
Operational Amplifiers

ECE 211 Circuits I

Lecture #13

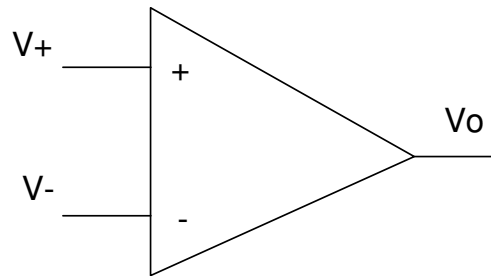
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Operational Amplifiers

An operational amplifier is a 2-input device with

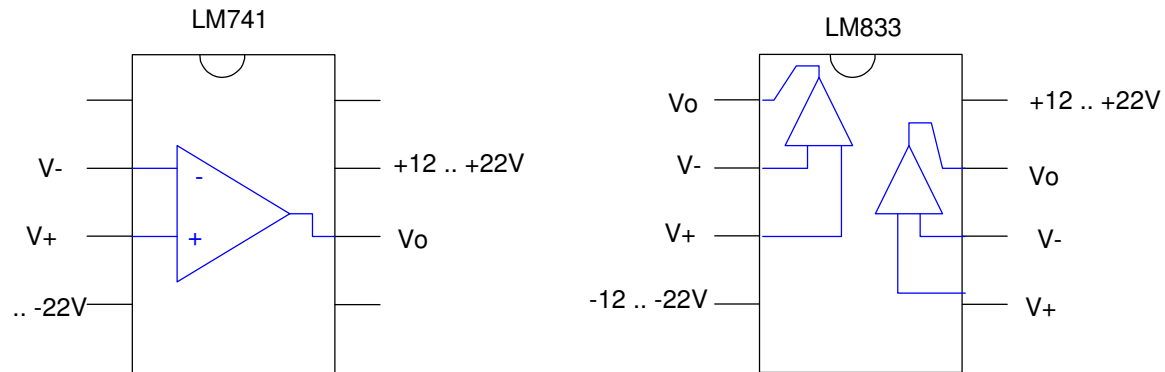
$$V_o \approx k(V^+ - V^-)$$

where k is a large number. For short, the following symbol is used for an differential amplifier:



Symbol for an operational amplifier (op-amp)

Operational Amplifier Characteristics



	LM741	LM833	Ideal
Input Resistance	2M Ohms	4G Ohms	infinite
Output Resistance	75 Ohms	20 Ohms	0
Output Short Circuit Current:	25mA	50 mA	infinite
Operating Voltage	+/- 12V .. +/- 22V	+/- 2.5V .. +/- 15V	any
Differential Mode Gain	200,000	100,000	infinite
Common Mode Rejection Ratio	90dB	100dB	common mode gain = 0
Slew Rate	0.5V/us	7V/us	infinite
Gain Bandwidth Product	1.5MHz	15MHz	infinite
Price (qty 100)	\$0.35	\$0.52	-

Translation

Input Resistance: The Thevenin equivalent of the op-amp at V_+ and V_-

Short Circuit Current: The maximum current you can get

Operating Voltage: What you need to make it work

Differential Mode Gain: The gain from $(V_+ - V_-)$ to the output

Slew Rate: How fast the output can change.

Gain Bandwidth Product = 1.5MHz:

- If you want a gain of one, the bandwidth is 1.5MHz
 - If you want a gain of 10, the bandwidth is 150kHz.
 - etc.
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Operational Amplifier Circuit Analysis

Problem: Write the voltage node equations for the following circuit. Assume (a) a LM741 op amp. (b) an ideal op-amp.

