Announcements

Today: Review midterm answers, review of operational amplifiers

Midterm Exam: Overall really good job!

Average: 81%. 9 A's, 9 B's.

I added 5 points to everyone's exam to compensate for "ambiguity" in the wording of problem 4. I don't think this is reflected in the grade you see.

Let's go over the answers to make sure everything's clear.

Remaining Topics in Class

Week #	Date	Topics	Homework	Labs
Week 0	10/1	**10:** Class introduction	• None	• NO LAB
Week 1	10/6	**10:** Review of Thevenin equivalent circuits + review of chapter 10 (first-order RC/LC circuits)	• HW 1 posted	• NO LAB
	10/8	**11:** Finish chapter 10 review + power and energy in 1st order circuits and digital logic		
Week 2	10/13 10/15	**12.1-12.3:** Undriven second-order LC/RLC circuits + stored energy	• HW 1 (10/15) • HW 2 posted	• Lab 1 due
Week 3	10/20 10/22	**12.5-12.9:** Driven RLC circuits + an intuitive analysis	• HW 2 (10/22)	• Lab 2 due
Week 4	10/27 10/29	**13.1-13.3** Transient analysis + the impedance method	• HW 3 posted	
Week 5	11/3	Review (if time allows)	• HW 3 (11/5) • Study Session	• Lab 3 due
	11/5	Midterm (in class)		
Week 6	11/10 11/12	Op Amp Review + Transfer functions	• HW 4 posted	
Week 7	11/17 11/19	**13.5-13.7:** Frequency response review + filter design	• HW 4 (11/19) • HW 5 posted	• Lab 4 due
Week 8	11/24	Review (if time allows)		
Week 9	12/1 12/3	**14:** Resonance in second-order circuits	• HW 5 (11/21) • HW 6 posted	• Lab 5 due
Week 10	12/8 12/10	**Final Topics TBD (possibly final exam review)**	• HW 6 (12/3) • Study Session	• Lab 6 due

Labs and Office Hours

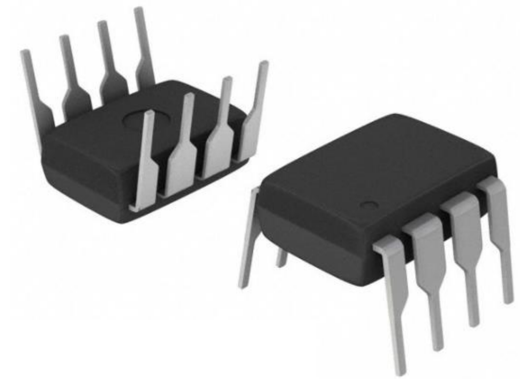
Lab Components: Many questions about missing components.

- Check the components list to see if you're missing anything.
- If you're in the SB/Goleta area, you can swing by the ECE shop to get any missing components.
- If you're not local, you can adapt the labs for the components you have (ask me or Kamyar about this).

Office Hours: Almost nobody is taking advantage of office hours for lecture or the labs. We're happy to help out and answer questions outside of office hours, but our responses may be slower, and we may be unresponsive over the weekend. Please try to take advantage of the office hours first.

