Lecture 3 : Op Amp Basics

0. Quiz
1. Review
2. Op Amp Intro
3. Some useful op amp circuits

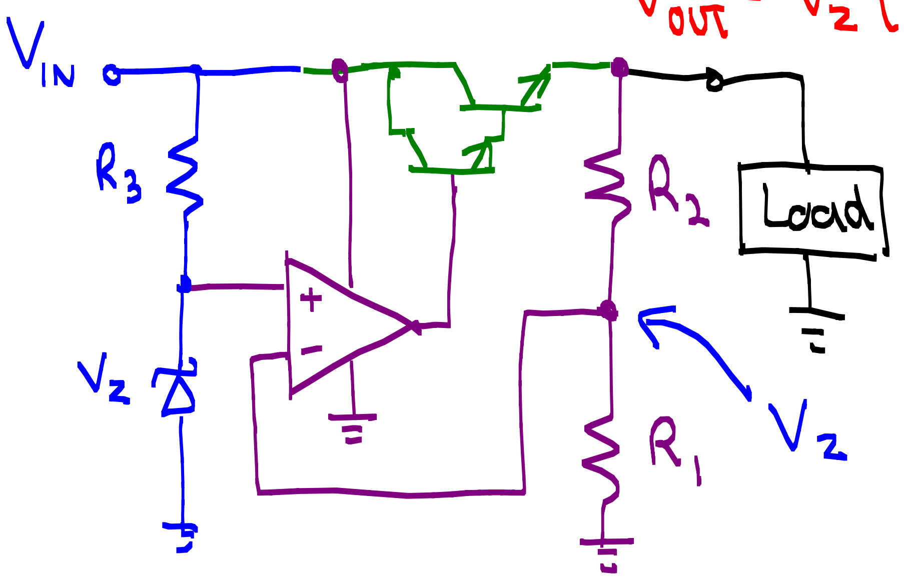
- Quiz next Tue (Sep 24)
- PreLab 2 ← due at lab session
- Lab 1 report
  ↑ see course website for template
- HW2 due next Fri (Sep 27)

Textbook reading: 16-1 Intro to Op Amps
16-4 Non-inverting amplifier

0. Review

- Zener follower + neg feedback
  - → V_{OUT} no longer depends on V_{BE}!
  - → use Darlington for larger I_{OUT}

$$V_{OUT} = V_Z\left(1 + \frac{R_2}{R_1}\right)$$

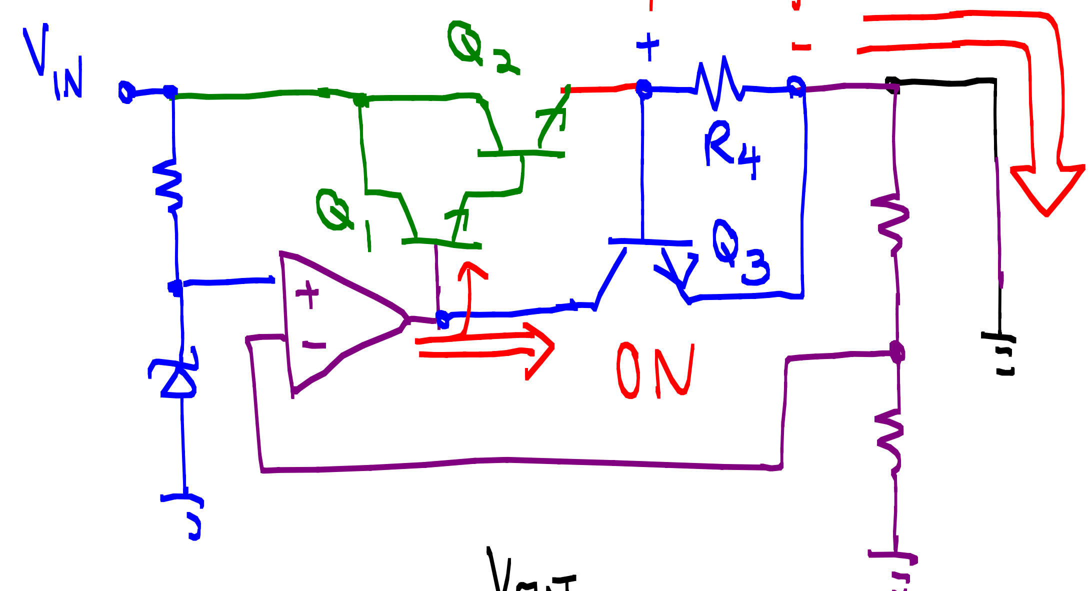


Short Circuit (Q_3 ON)