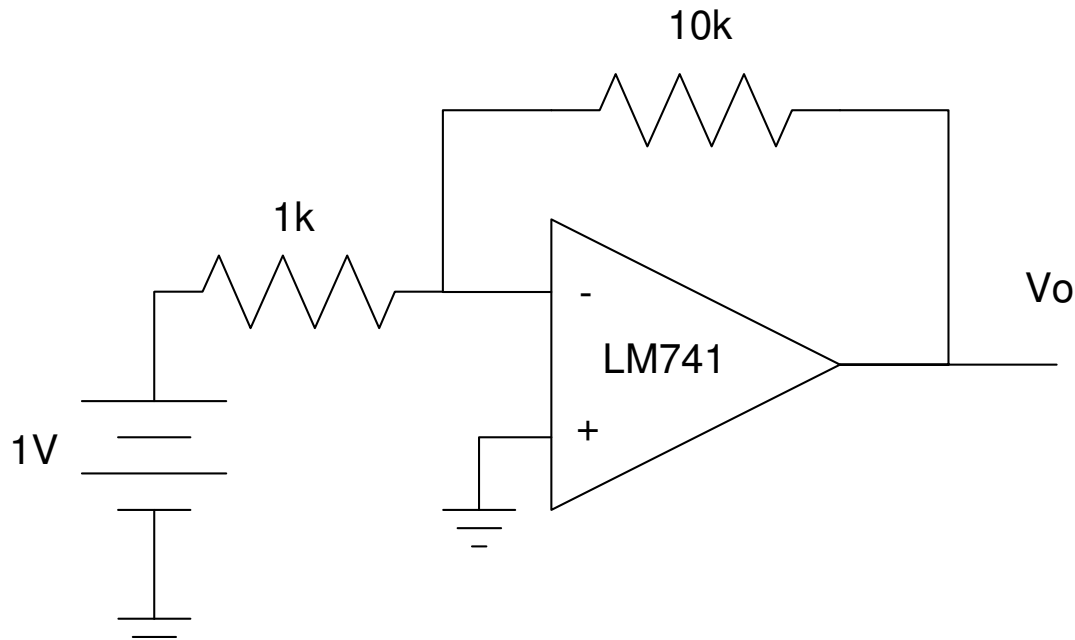


Figure 2: Find V_o for this op-amp circuit

741 Op Amp Analysis:

First, replace the op-amp with a model taking into account the input, output resistance and gains:

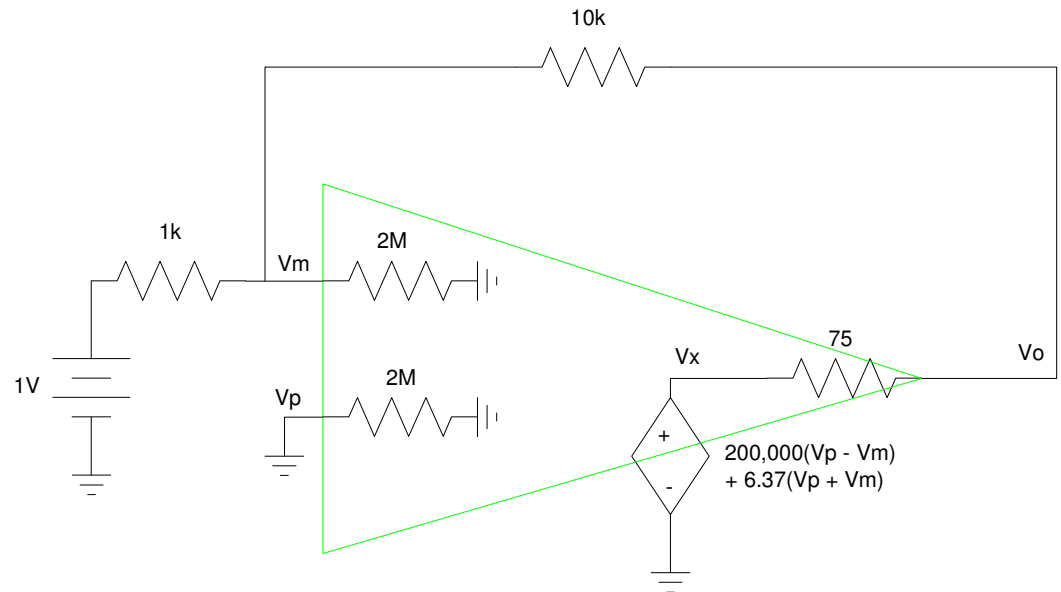
$$V_p = 0$$

$$\left(\frac{V_m - 1V}{1k} \right) + \left(\frac{V_m}{2M} \right) + \left(\frac{V_m - V_x}{10k + 75} \right) = 0$$

