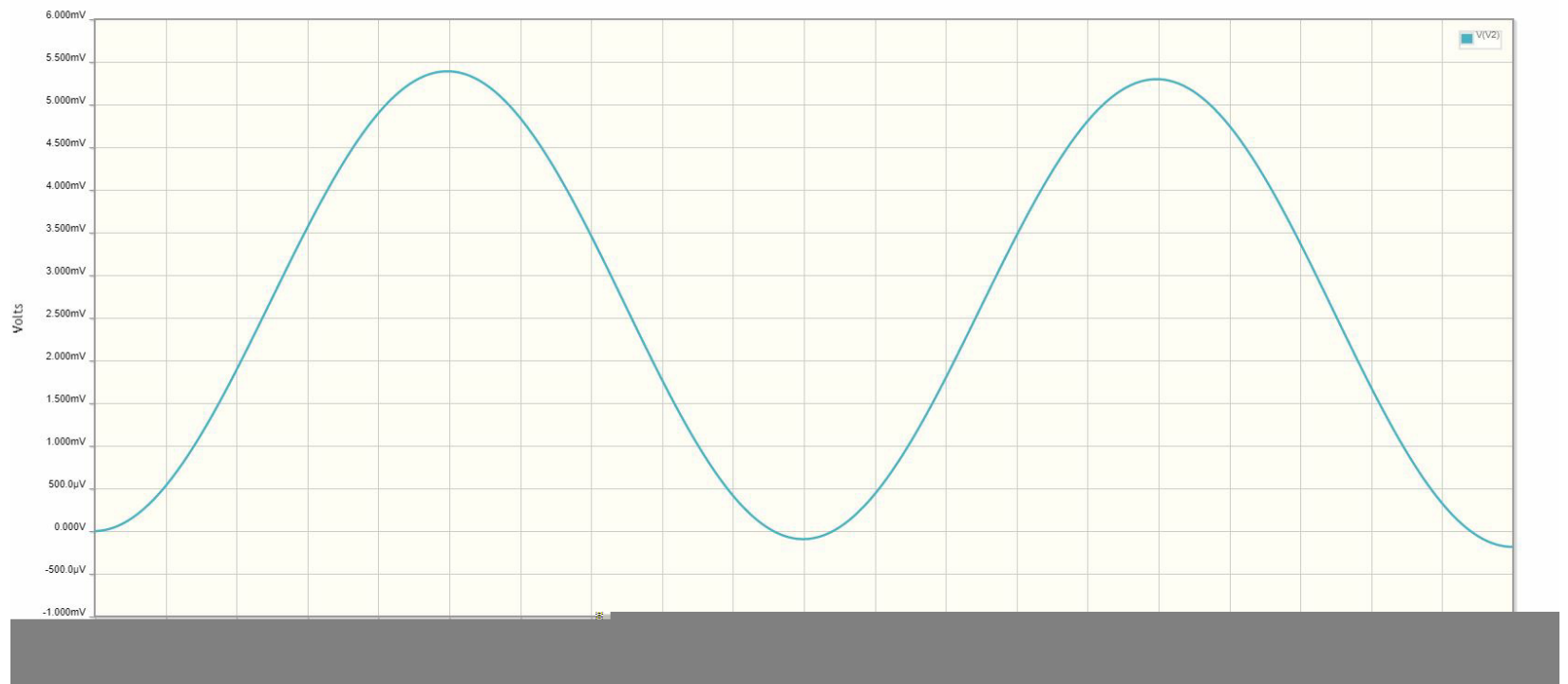
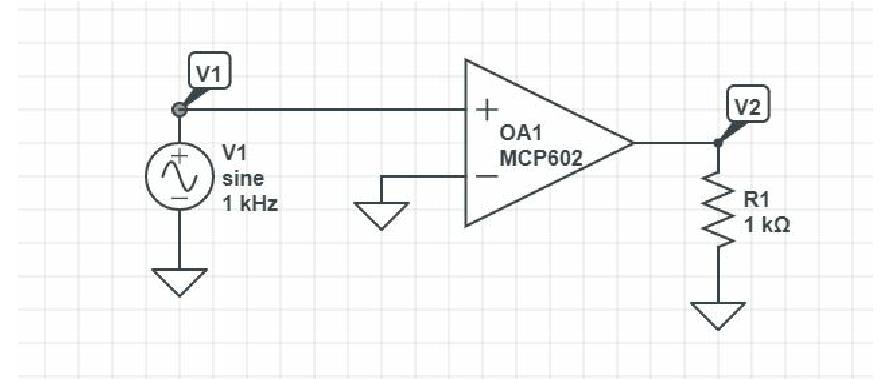
Operational Amplifiers (Op-Amps) are high gain differential amplifiers.

The heart is emitter-coupled logic:



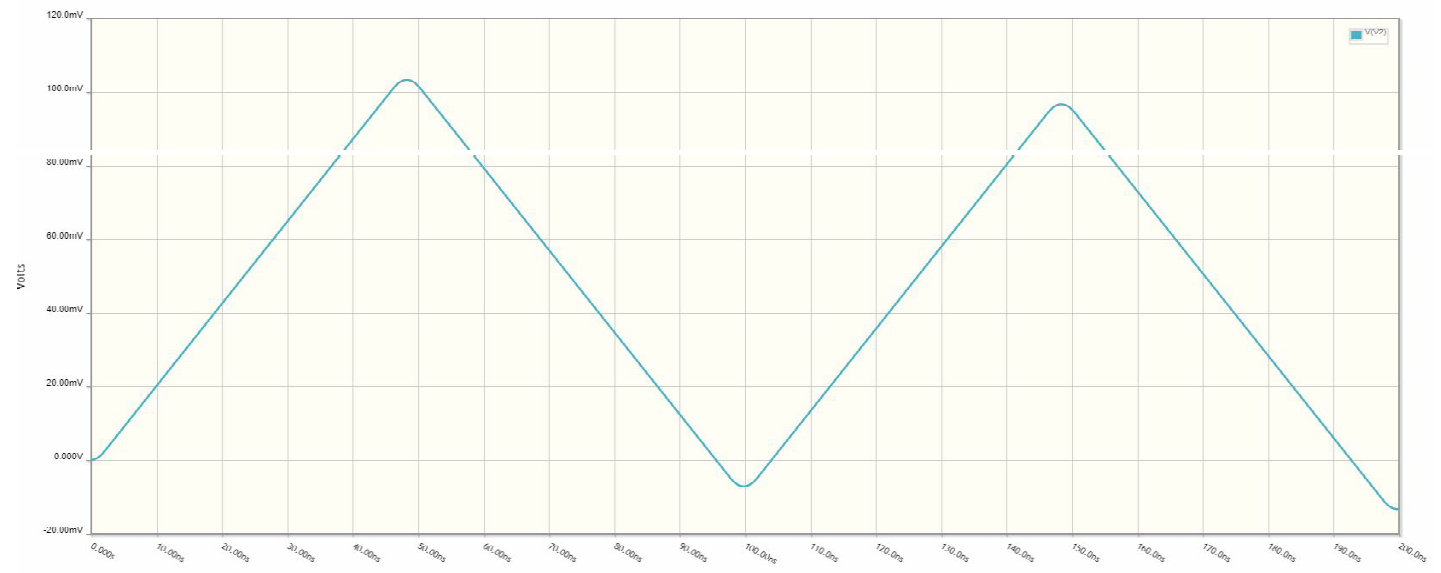
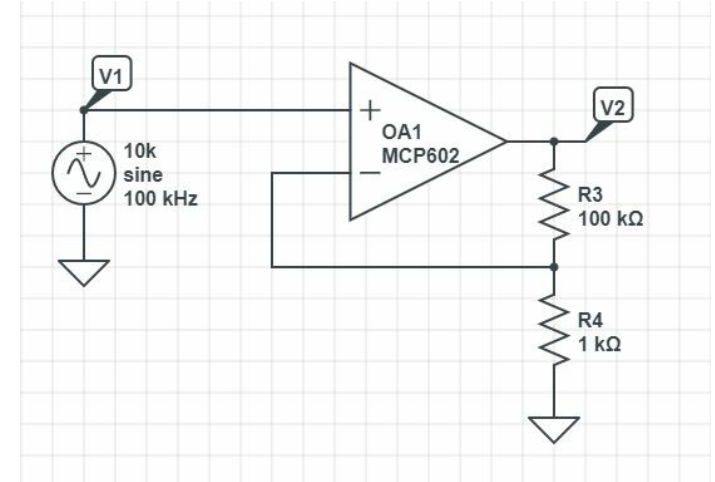
Differential Gain (CircuitLab)