Q_3 steals Q_1 base current

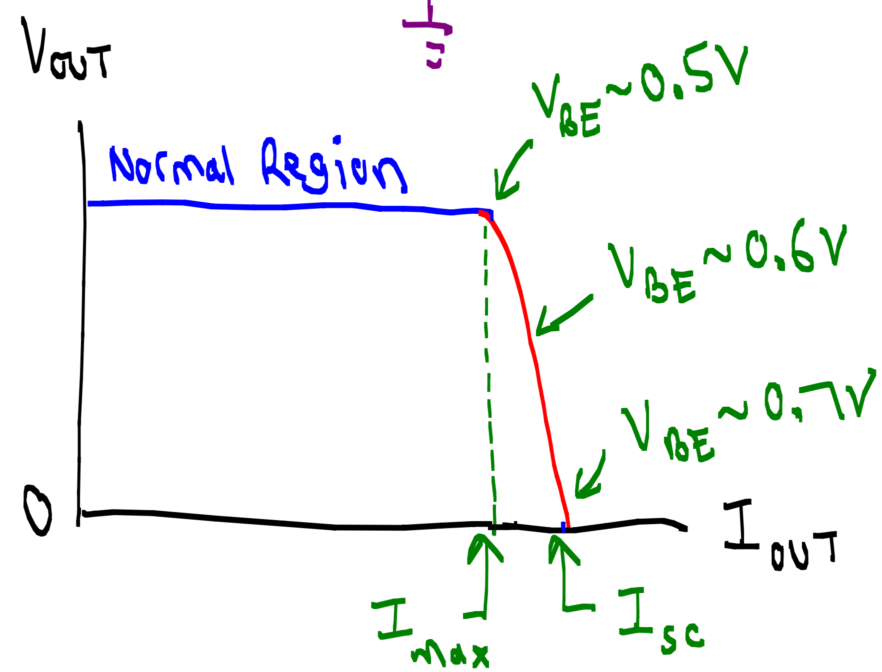
~0.7V → $I_{SC} R_4$

↓ I_{SC}



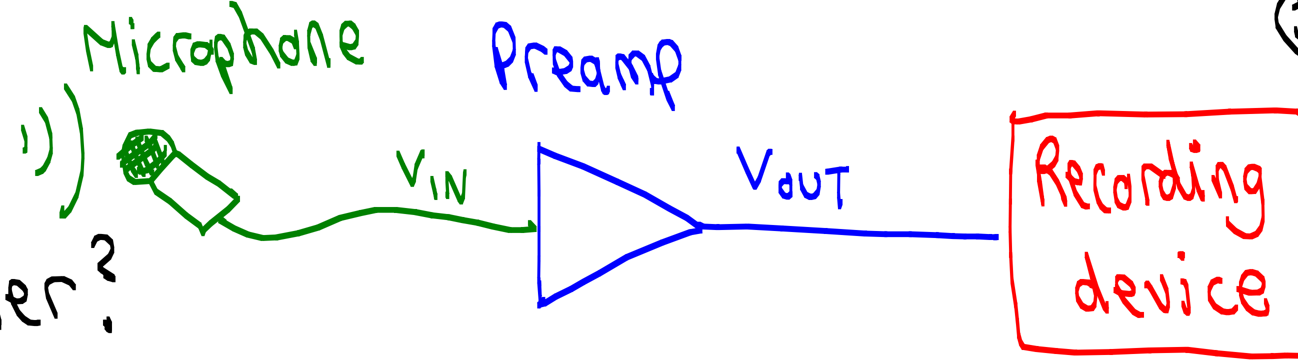
NOTE:

1. Q_3 does not abruptly turn ON
2. Q_3 can dissipate lots of power!



1. Op Amp Intro

- Consider the following application ...



Q: How to make an audio preamplifier?

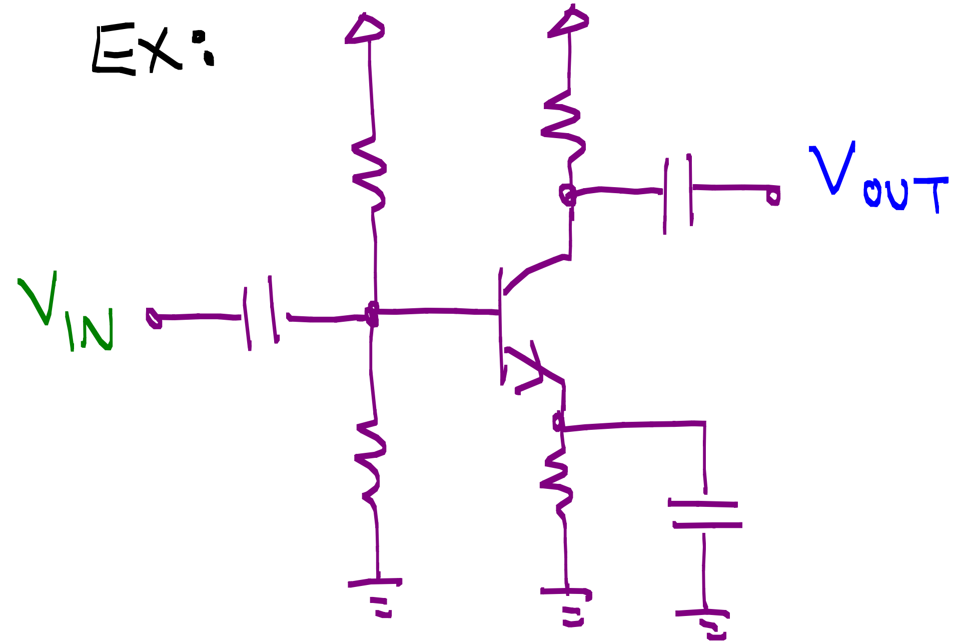
- How about a common emitter amplifier?

  Only for AC signals

  Medium Z_{IN} ($k\Omega$), Large Z_{OUT} ($k\Omega$)

  Variations in β affect performance

Ex:

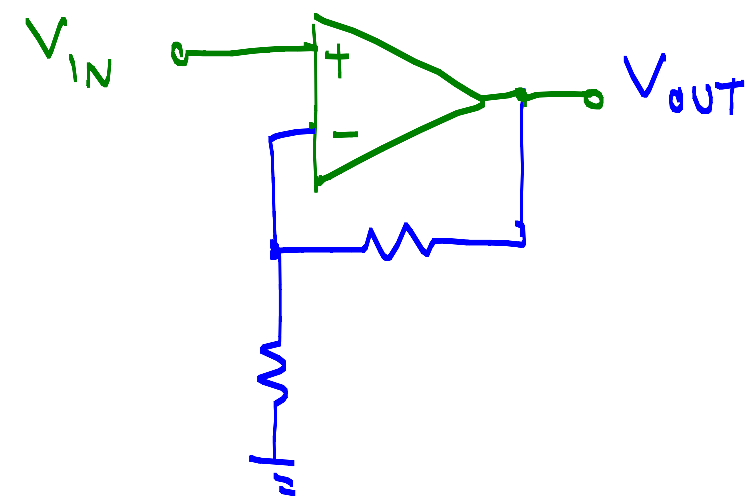


☆ An op amp is usually the best choice for designing an amplifier!

