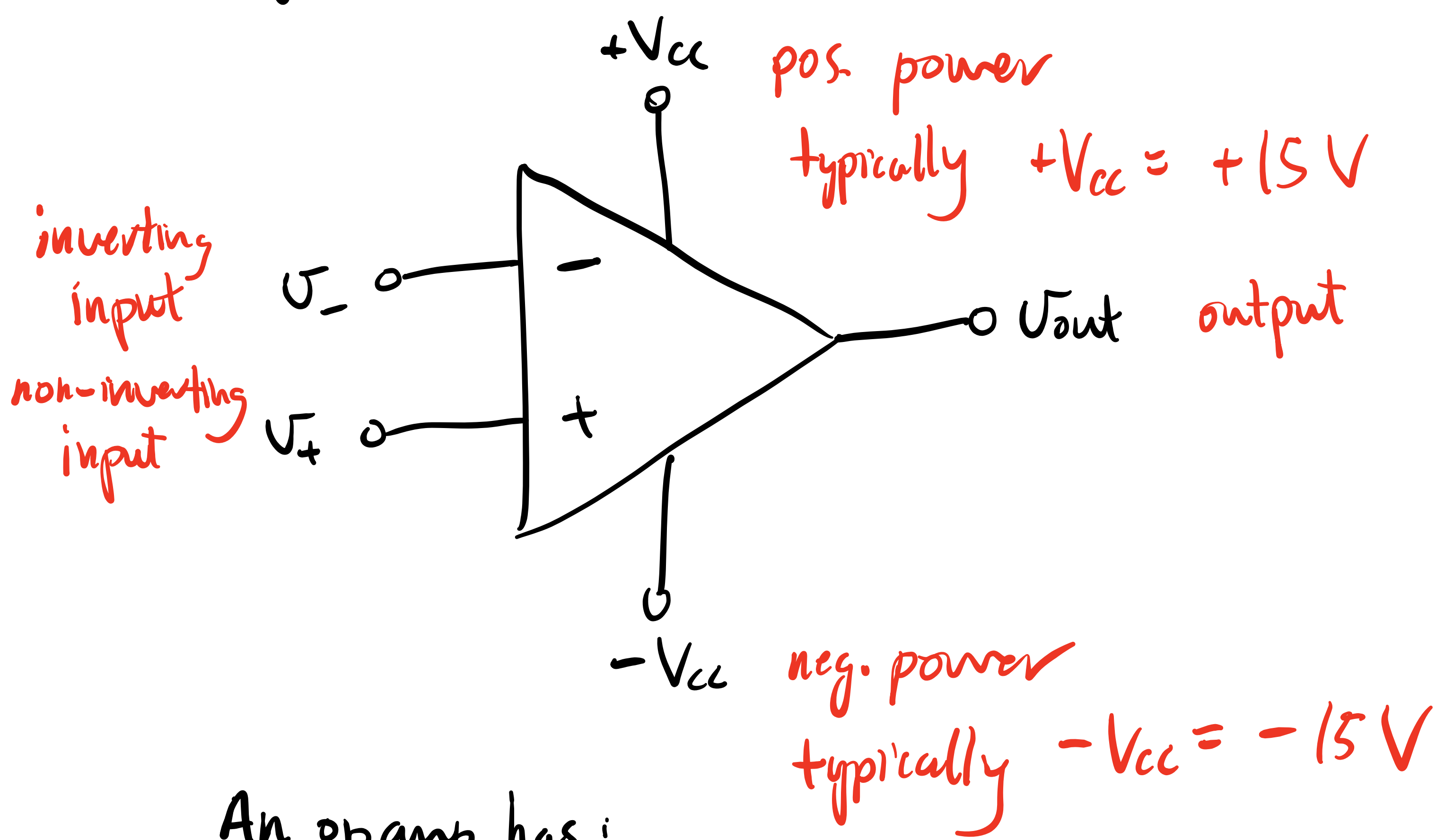
PHYS 231 - Oct. 30, 2023

Today: Operational Amplifiers (Op Amps)



An opamp has:

- two inputs
- one output
- two power terminals

The two inputs v_- & v_+ can each be positive or negative voltages.