- $V1 = 1\mu\text{Vp}$
- $V2 = 5.5\text{Vp}$
- Gain = 5,500,000



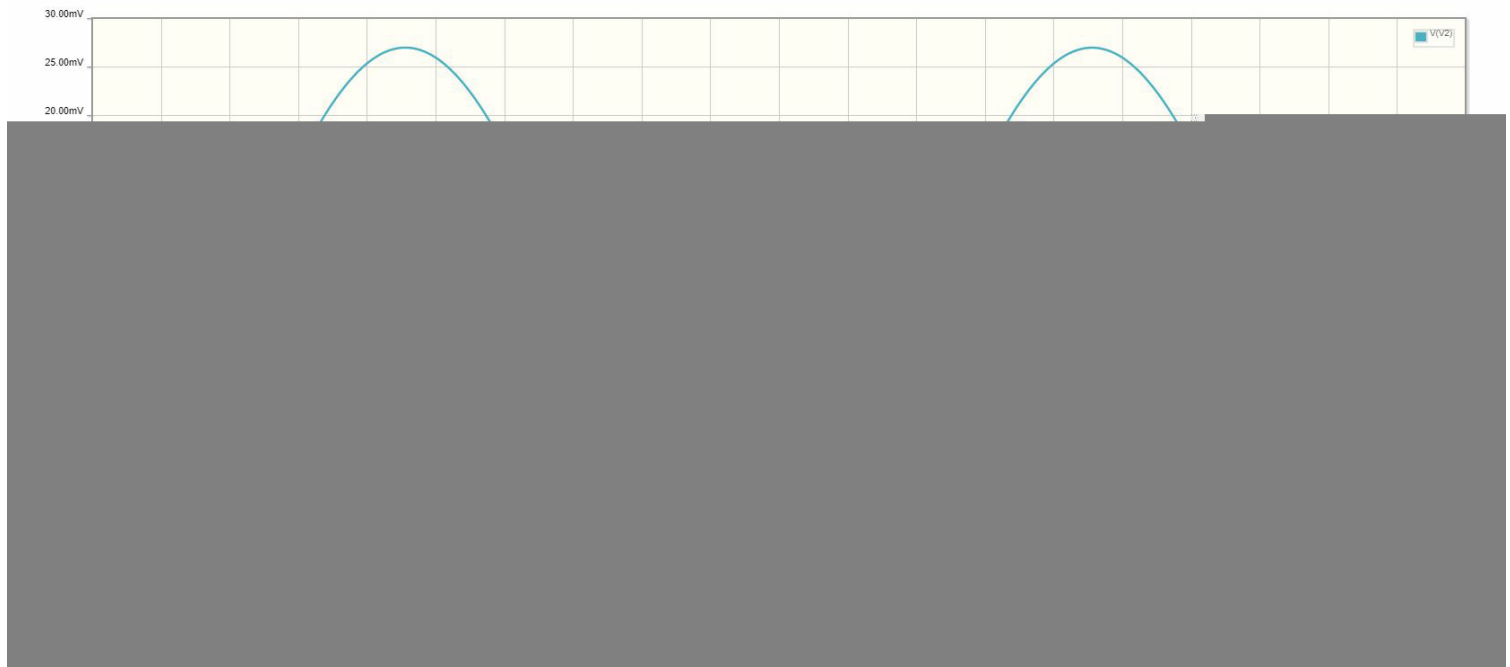
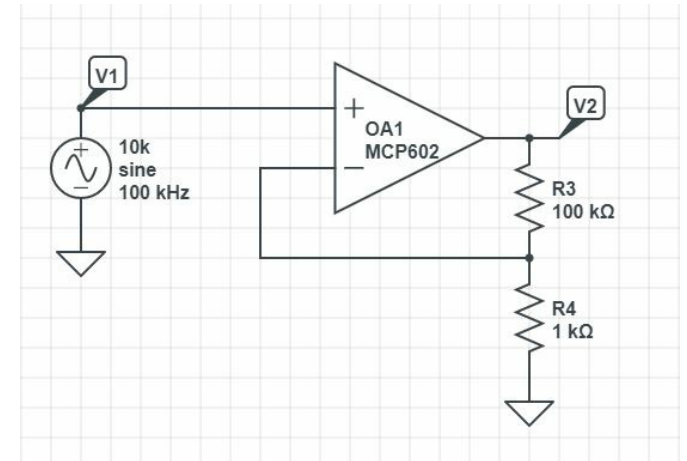
Slew Rate (CircuitLab)

- V1 = 1Vp, 100kHz sine wave
- V2 = triangle wave
- Slope = $2.3e6$ V/s (Slew Rate)

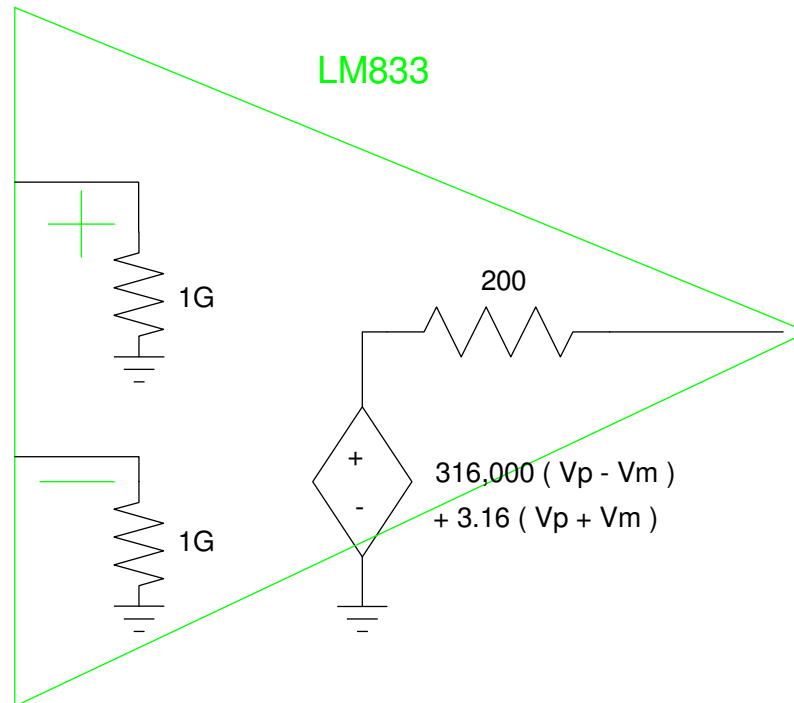


Gain-Bandwidth Product

- $V1 = 1\text{mVp}$, 100kHz
- $V2 = 101\text{mVp}$, 100kHz (ideally)
- $V2 = 28\text{mVp}$, 100kHz (actual)
- $(28) * (100\text{kHz}) = 2.8\text{e}6 = \text{GPW}$