$$V_x = -199,994V_m$$

Solving

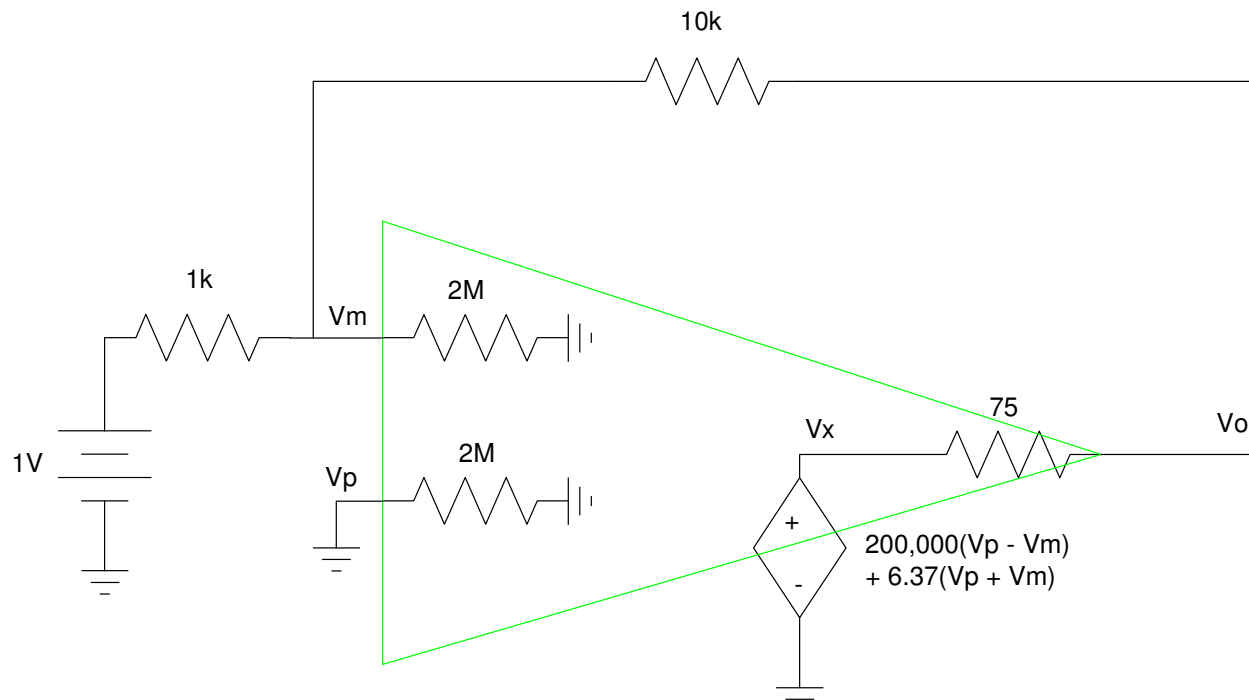
- $V_p = 0.000\ 0000\ V$
- $V_m = 0.000\ 050\ V$
- $V_o = -9.999\ 940\ V$



Ideal Op Amp:

Note that many of the terms don't affect the output all that much:

- $2M\Omega \parallel 1k\Omega \approx 1k\Omega$
- $0.0000504V \approx 0V$



If you approximate these terms, you're essentially using an ideal-op amp.