Treat the op amp as a black-box device (not concerned with internal structure).

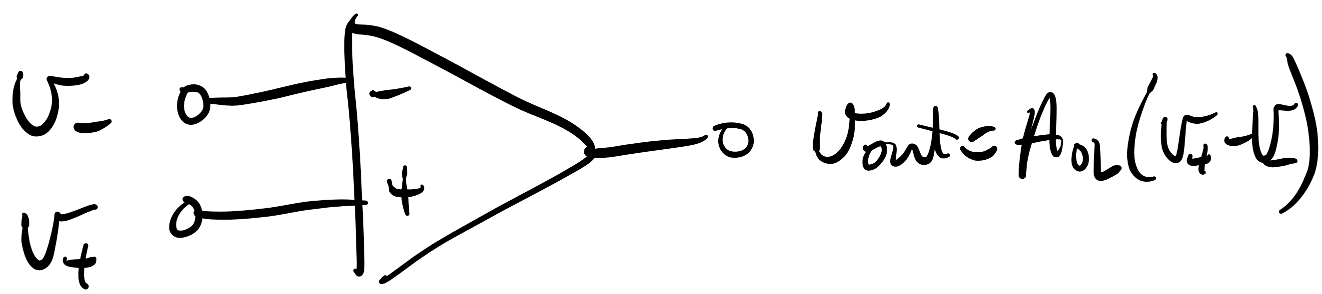
Op Amp is designed s.t.

$$V_{out} = A_{OL}(V_+ - V_-)$$

A_{OL} is called the "open loop" gain of the op amp. For the device that we'll use in PHYS 231 (LM 741)

$$A_{OL} \approx 2 \times 10^5$$

In circuit diagrams, the power terminals are often omitted for clarity (to reduce clutter). However, the op amp <u>always</u> needs to be powered with ±15 V.



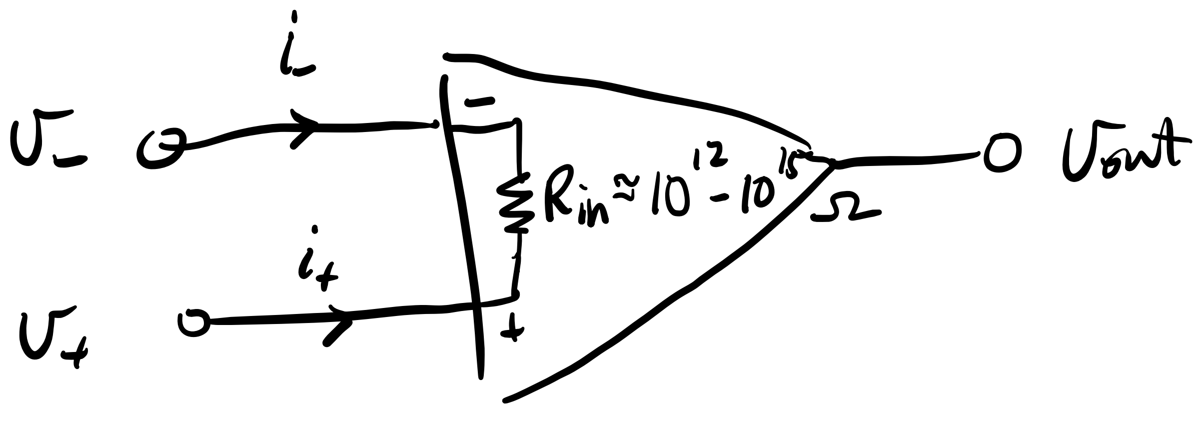
Limitations:

saturation volt.

① $|v_{out}| \leq V_{sat} \approx V_{cc} - 1\,V$

if $V_{cc} = 15\,V$, $V_{sat} \approx 14\,V$

② The input impedance/resistance of the op amp is very high.



Assume $R_{in} \to \infty$ s.t. $i_- = i_+ = 0$

No current flows into or out of the op amp inverting & non-inverting inputs.

Note: Output can have non-zero current.