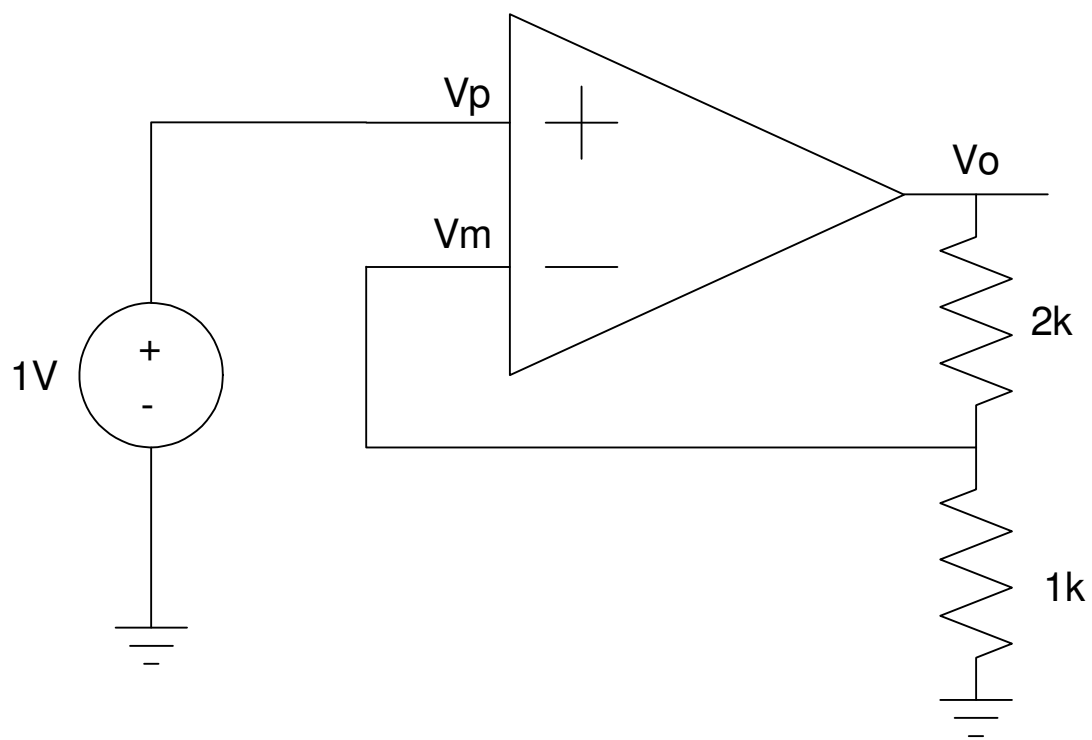


Translation: LM833



Circuit Model for an LM833.

Example: Determine the voltages



Case 1: LM833 Op-Amp

- Very similar to an MCP602

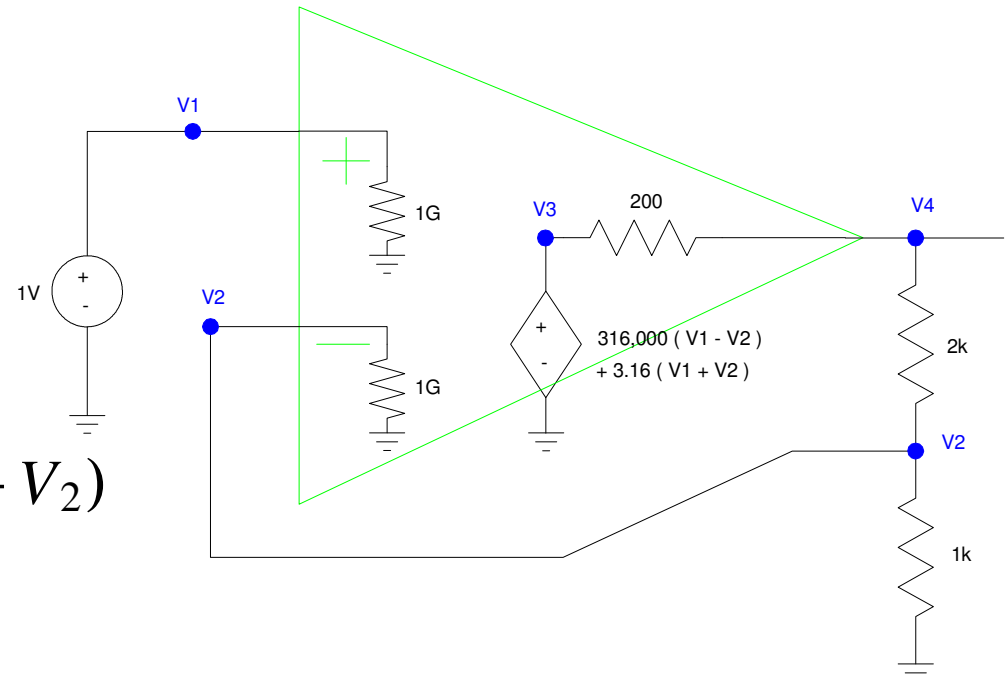
Node equations:

$$V_1 = 1$$

$$\left(\frac{V_2}{1G}\right) + \left(\frac{V_2 - V_4}{2k}\right) + \left(\frac{V_2}{1k}\right) = 0$$

$$V_3 = 316,000(V_1 - V_2) + 3.16(V_1 + V_2)$$

$$\left(\frac{V_4 - V_3}{200}\right) + \left(\frac{V_4 - V_2}{2000}\right) = 0$$



Solve in Matlab:

V1	1.
V2	0.9999899
V3	3.1999698
V4	2.9999716

Case 2: Ideal Op-Amp

Node equations

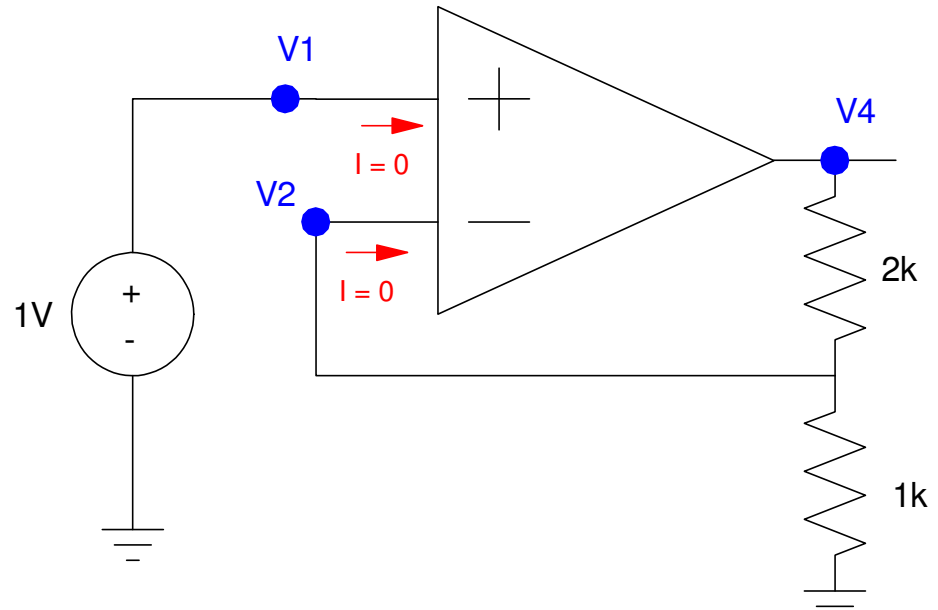
$$V_1 = 1$$

$$V_1 = V_2$$

$$\left(\frac{V_2}{1k}\right) + \left(\frac{V_2 - V_4}{2k}\right) = 0$$

Solve

	Ideal OpAmp	LM833
V1	1.	1.
V2	1.	0.9999899
V3	n/a	3.1999698
V4	3.000000	2.9999716



Ideal Op-Amp Model:

- The results are almost identical.
- It's a *lot* easier to use the ideal op-amp model.
- If you use a different op-amp, the results will be about the same.

note: "about" means

- *You keep impedances less than 10M Ohms (so you can ignore the 1G input impedance), and*
- *You keep impedances more than 100 Ohms (you draw less than 50mA)*

Likewise, from here on, we'll be assuming ideal op-amps.

Voltage Nodes with Op-Amps

Node equation at V_o (assuming negative feedback):

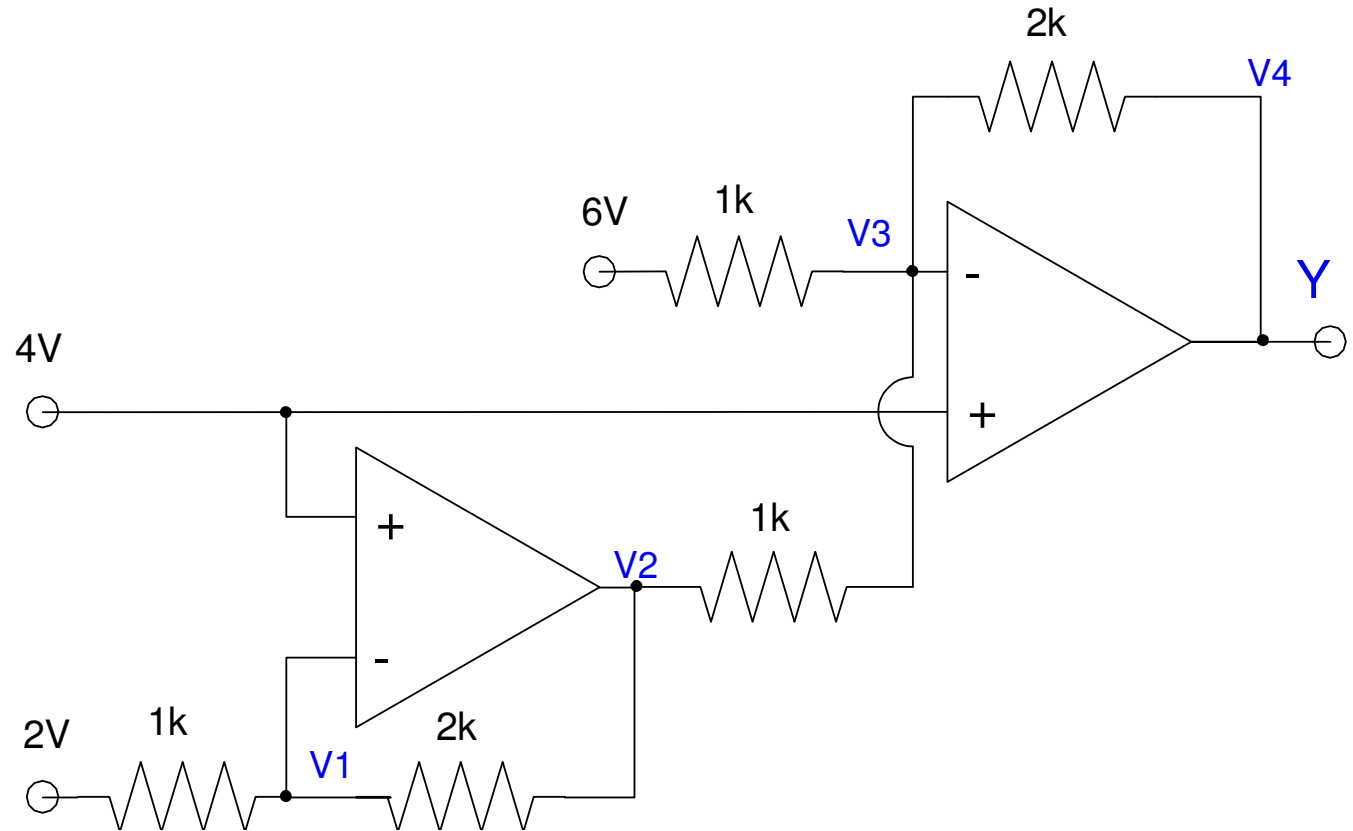
$$V_p = V_m$$

You do this for two reasons:

- (1) If you have negative feedback (i.e. are analyzing an amplifier as opposed to a Schmitt trigger), the high gain will force V_m to be close to V_p . Otherwise, the output would rail at the power supply.
 - (2) You can't write the voltage node equation at V_o . The op-amp is an active device and will source or sink as much current as needed to force V_m to match V_p . If you try to write the voltage node equation at V_o , the current from the op-amp is "as much as needed." That doesn't help when writing voltage node equations.
-

Example 1: Write the voltage node equations:

- 4 equations for 4 unknowns
- (handout problem #1)



Solution: (Take 1)