→ DC or AC amplifiers possible

→ Large Z_{IN} ($M\Omega$), tiny Z_{OUT} ($< 1\Omega$)

→ Accurate + stable performance



- Most op amp circuits can be understood by using two **Golden Rules**:

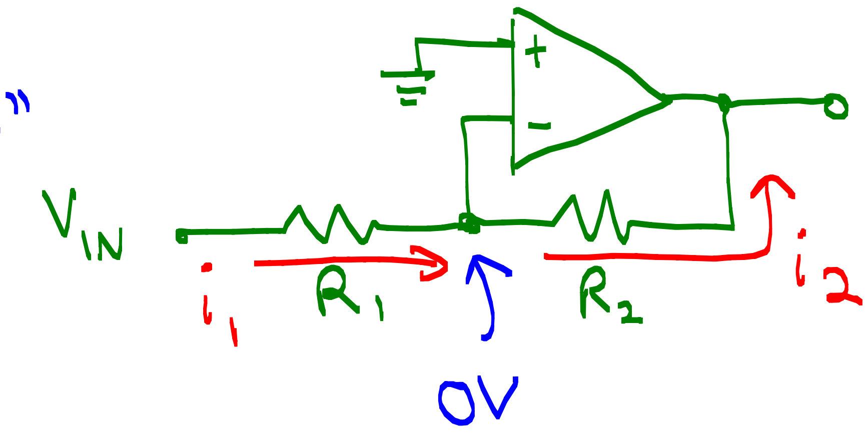
① The two input terminals are at the same voltage. ← "virtual short"

② The two input terminals draw no current.

NOTE: These golden rules assume an ideal op amp used with negative feedback!

We'll soon discuss real properties...

Ex: **Inverting Amplifier**



$V_{out} = -\frac{R_2}{R_1} V_{IN}$

(1) Golden Rule #1: $V_- = V_+ = 0$

(2) KCL at node V_-: $i_1 = i_2$

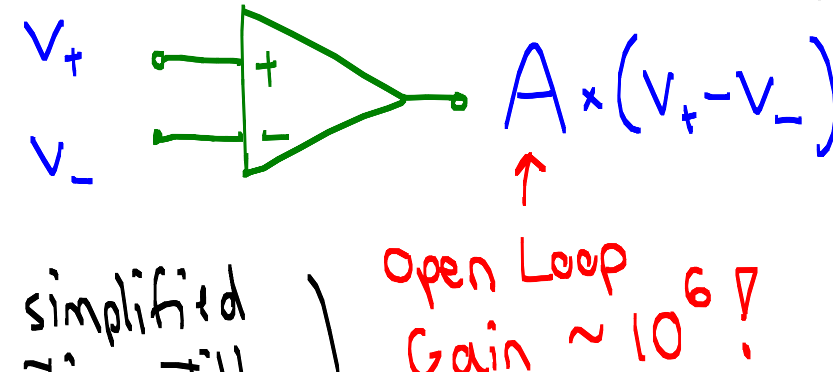
$$\frac{V_{IN} - 0}{R_1} = \frac{0 - V_{OUT}}{R_2}$$

$$\Rightarrow V_{OUT} = -\frac{R_2}{R_1} V_{IN} \checkmark$$

$$\boxed{\text{Gain} = \frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1}}$$

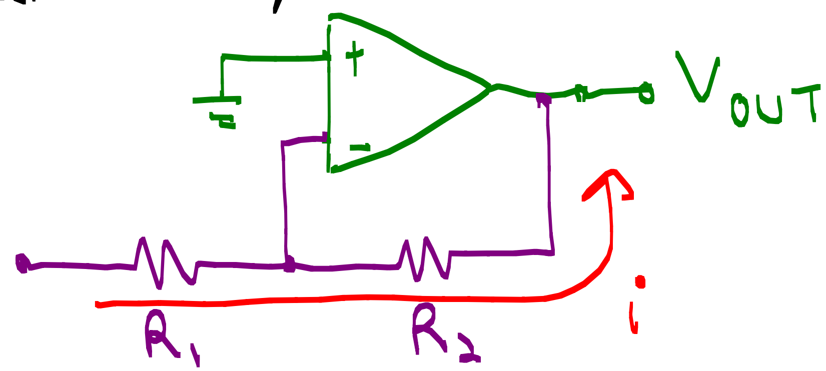
← inverting!

An op amp is really a differential amplifier with HUGE GAIN.



→ Negative feedback means a portion of the output is fed back to (−) input.

(NOTE: This simplified derivation still assumes op amp draws zero current.)



$$V_{OUT} = A \times (V_+ - V_-) = A \times (0 - V_-) = -A V_-$$

$$= -A V_{IN} \frac{R_2}{R_1 + R_2} - A V_{OUT} \frac{R_1}{R_1 + R_2}$$

$$V_- = V_{IN} - i R_1 = V_{IN} - \frac{V_{IN} - V_{OUT}}{R_1 + R_2} R_1$$

$$= V_{IN} \underbrace{\left(1 - \frac{R_1}{R_1 + R_2}\right)}_{\frac{R_2}{R_1 + R_2}} + V_{OUT} \frac{R_1}{R_1 + R_2}$$

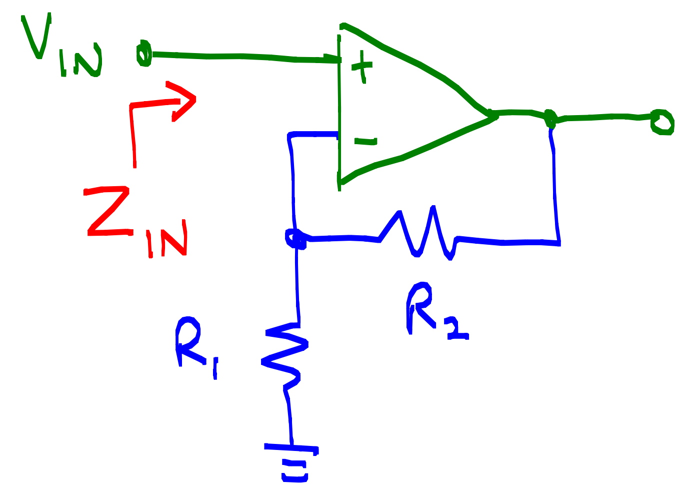
$$V_{OUT} = \frac{-A \frac{R_2}{R_1 + R_2}}{1 + A \frac{R_1}{R_1 + R_2}} V_{IN} \approx \frac{-\cancel{A} \cancel{\frac{R_2}{R_1 + R_2}}}{\cancel{A} \cancel{\frac{R_1}{R_1 + R_2}}} V_{IN}$$