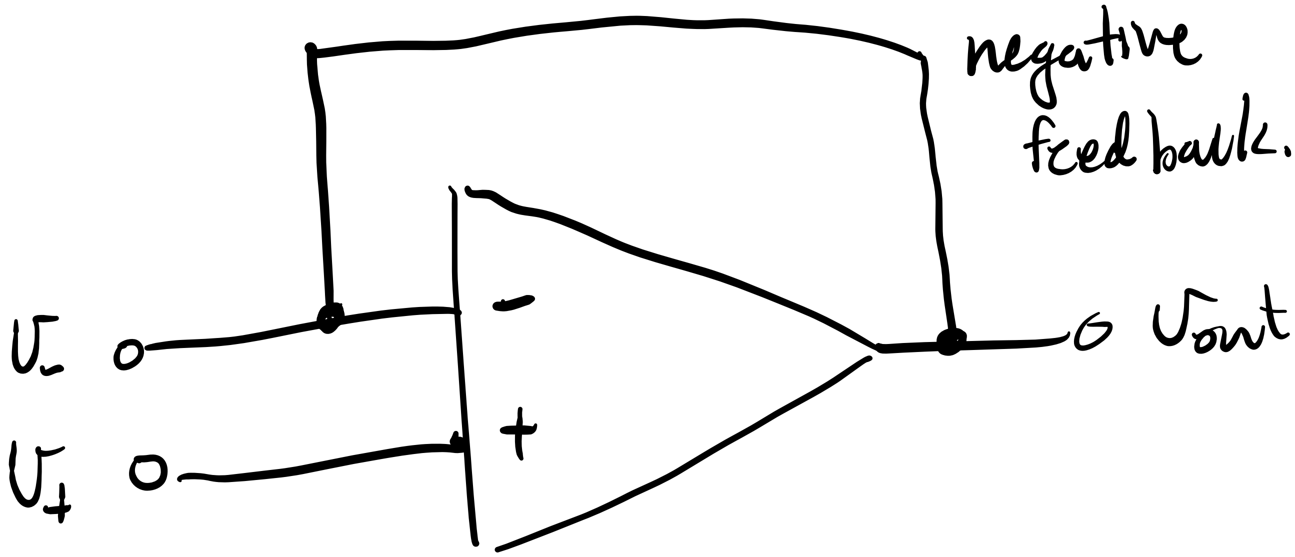
Sec. 6.3 in Textbook.

Op Amp Golden Rules.

1. Op Amp input impedance → ∞.

$$i_- = i_+ = 0$$

2. The second op amp Golden Rule applies to op amp circuits using negative feedback.



If the feedback loop is broken, then we have the "open loop" case.