$$V_p = V_m$$

$$V_1 = 4$$

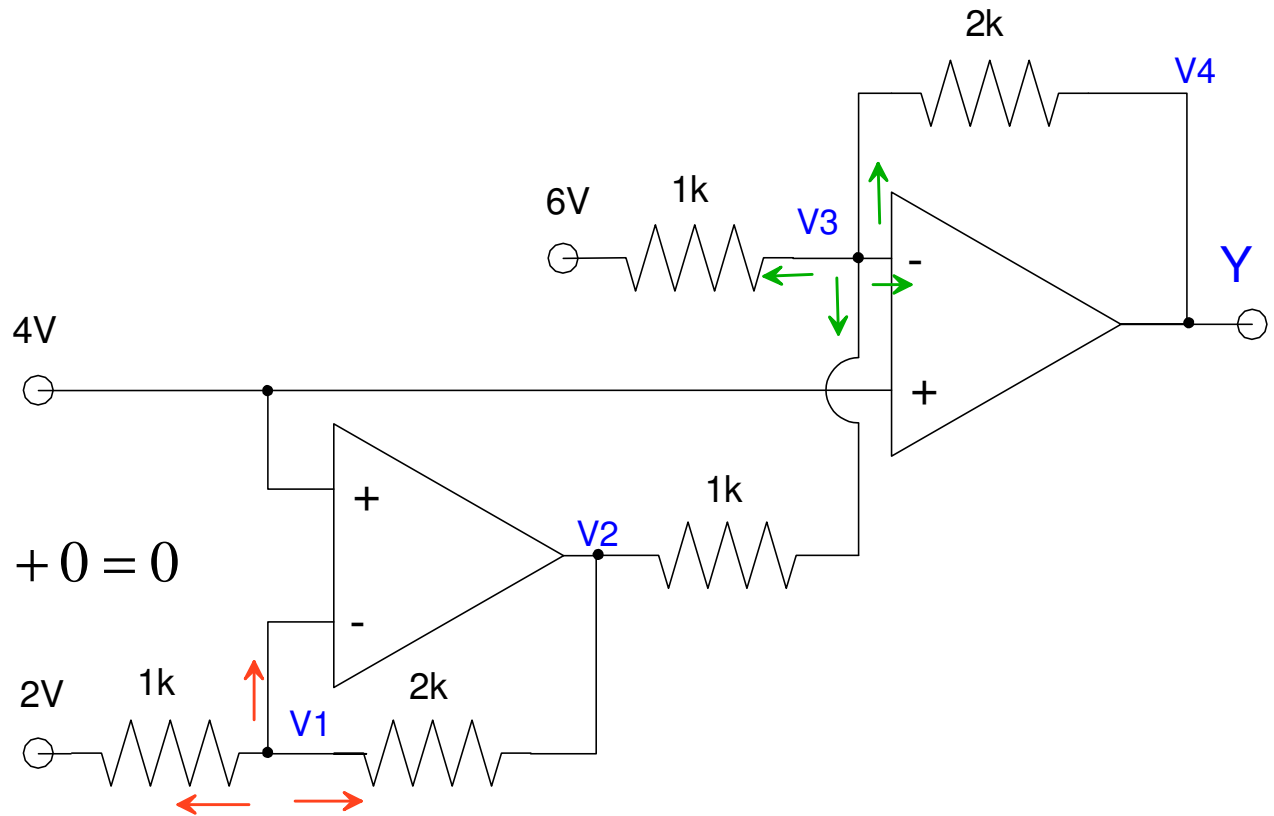
$$V_3 = 4$$

Node V1 (red)

$$\left(\frac{V_1 - 2}{1k}\right) + 0 + \left(\frac{V_1 - V_2}{2k}\right) = 0$$

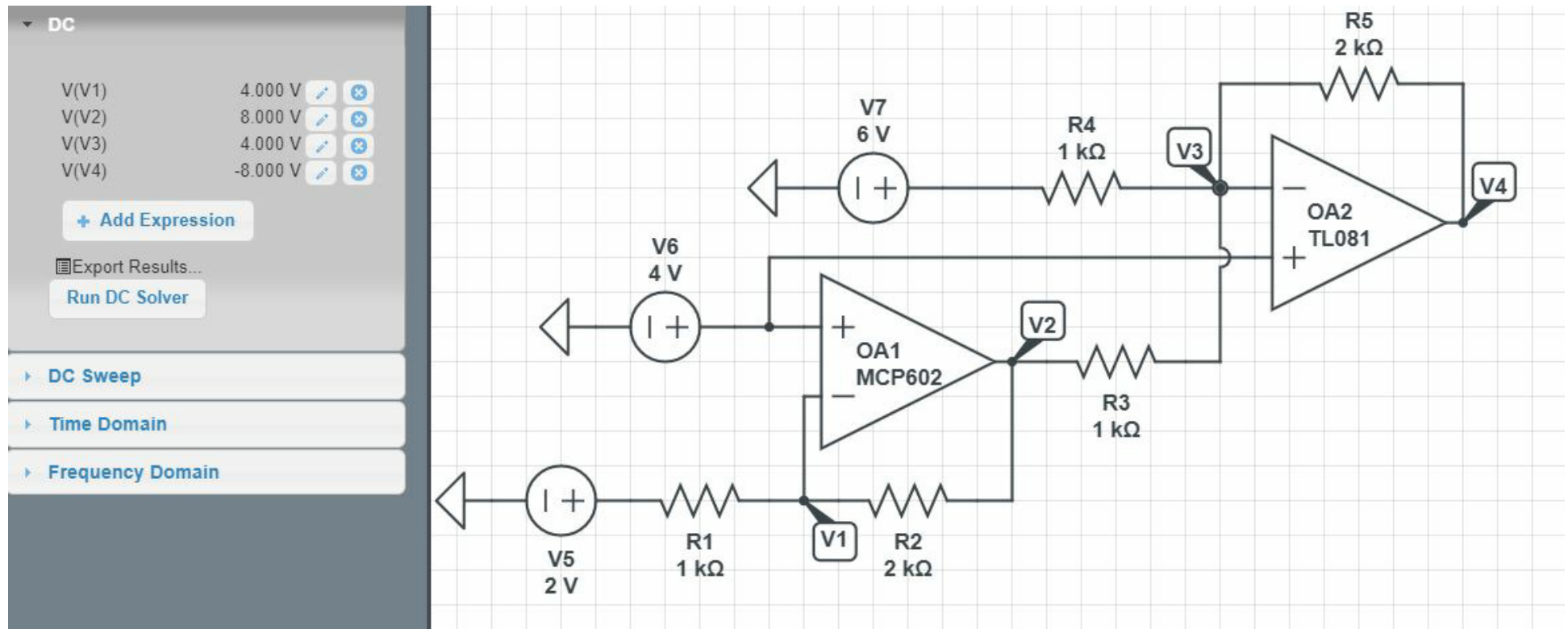
Node V3 (green)

$$\left(\frac{V_3 - V_2}{1k}\right) + \left(\frac{V_3 - 6V}{1k}\right) + \left(\frac{V_3 - V_4}{2k}\right) + 0 = 0$$