(A is HUGE)

$$= -\frac{R_2}{R_1} V_{IN} \quad ✓$$

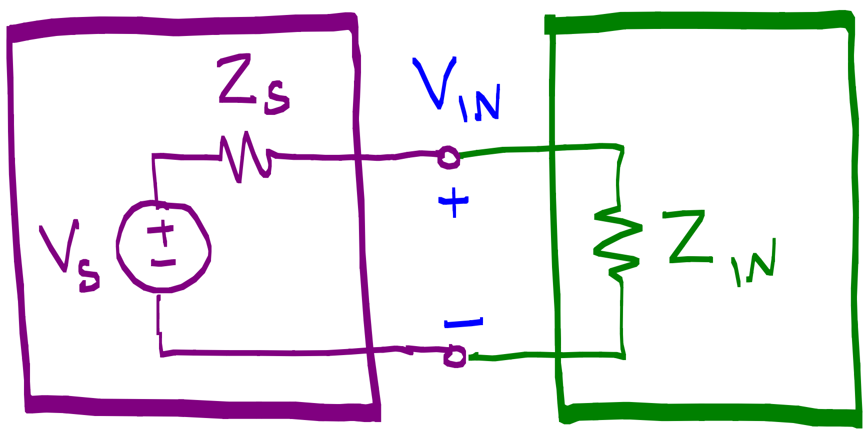
2. Some useful op amp circuits

- Non-inverting amplifier



$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{IN}$

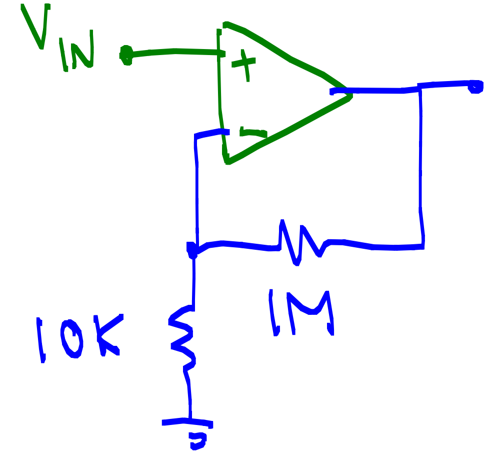
✱ Very high Z_{IN} ($> 100\,M\Omega$) is good for signal sources with large Z_s!



NOTE: Typically, $R_1 > 1\,K\Omega$

$R_2 < 10\,M\Omega$

Ex:

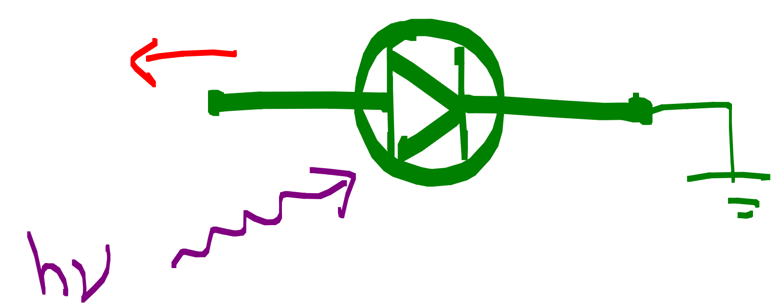


$V_{OUT} = 101\,V_{IN}$

• Photodetector Amplifier

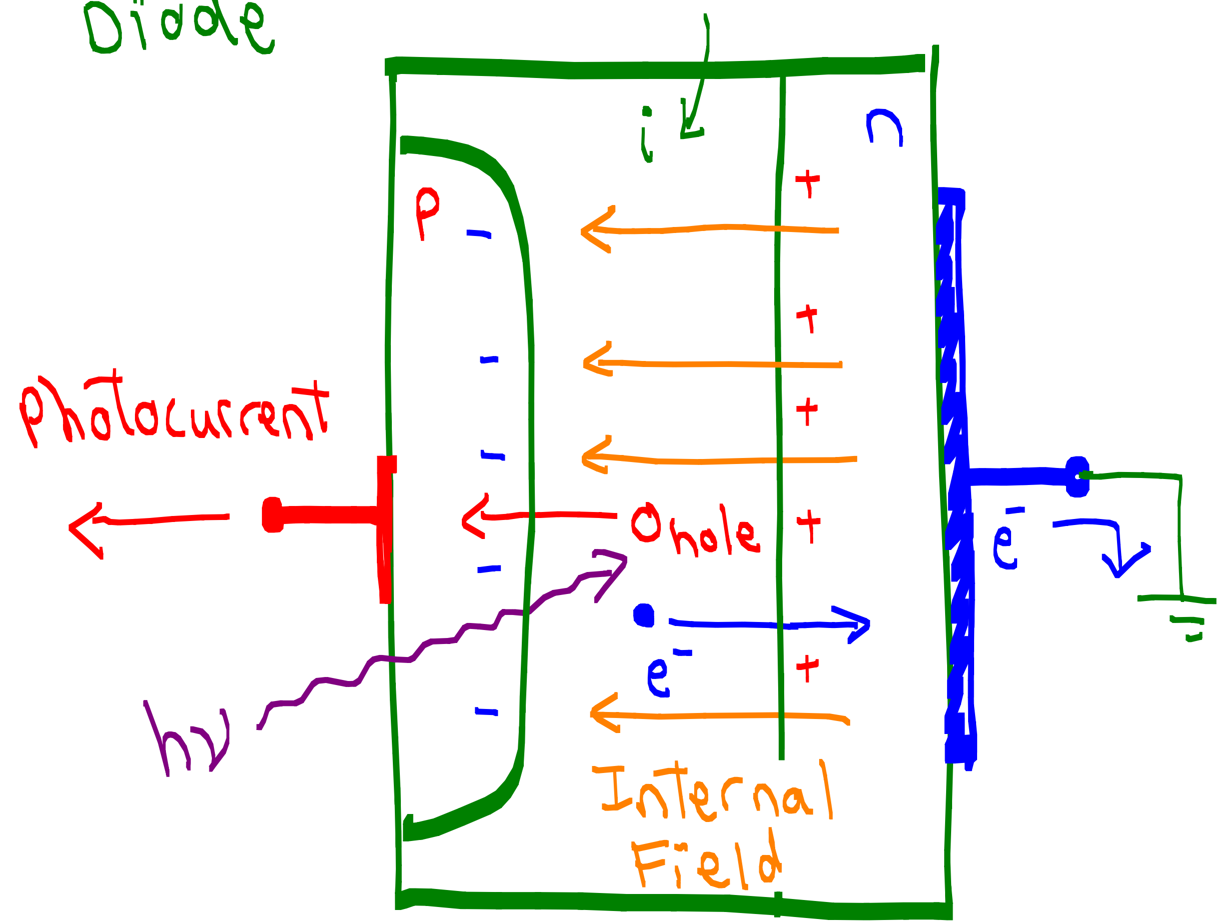
Many photodetectors produce a current output. Why?