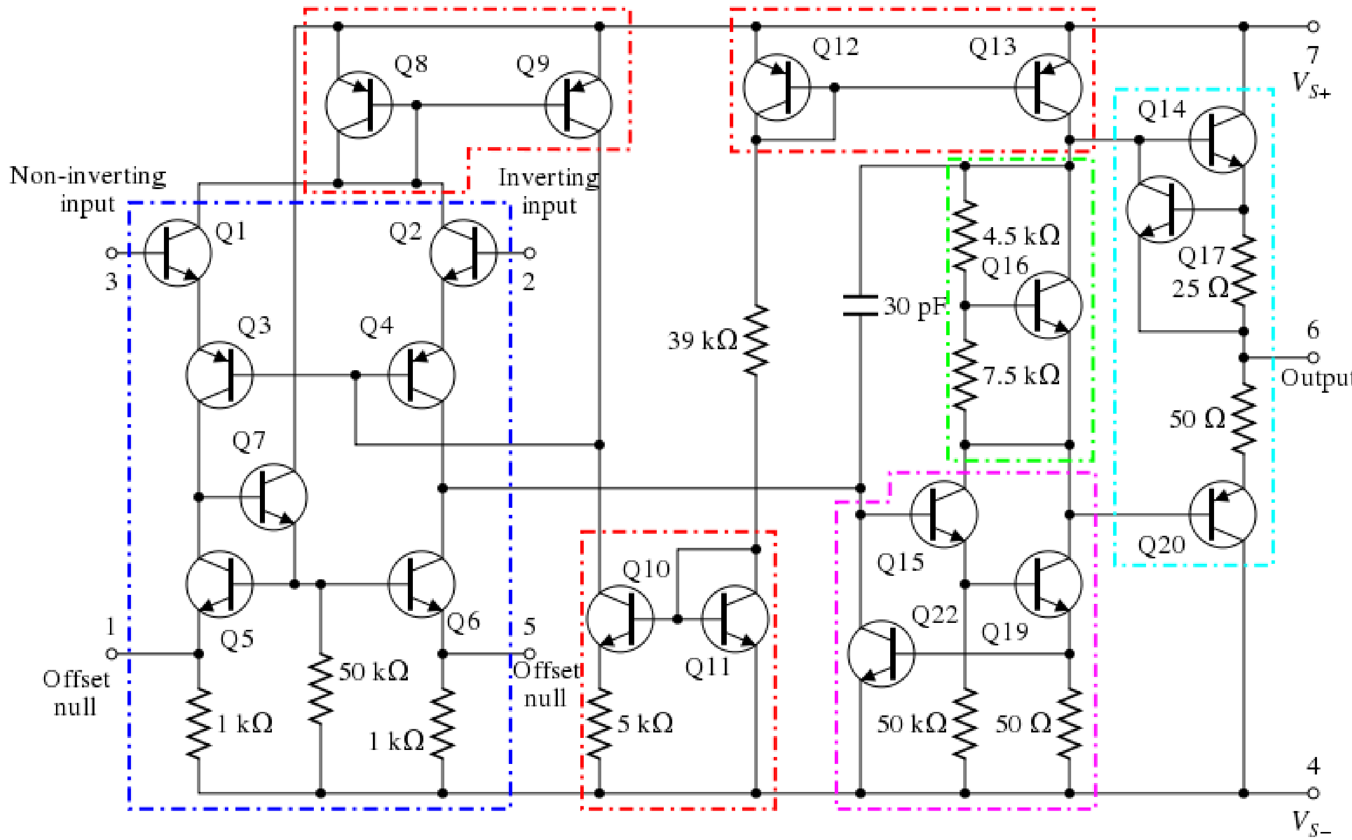
Operational Amplifiers – Review

- **What is an Op-Amp?**
- Characteristics of Ideal and Real Op-Amps
- Common Op-Amp Circuits