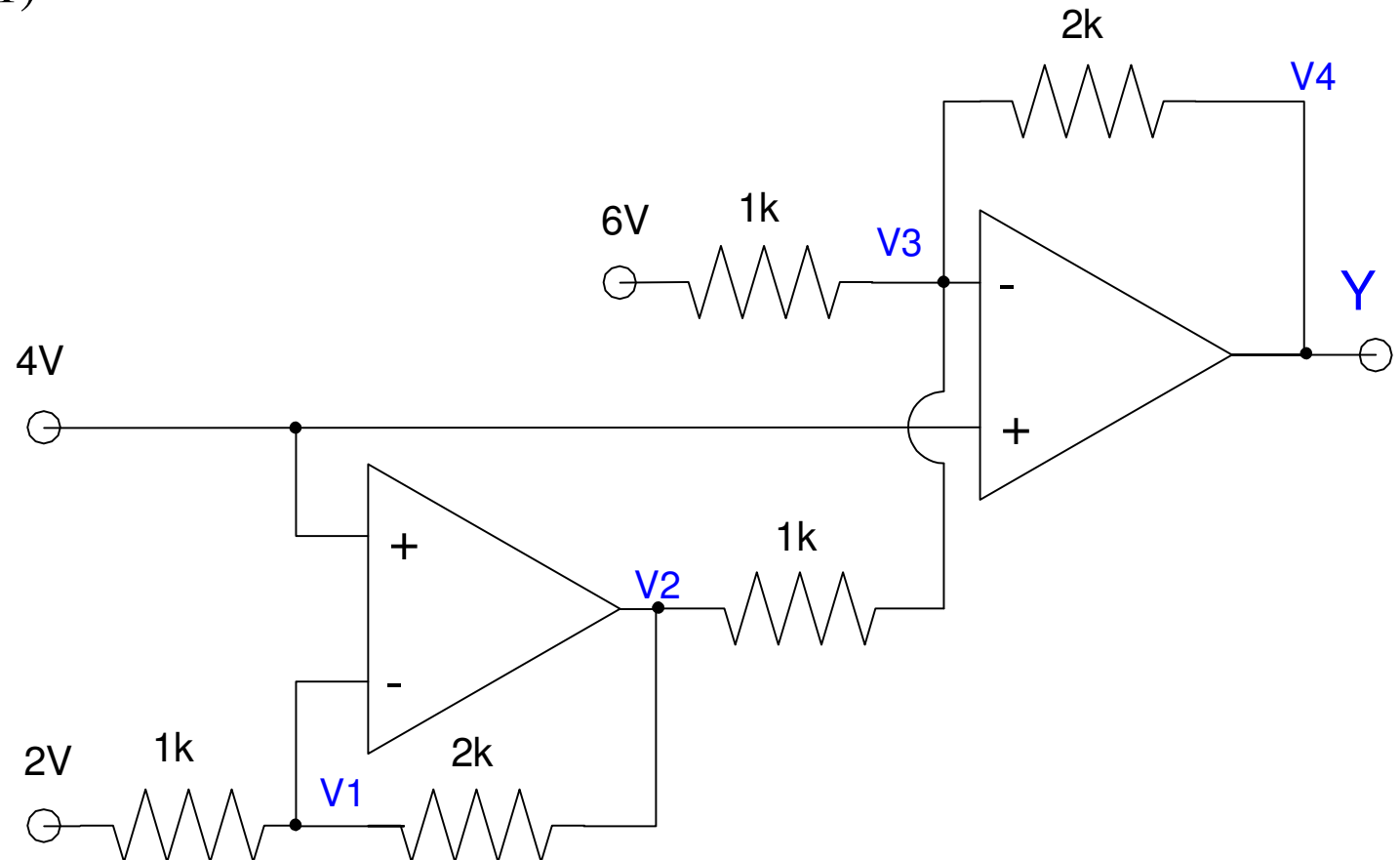
Check in CircuitLab

- Same answer

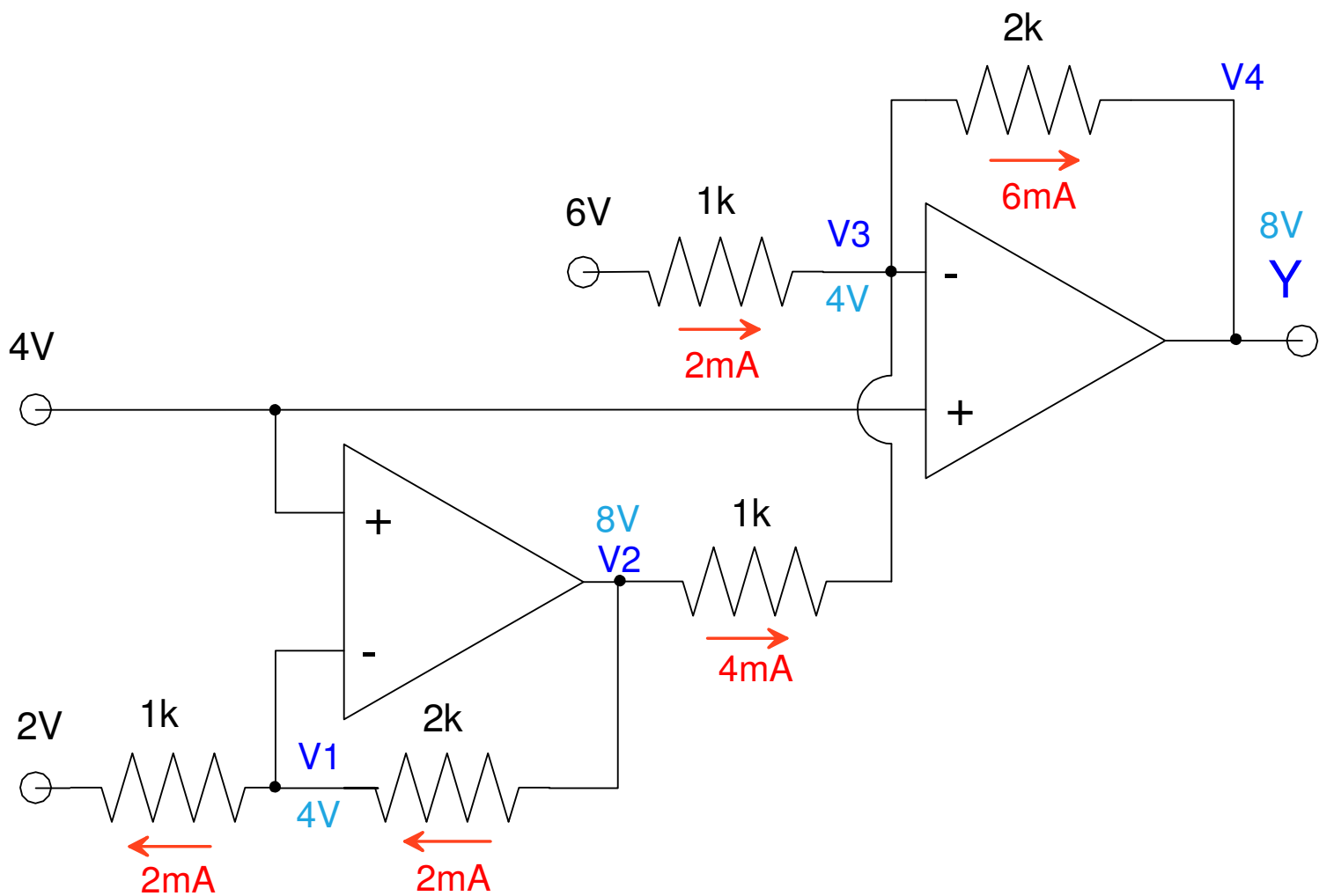


Determine the voltages and currents (take 2)

- Use conservation of current
- (handout problem #1)