→ Usually based on semiconductors



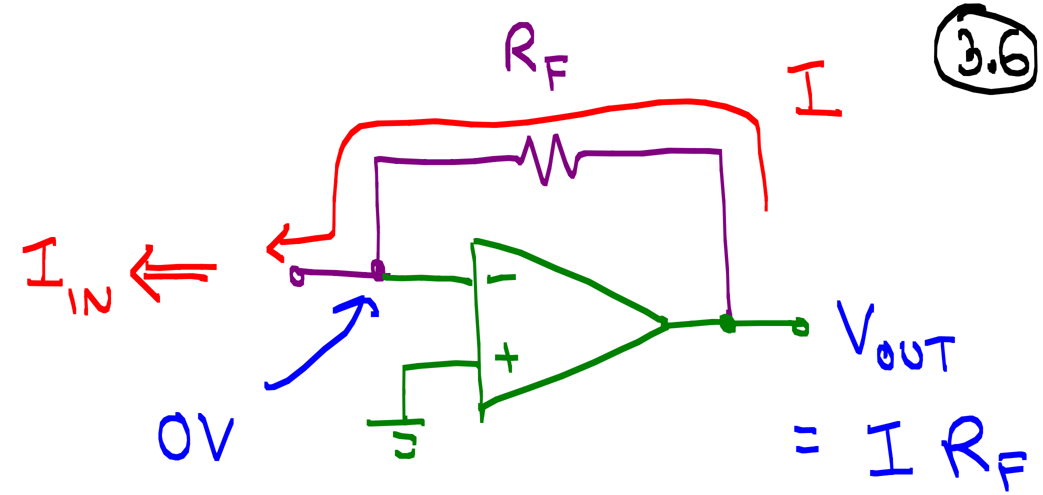
1. Light generates electron-hole pairs
2. Internal field separates the pairs
3. output is a "photo current"

"pin Diode"



Q: How to convert this into a voltage signal?

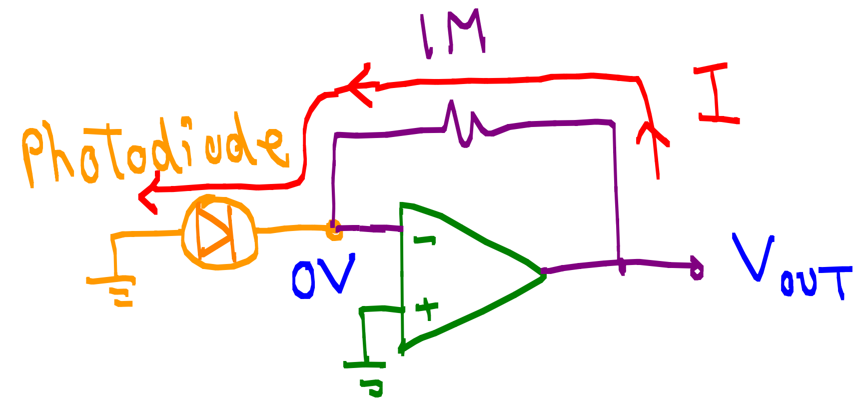
- Transimpedance Amplifier ← Also called "current-to-voltage converter"



KCL at node V_-:

$$I_{IN} = I = \frac{V_{OUT} - 0}{R_F}$$

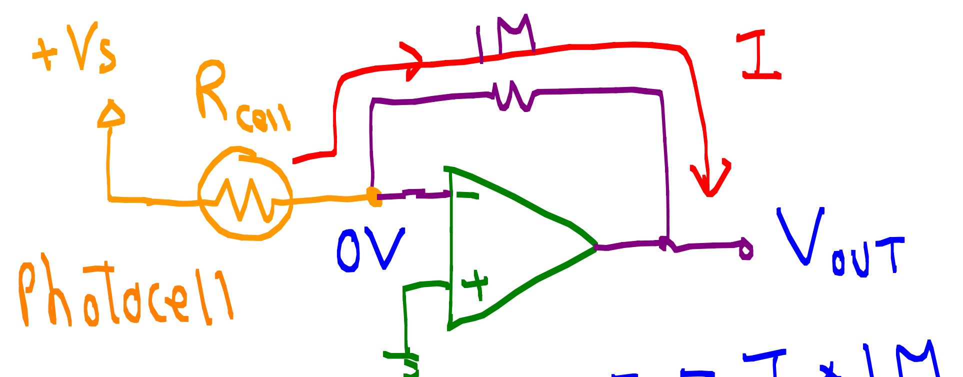
$$\Rightarrow \boxed{V_{OUT} = I_{IN} R_F}$$



☆ Very useful for photodetectors!

- Light produces current
- Virtual ground makes $Z_{IN} \sim 0$
- Fixed sensor voltage leads to more linear response

] Good for sensor producing a current



$$= -I \cdot 1M$$

$$= -V_s \frac{1M}{R_{cell}}$$

- Summing amplifier ← e.g. audio mixer

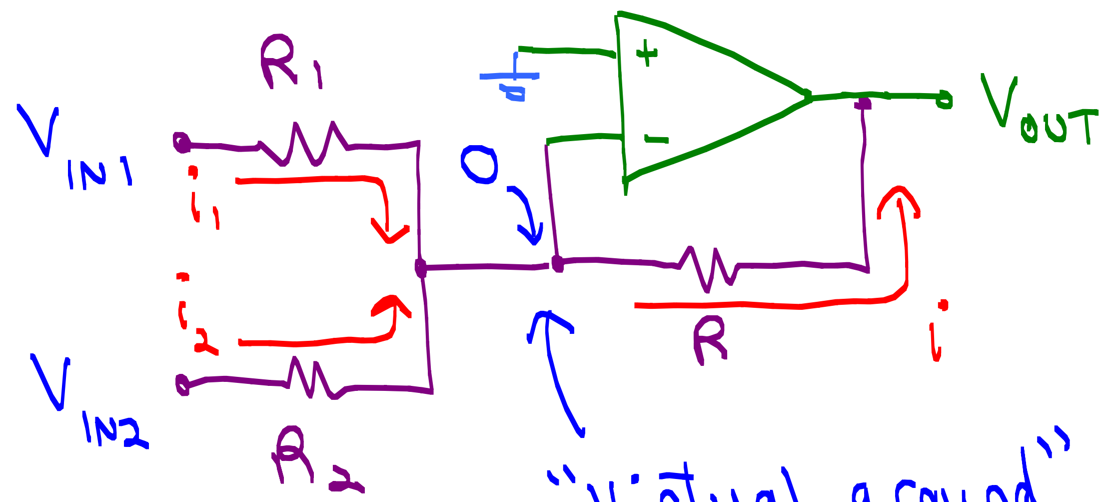
$V_- = V_+ = 0$ (Rule #1)