Know $V_{out} = A_{OL}(V_+ - V_-)$

w/ negative feedback drawn above, we require $V_{out} = V_-$

$$\therefore\ V_- = A_{OL}(V_+ - V_-)$$
$$= A_{OL}V_+ - A_{OL}V_-$$

$$\therefore\ V_-(1 + A_{OL}) = A_{OL}V_+$$

$$\therefore\ V_- = \left(\frac{A_{OL}}{A_{OL}+1}\right)V_+$$

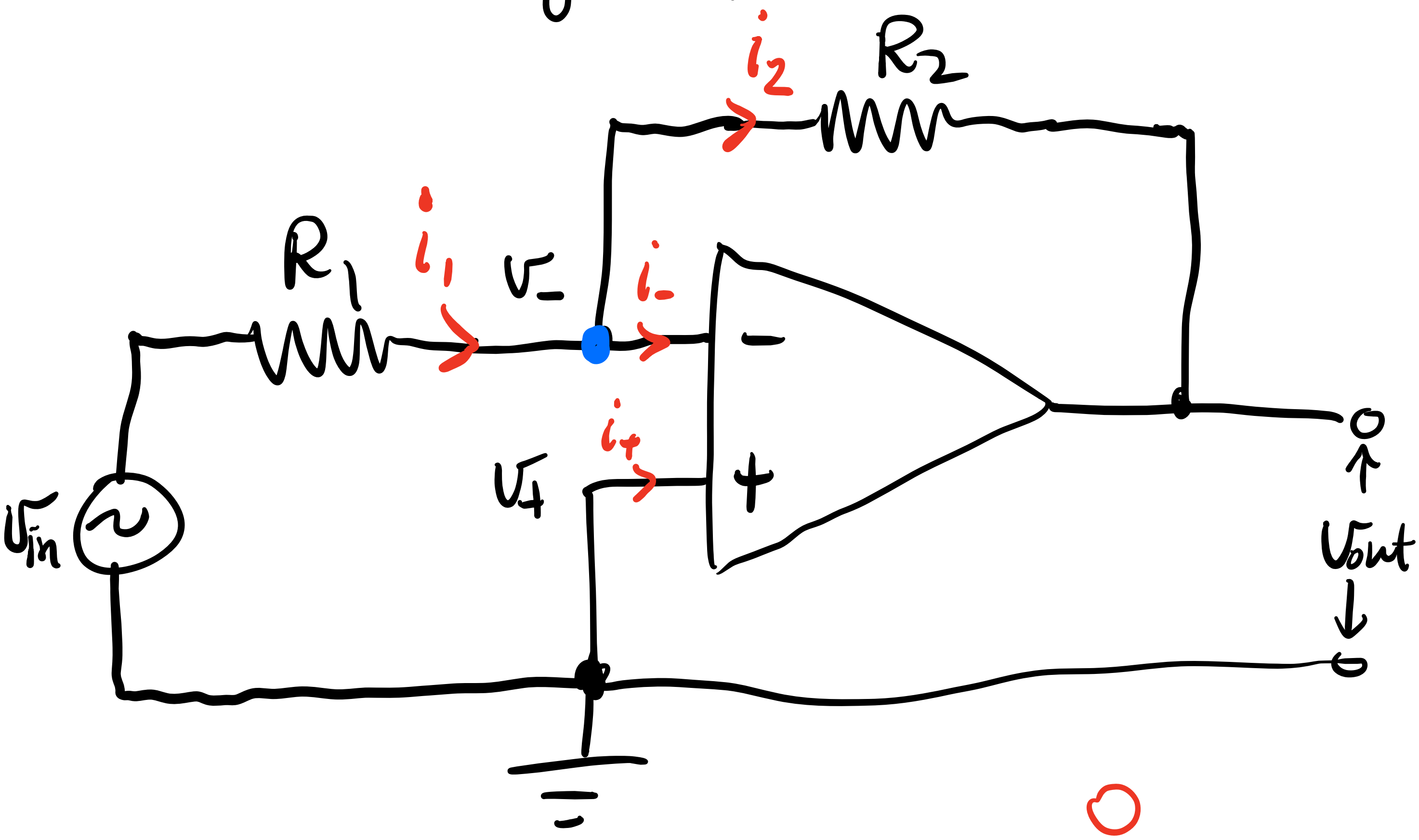
If $A_{OL} \gg 1$ (always the case)

$$\boxed{V_- \approx V_+}$$

2nd Golden Rule: When using negative feedback, volt. difference across op amp inputs is zero $\Rightarrow$ $v_- = v_+$

First Op Amp Application:

Inverting Amplifier.