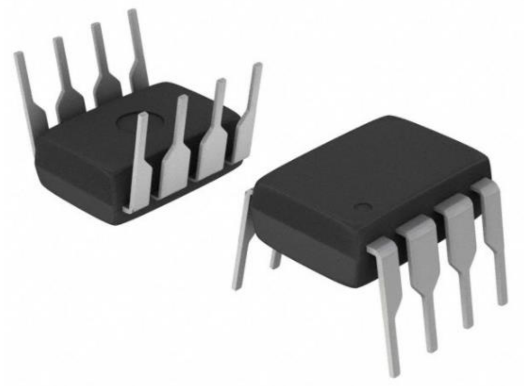


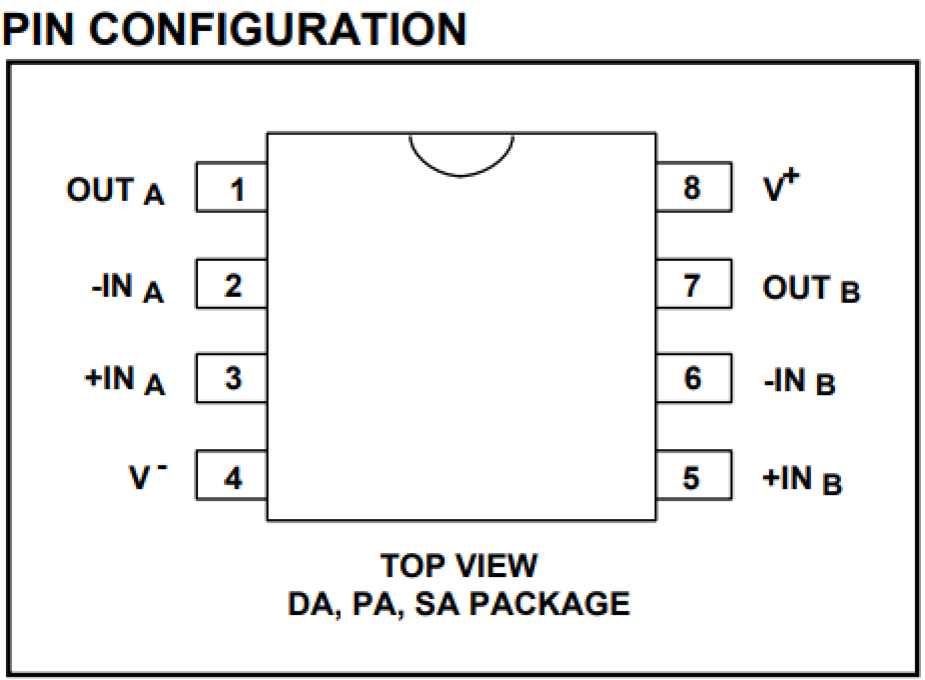
- **What is an Op-Amp?**

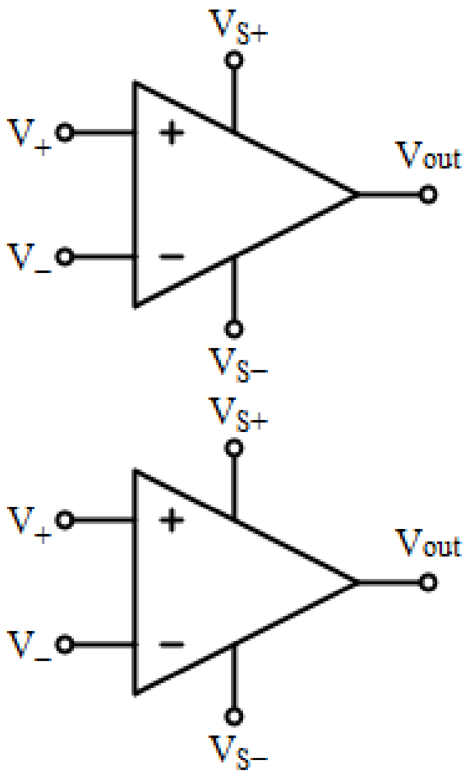
An *Operational Amplifier* (known as an "Op-Amp") is a device that is used to amplify a signal using an external power sour



- How to connect it!