$i_1 + i_2 = i$

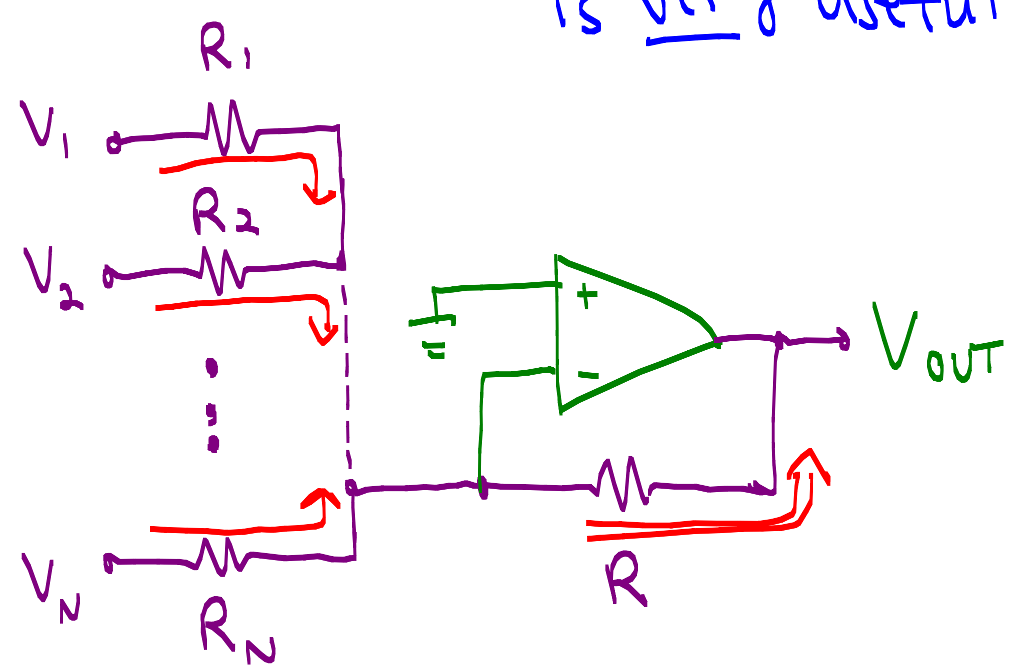
$$\frac{V_{IN1} - 0}{R_1} + \frac{V_{IN2} - 0}{R_2} = \frac{0 - V_{OUT}}{R}$$

$$\Rightarrow \boxed{V_{OUT} = -\left(\frac{R}{R_1} V_{IN1} + \frac{R}{R_2} V_{IN2}\right)}$$

Sometimes (+) input is top



"Virtual ground" is very useful!



$$V_{OUT} = -\left(\frac{R}{R_1} V_1 + \frac{R}{R_2} V_2 + \cdots + \frac{R}{R_N} V_N\right)$$

• For other useful circuits, consult application notes from manufacturers!

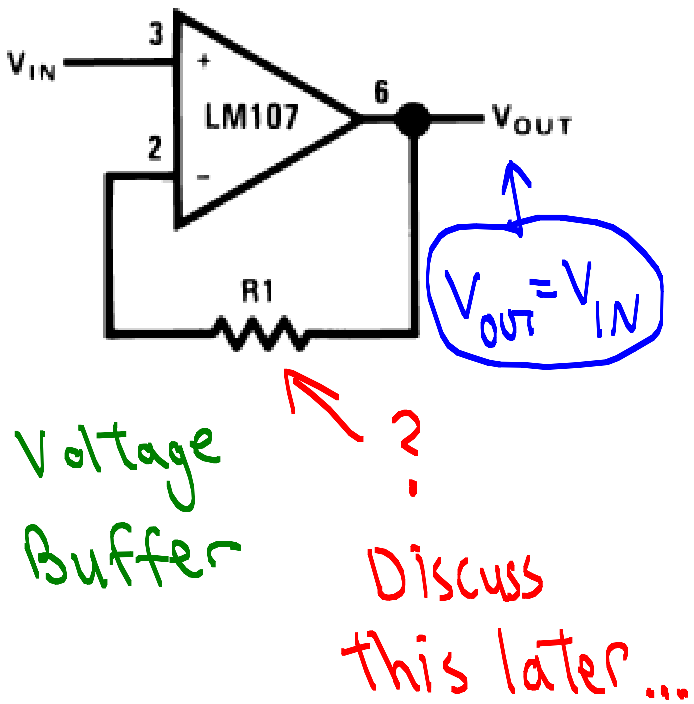
Ex:

TEXAS INSTRUMENTS

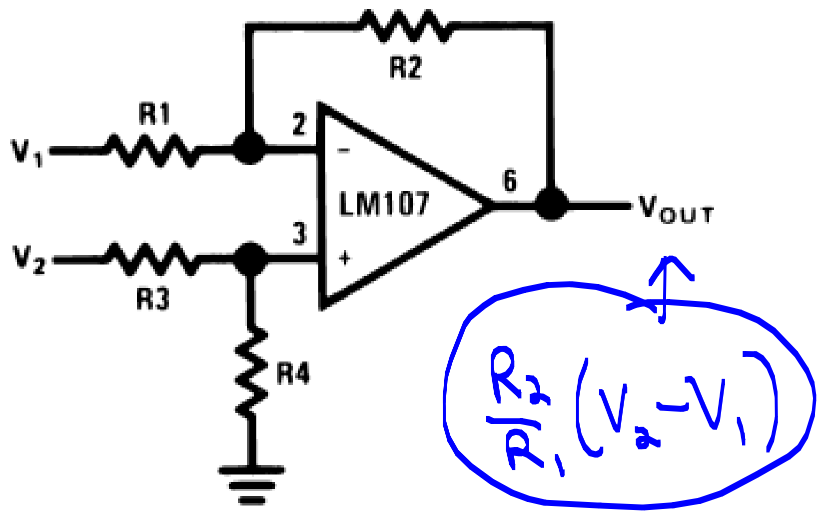
Application Report

SNOA621C–February 1969–Revised May 2013

AN-20 An Applications Guide for Op Amps

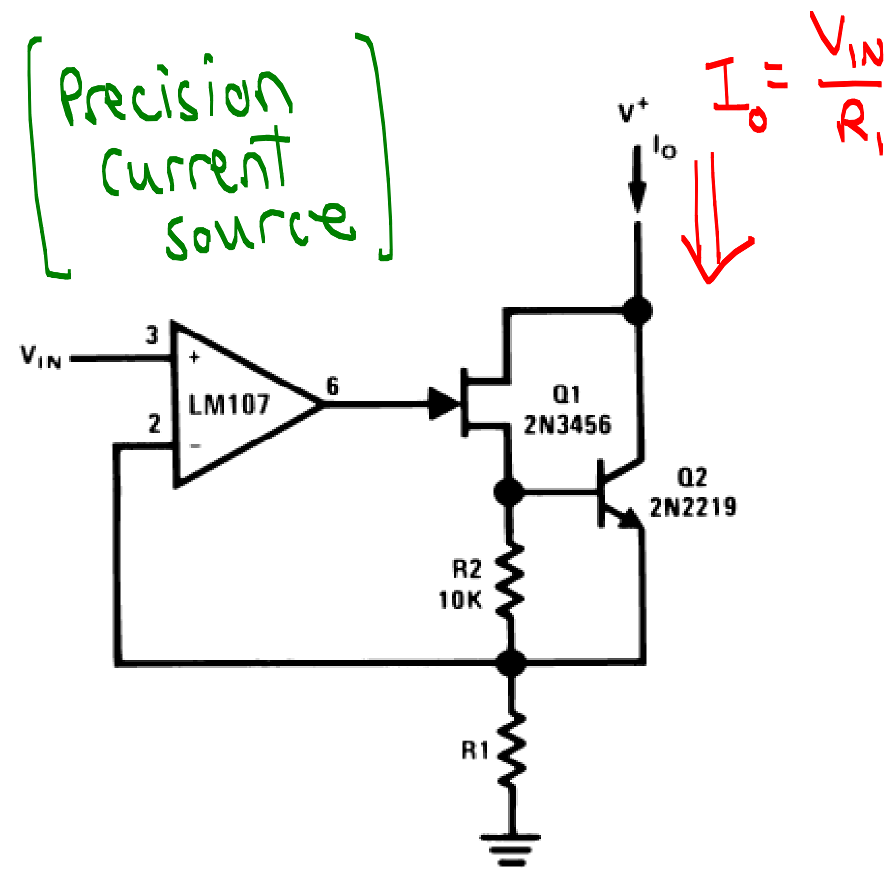


Voltage Buffer



Difference Amplifier

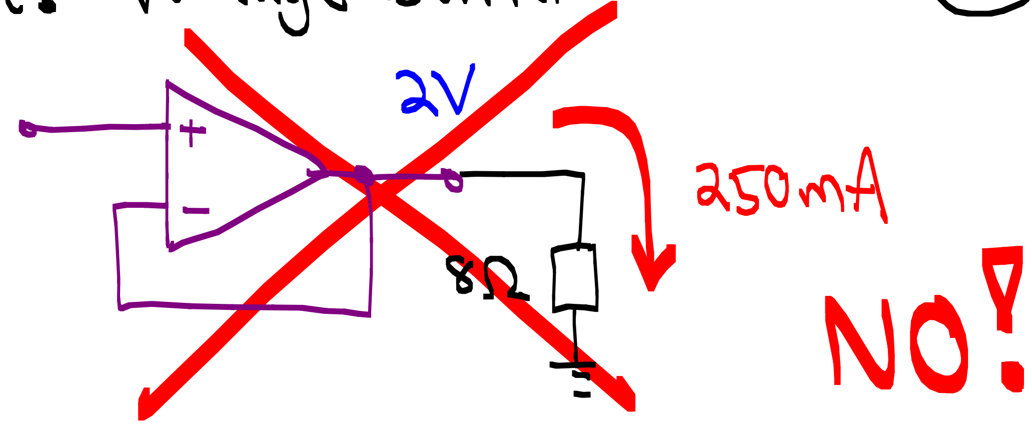
[Precision current source]