This is *much* easier to analyze

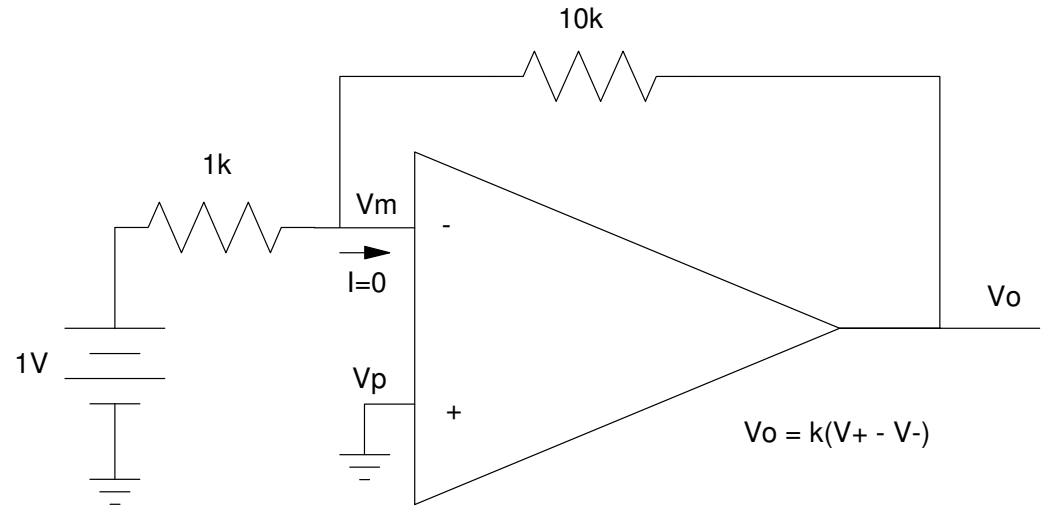
$$V_p = 0$$

$$V_p = V_m$$

$$\left(\frac{V_m - 1V}{1k} \right) + \left(\frac{V_m - V_o}{10k} \right) = 0$$

which gives

$$V_o = -10.000V$$



Note:

- When analyzing an op-amp circuit, you almost have to use voltage nodes.
- If assuming an ideal op-amp, the voltage node equation at V_o is