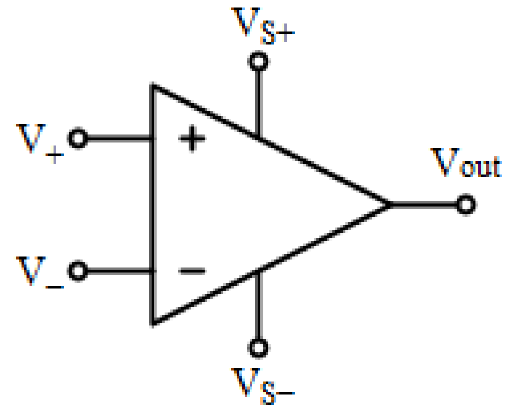




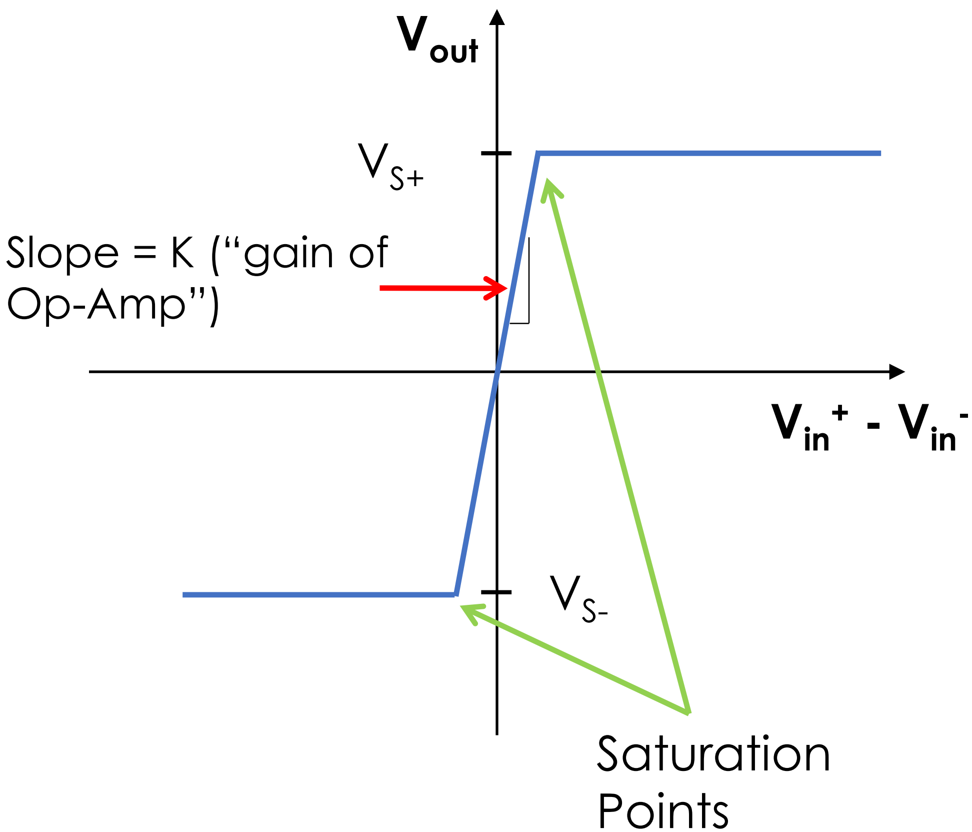


Saturation

Saturation is caused by increasing/decreasing the input voltage to cause the output voltage to equal the power supply's voltage



$$V_{out} = gain \times (V_+ - V_-)$$



So if V_+ is greater than V_-, the output goes positive

If V_- is greater than V_+, the output goes negative

Operational Amplifiers – Review

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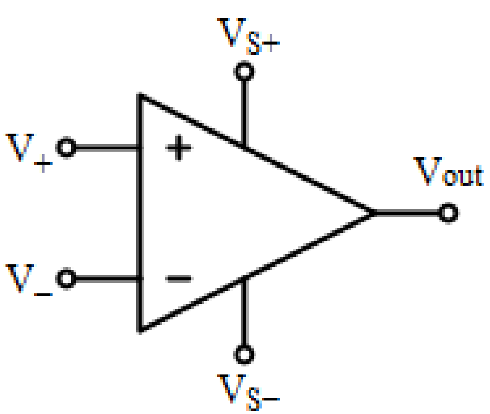
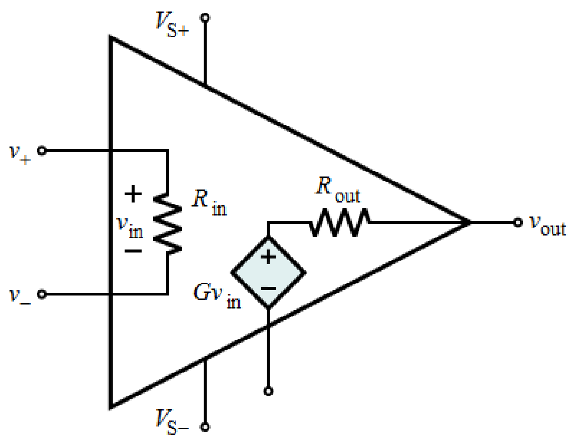
Ideal versus Real Op-Amps