3. Unidirectional Current Boosters

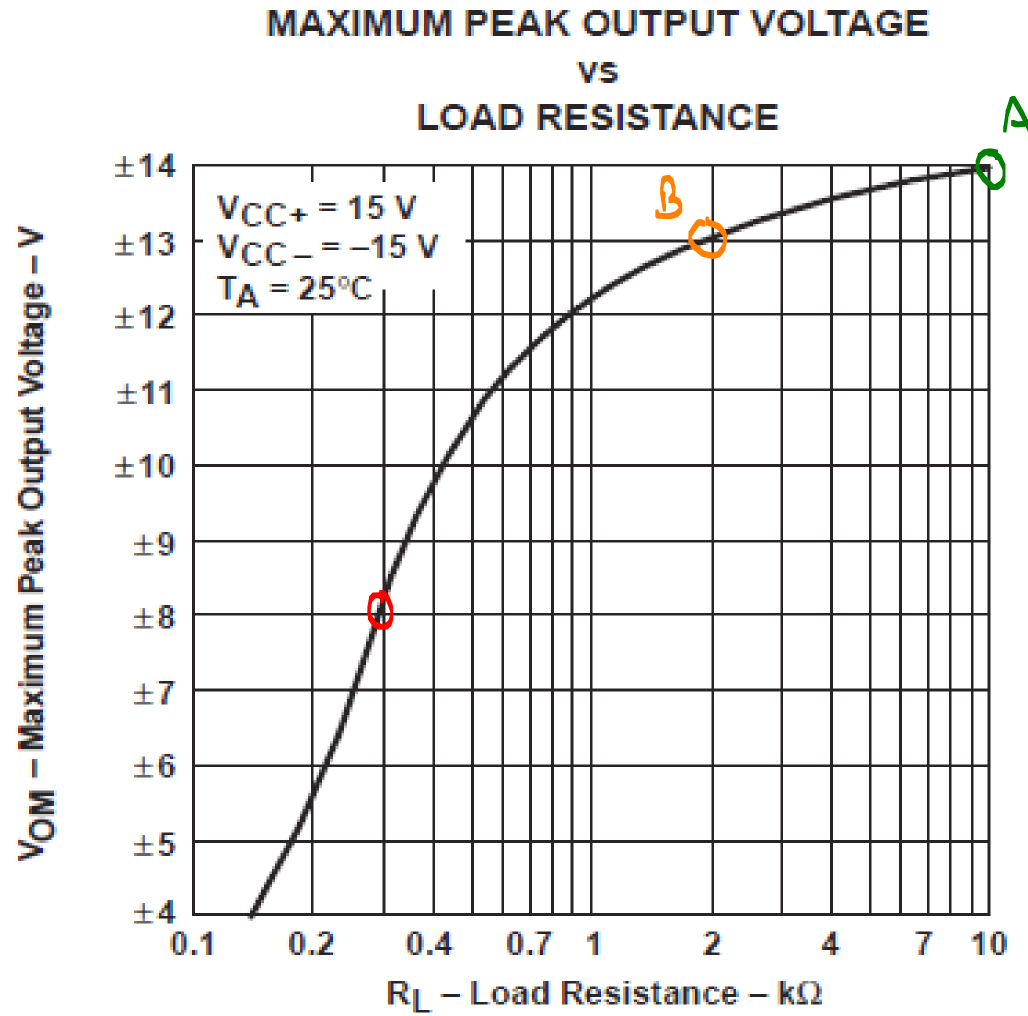
- Op amps can be used to make a huge variety of circuits. ↙ (see App notes)

Example: Voltage Buffer



- HOWEVER, most op amps are limited to ~25 mA output current.

	Max V_{OUT}	I_{OUT}
A:	±14V	$\pm\frac{14V}{10K} = \pm 1.4mA$
B:	±13V	$\pm\frac{13V}{2K} = \pm 6.5mA$
C:	±8V	$\pm\frac{8V}{.3K} = \pm 26.7mA$



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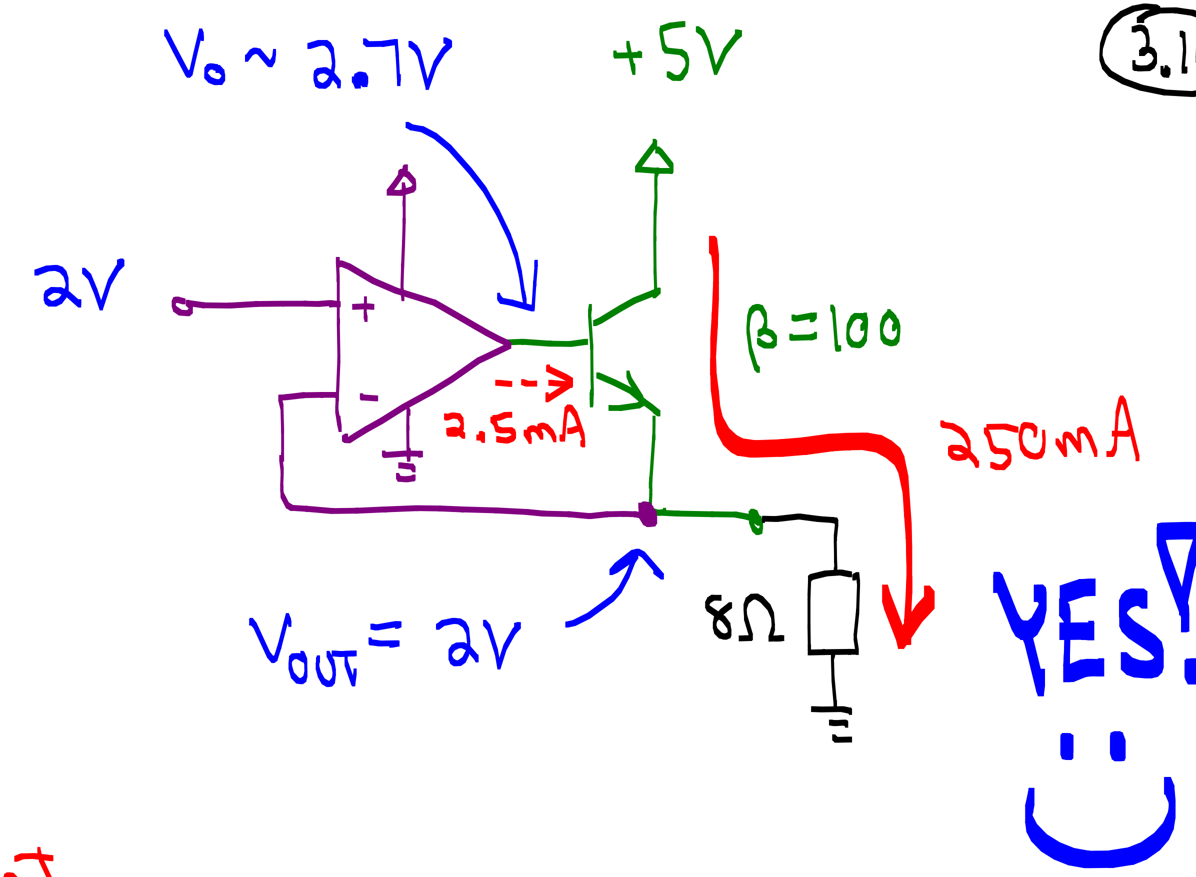
$V_s = \pm 15V$

- Adding an external transistor (e.g. emitter follower) can significantly boost the load current.



NOTE: Most op amp outputs are limited to $\sim V_{supply} - 1V$ for tiny current

* Usually a good idea to include ~2V "head room"

⟹ Max expected $V_o < V_{supply} - 2V$