$$V_p = V_m$$

Example 2: Find V1..V4

- Assume ideal op-amps

$$V_p = V_m$$

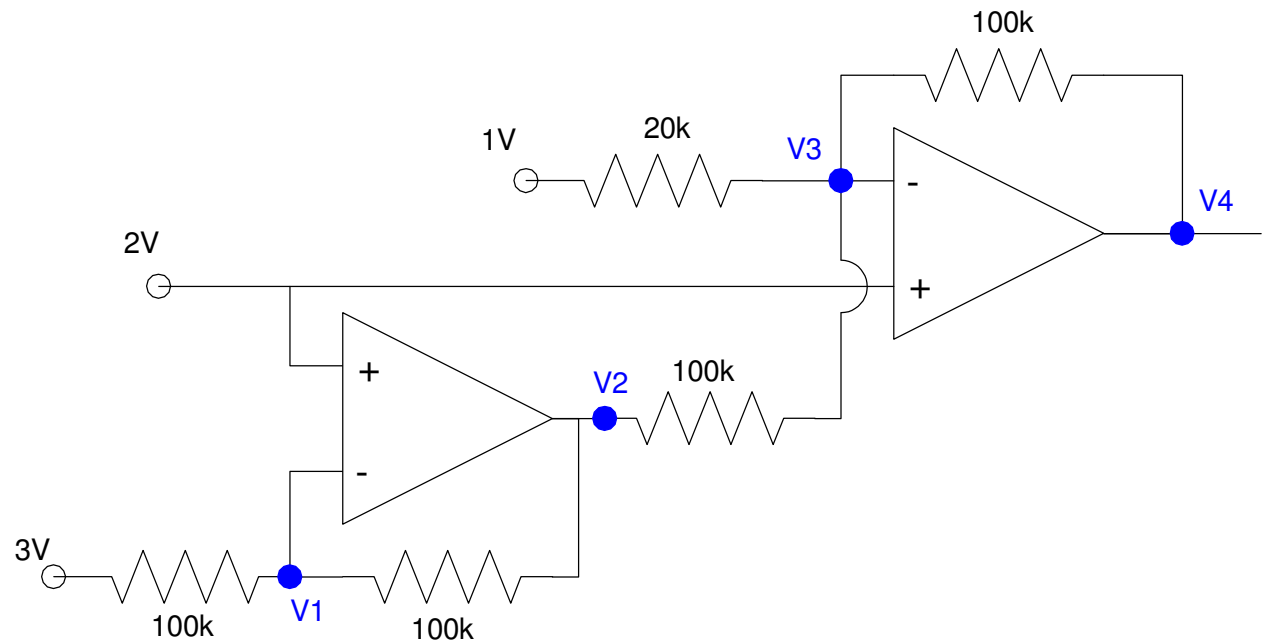
meaning

$$V_1 = 2V$$

$$V_3 = 2V$$

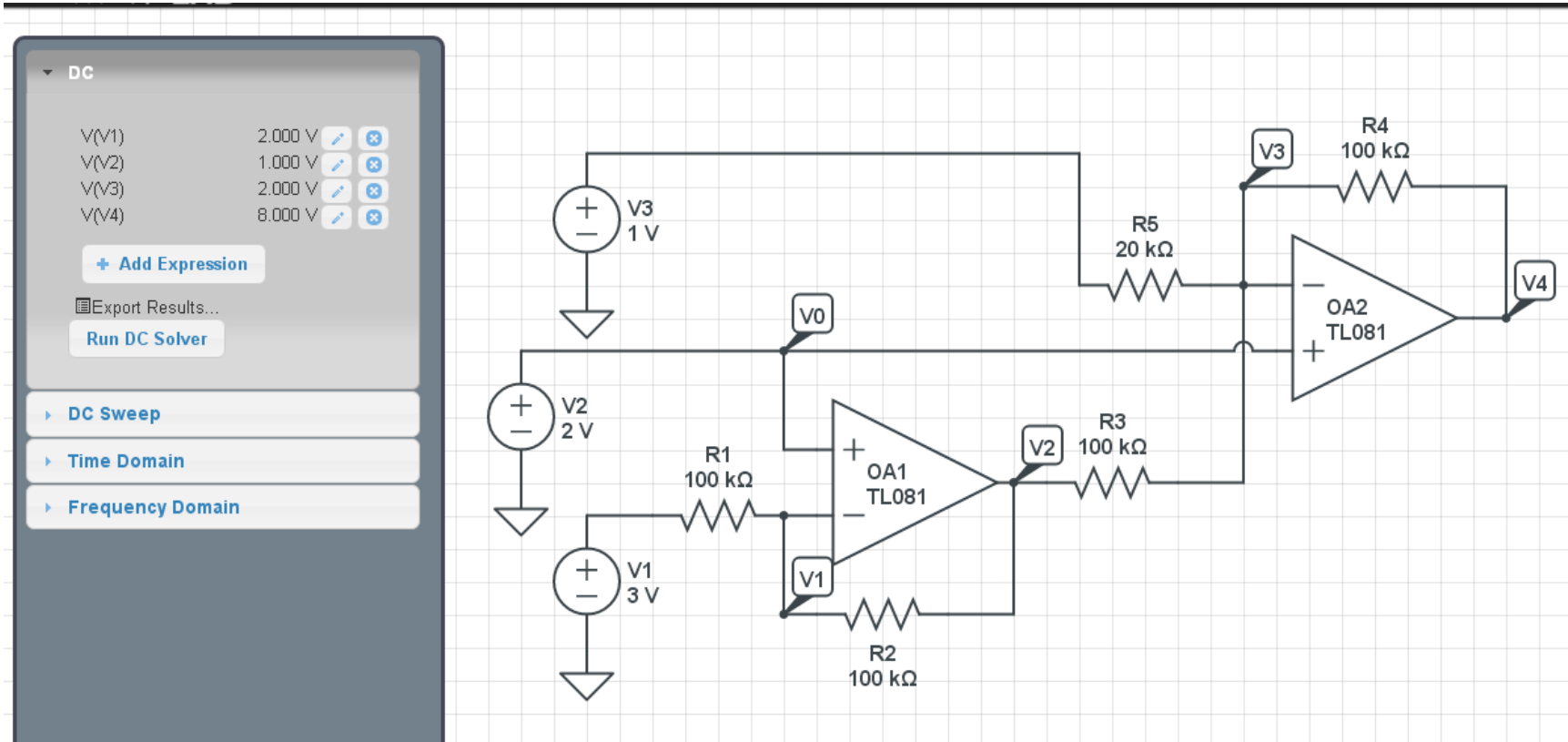
$$\left(\frac{V_1-3}{100k}\right) + \left(\frac{V_1-V_2}{100k}\right) = 0$$