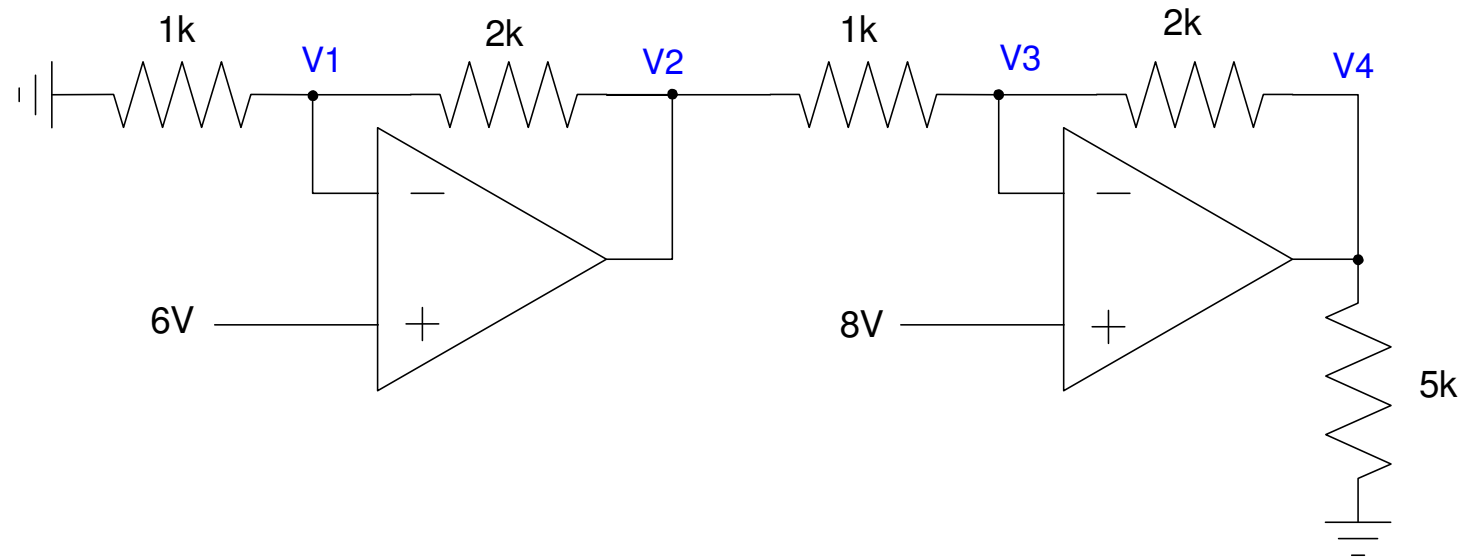


Solution



Example 2: Write the voltage node equations

- 4 equations for 4 unknowns
- (handout problem #2)



Example 2: Solution

$$V_p = V_m$$

$$V_1 = 6V$$

$$V_3 = 8V$$

Node 1 (red)

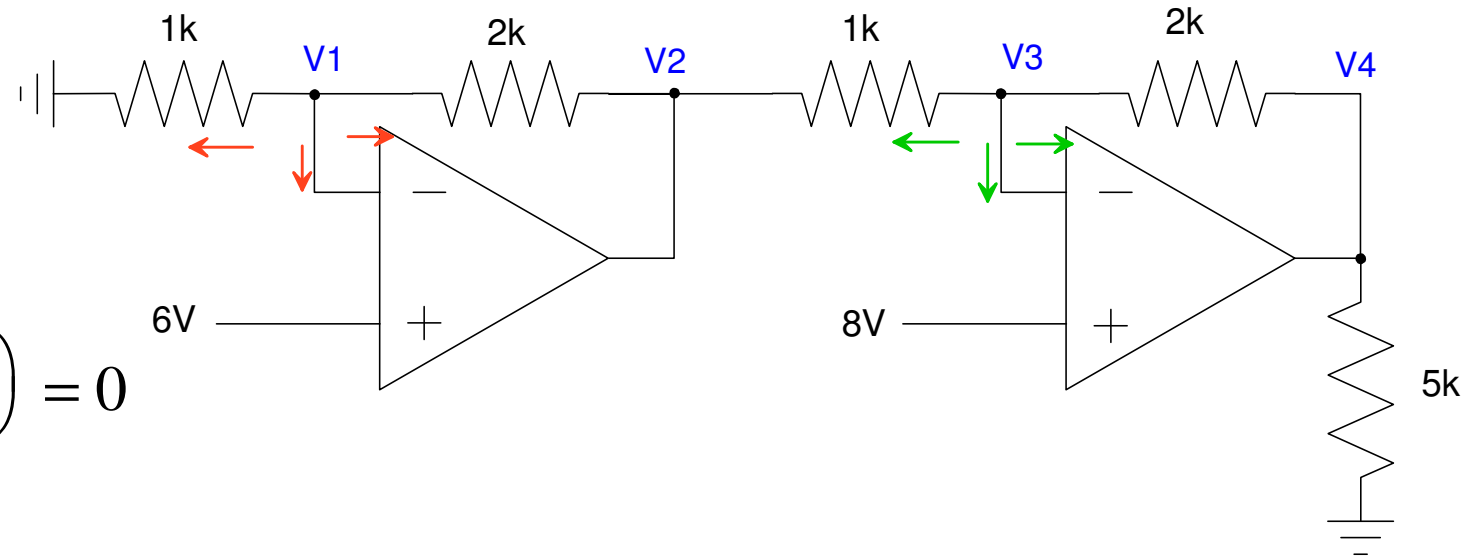
$$\left(\frac{V_1}{1k}\right) + 0 + \left(\frac{V_1 - V_2}{2k}\right) = 0$$

Node 3 (green)

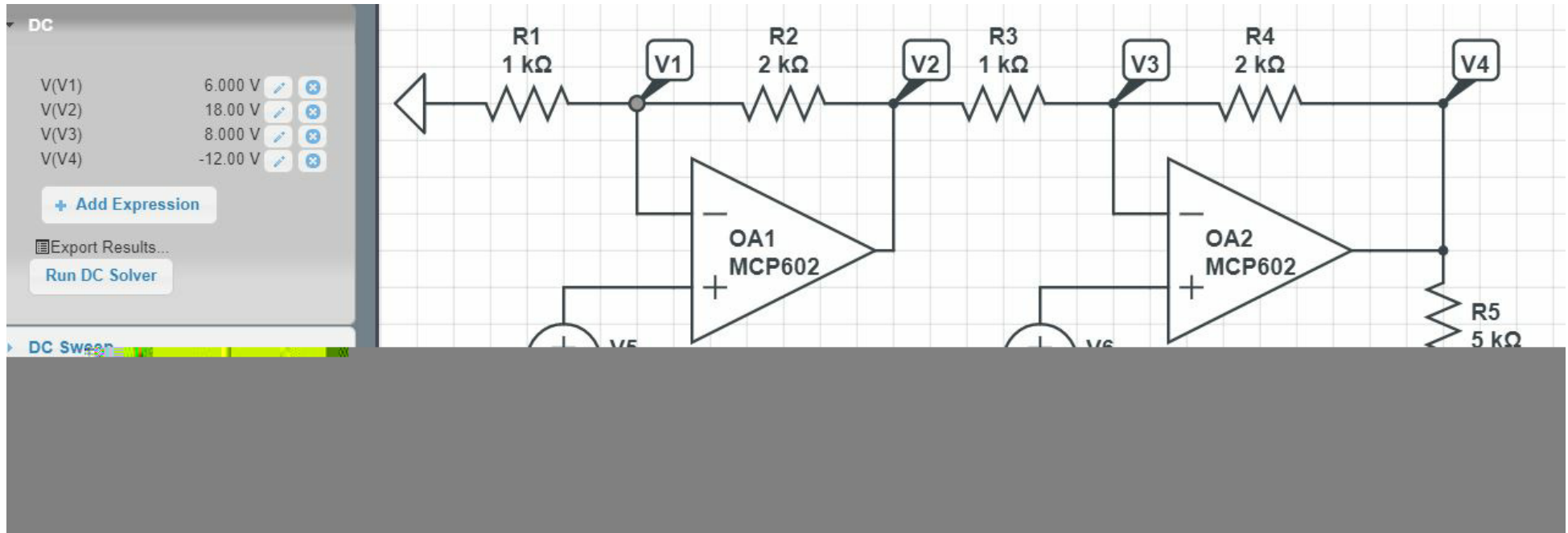
$$\left(\frac{V_3 - V_2}{1k}\right) + 0 + \left(\frac{V_3 - V_4}{2k}\right) = 0$$