Parameter	Ideal Op-Amp	Real Op-Amp
Differential Voltage Gain	∞	10^5 - 10^9
Gain Bandwidth Product (Hz)	∞	1-20 MHz
Input Resistance (R)	∞	10^6 - 10^{12} Ω
Output Resistance (R)	0	100 - 1000 Ω



Ideal

Real



Operational Amplifiers – Review

- What is an Op-Amp?
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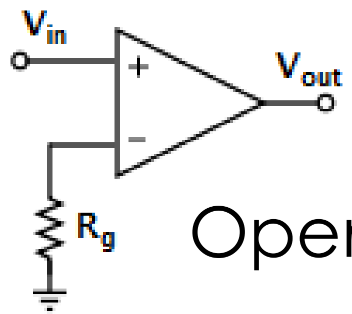
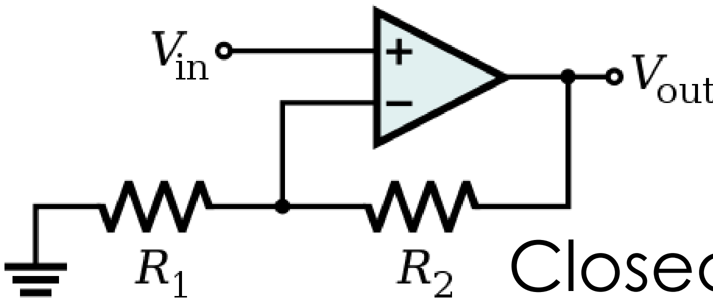
- **Common Op-Amp Circuits**

Open Loop vs Closed Loop

- A closed loop op-amp has feedback from the output to the input, an open loop op-amp does not



Open Loop



Closed Loop

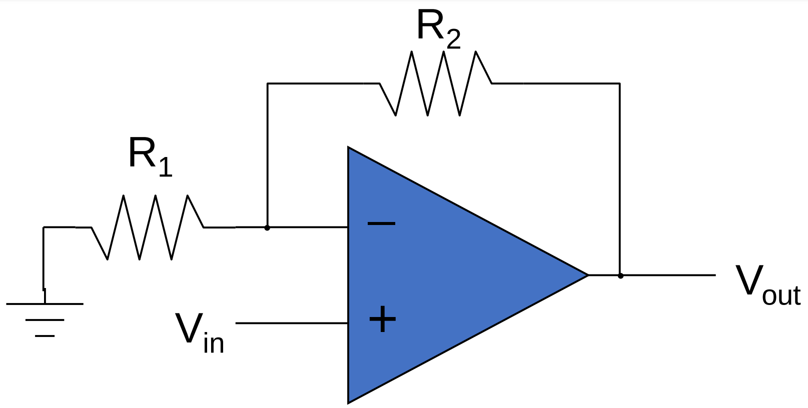
Op-Amp "Golden Rules"

- The inputs to the op-amp draw or source no current (infinite input resistance)

- The op-amp output will do whatever it can (within its limitations) to make the voltage difference between the two inputs zero

Operational Amplifiers – Review

Non-inverting Amplifier



$V_{out}=K(V_+-V_-)$

$R_1/(R_1+R_2)$ ← Voltage Divider

$V_-=V_{out}\ (R_1/(R_1+R_2)\ )$

$V_{out}=[V_{in}-V_{out}\ (R_1/(R_1+R_2))]\ K$

$V_{out}=V_{in}/[(1/K)+\ (R_1/(R_1+R_2))]$

As discussed previously assuming, K is very large, we have:

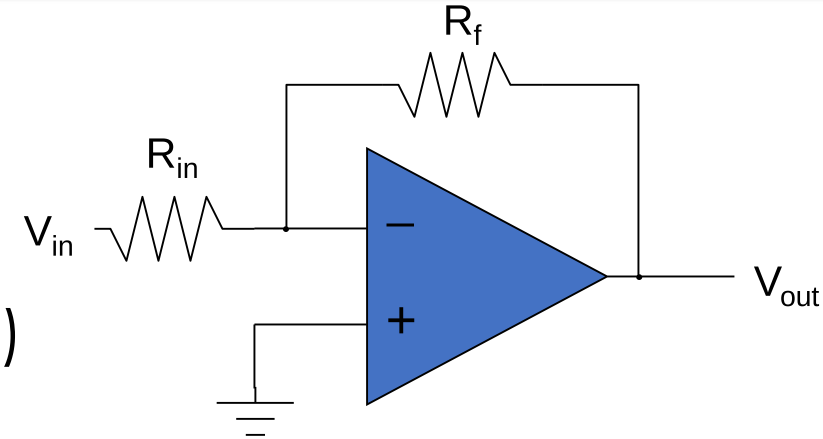
$V_{out}=V_{in}/(R_1/(R_1+R_2))$

$V_{out}=V_{in}\ (1+(R_2/R_1))$ **AMPLIFIER**

For R2 = 0, V_{out} = V_{in} **BUFFER**

Operational Amplifiers – Review

Inverting Op Amp



$V_{out}=K(V_+-V_-)$

$V_-=V_{out}(R_{in}/(R_{in}+R_f))+V_{in}(R_f/(R_{in}+R_f))$

$V_-=(V_{out}R_{in}+V_{in}R_f)/(R_{in}+R_f)$

$V_{out}=K(0-V_-)$

$V_{out}=-V_{in}R_f/[(R_{in}+R_f)/K+(R_{in})]$

$V_{out}=-V_{in}R_f/R_{in}$ negative sign earns title "inverting" amplifier

We don't use this configuration in our labs since Arduino can't detect negative outputs

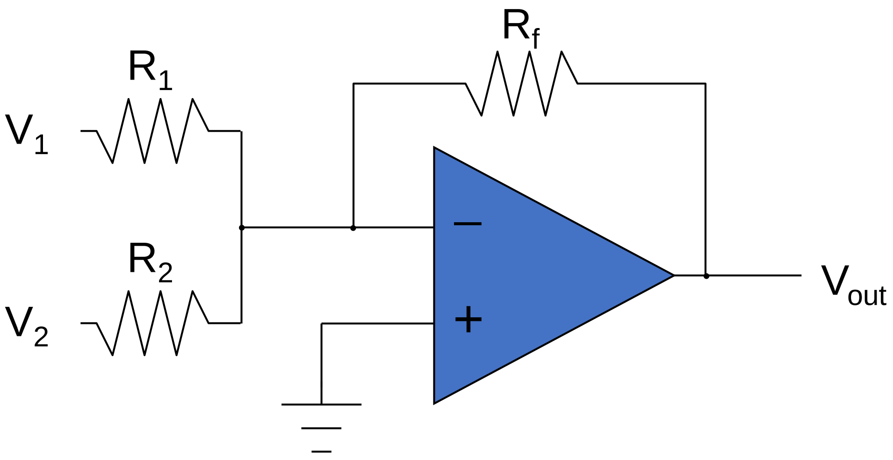
Operational Amplifiers – Review

Summing Amplifier

Much like the inverting amplifier, but with two input voltages

$V_{out} = -R_f \times (V_1/R_1 + V_2/R_2)$

if $R_2 = R_1$, we get a sum proportional to $(V_1 + V_2)$



Low-pass filter (integrator)

$I_f = V_{in}/R$, so $C \cdot dV_{cap}/dt = V_{in}/R$

and since left side of capacitor is at virtual ground:

$$-dV_{out}/dt = V_{in}/RC$$

so

$$V_{out} = -\frac{1}{RC}\int V_{in}\,dt$$

and therefore we have an integrator (low pass)