$$\left(\frac{V_3-V_2}{100k}\right) + \left(\frac{V_3-1}{20k}\right) + \left(\frac{V_3-V_4}{100k}\right) = 0$$



Solving gives $V1 = 2.00\text{V}$, $V2 = 1.00\text{V}$, $V3 = 2.00\text{V}$, $V4 = 8.00\text{V}$

- Same as CircuitLab



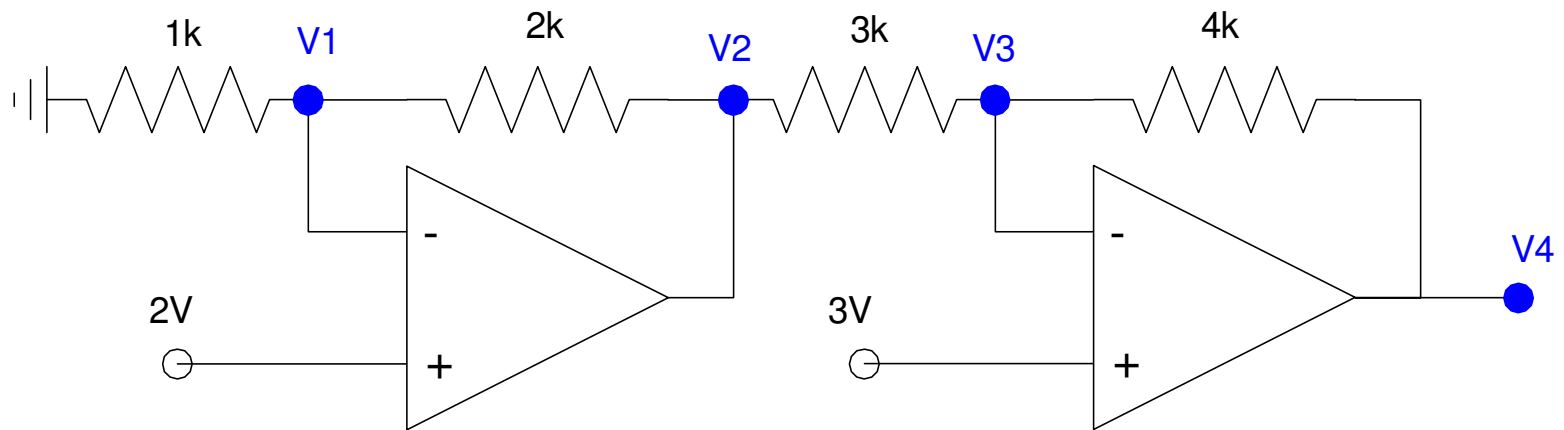
Example 3: Assume ideal op-amps. Find the node voltages.

$$V_1 = 2$$

$$V_3 = 2$$

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

$$\left(\frac{V_3 - V_2}{3k}\right) + \left(\frac{V_3 - V_4}{4k}\right) = 0$$



Solving

V1 2.0000
V2 6.0000
V3 3.0000
V4 -1.0000

Same as CircuitLab