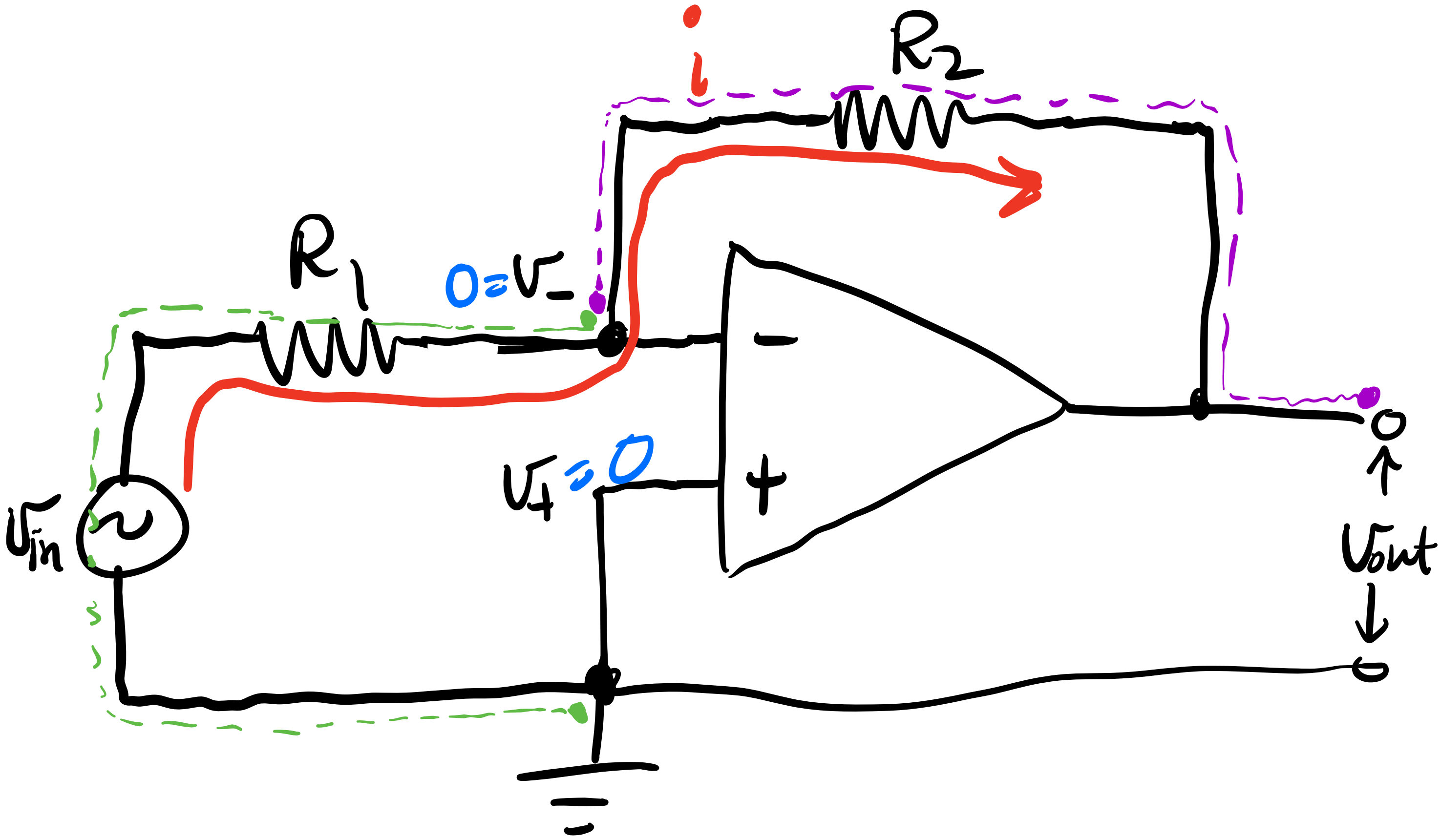


KCL Rule @ •

$$i_1 = i_- + i_2$$

$$\therefore \; i_1 = i_2 \equiv i$$

By GR#1 $i_- = i_+ = 0$



Effectively, the first GR makes this like a single-loop circuit (outer loop that includes v_{in}, R_1, R_2, v_{out}, i.

By the second GR, $v_- = v_+$.

But... $v_+ = 0$ b/c of direct connection to gnd. $\therefore$ $v_+ = v_- = 0$.

Consider Kirchhoff voltage loop analysis from gnd to $V_- = 0$.

$$0 + V_{in} - iR_1 = V_- = 0$$

$$\Rightarrow \boxed{i = \frac{V_{in}}{R_1}}$$

we now know current.

Following the purple path, loop rule analysis requires:

$$V_- = 0 - iR_2 = V_{out}$$

$$\boxed{\therefore V_{out} = -iR_2}$$

$$\therefore V_{out} = -\left(\frac{V_{in}}{R_1}\right) R_2$$

$$\therefore V_{out} = -\underbrace{\frac{R_2}{R_1}}_{\text{Gain of our amplifier.}} V_{in}$$

Gain of our amplifier.

Gain < 0 is called an inverting amplifier.