Solve in Matlab

V1	6.000
V2	18.000
V3	8.000
V4	-12.000

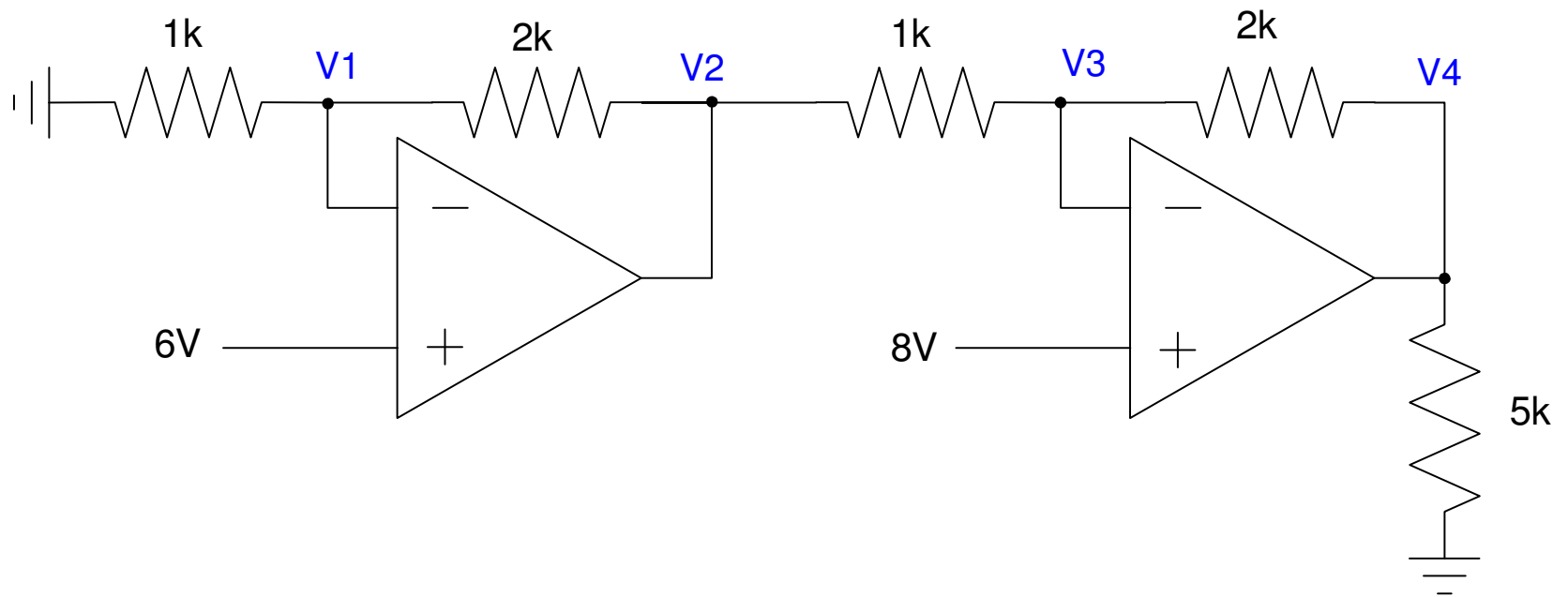


This checks with the CircuitLab

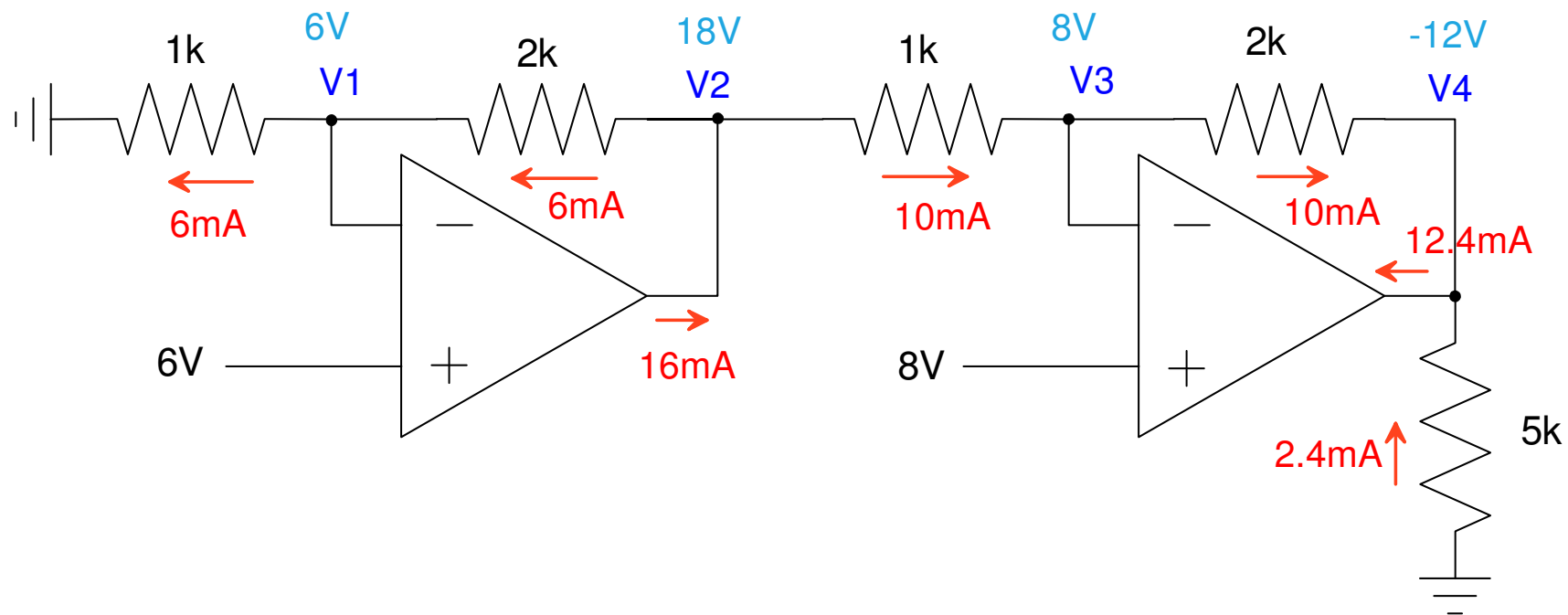


Example 2: Determine the voltages and currents

- Use conservation of current



Solution:



Note:

- You don't need to use the op-amps with the +/- power supplies
 - For analog circuits, the output should be finite
 - As long as the power supply allows this, the power supply doesn't matter.
- Using the wrong op-amp (TL081 instead of an LM833) is also OK.
 - They both behave like an ideal op-amp (and likewise have almost identical results).

Summary

Ideal Op-Amp Model is very close

- Keep $100 < R < 10M$

Voltage Nodes works for op-amp circuits

- For analog circuits, $V_p = V_m$

You can also solve for voltages and currents using conservation of current
