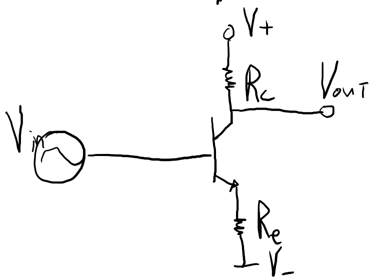
# Day 3: Differential amplifiers to op-amps

A transistor amplifier:




Gain: $G = \frac{V_{out}}{V_{in}} \simeq \frac{I_c R_c}{I_e R_e}$

$\simeq \frac{R_c}{R_e}$.

How does this work?

1. $V_{in}$ controls $V_e$, changing emitter current.

$$I_e = \frac{V_{in} - V_-}{R_e}$$

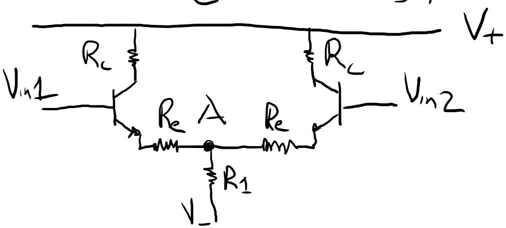
2. Due to the large current gain of transistor, ($\beta$), the current drawn from $V_+$ through $R_c$:

$$I_c = \frac{V_+ - V_{OUT}}{R_c} \Rightarrow V_{out}$$

Often we're more interested in a voltage difference than a voltage signal.


How do we **build** such an amplifier?

Use 2 transistors!

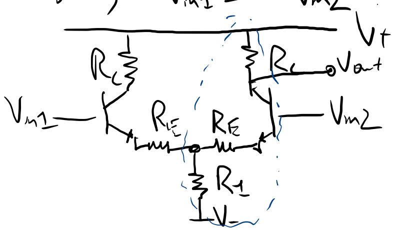


Suppose both $V_{in1}$ & $V_{in2}$ are the <u>same</u>.

- The voltage at A will vary with the applied voltage @ $V_{in1}$ & $V_{in2}$

Then we can calculate the gain: "common-mode" $G_{CM} = \dfrac{R_C}{(R_E + 2R_1)}$

Now, consider the case where we apply a perfectly asymmetric signal, $V_{in1} = -V_{in2}$.




What is the voltage at point A? 0! by Symmetry. Both ΔV's cancel out.

What is the gain?

"Differential"

$$G_{Diff} = \frac{R_C}{2R_E}$$

From symmetry of voltage fluctuation.

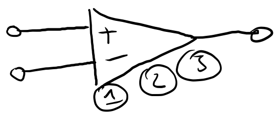
How well does this amp reject the common mode?

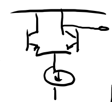
$$\frac{G_{diff}}{G_{CM}} = \frac{R_C}{2R_E}\frac{(R_E+2R_1)}{R_C} \simeq \frac{R_1}{R_E}$$

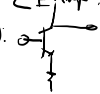
when $R_1 >> R_E$.

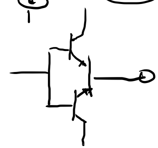
"Common mode rejection ratio" CMRR.

On to op-amps:




1: 

2: CE Amp: 

3  push-pull.

Op-amps have a lot of gain
They use negative feedback: → often incredible Δ
consistent performance

Why negative feedback?
- Build in an excess of gain: feed that signal into the inputs so as to discard the excess gain & stabilize the amp's performance.

Feedback will close the loop unlike our transistor amplifiers, which are run open-loop.
The excess gain is enormous. Open-loop gain of LF411 is typically 200,000.

"Golden rules" for op-amp operation:

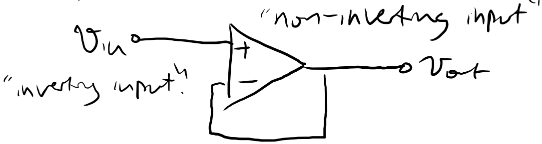
1. The <u>output</u> does whatever it can to make the voltage difference at the input 0.

2. The <u>inputs</u> draw <u>NO current</u>

   → <u>Supply</u> is different: V+, V−. <u>must</u> be powered to work.

n.b. these rules only apply when op-amp is used with negative feedback.

* A follower :




estimate: What is the input impedance, $R_{in}$?

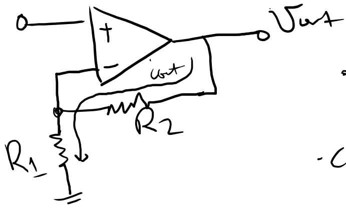
What is the voltage offset: $v_{out} - v_{in}$?

! compare to emitter follower !

What is the output impedance $R_{out}$?


1. Apply $\Delta v$ ↓
2. High-gain op-amp sensing this change (all hell breaks loose, and an enormous current comes)

* Non-inverting amplifier:



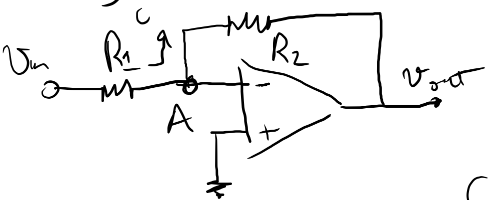

What is the gain of this amplifier?

- Apply 1V to "+" input: @point A, $V = 1V$.
- current to ground is $\frac{1V}{R_1}$.
- $\frac{V_{out} - 1V}{R_2} = \frac{1V}{R_1}$

$$\rightsquigarrow V_{out} = 1 + \frac{R_2}{R_1} \Rightarrow G = 1 + \frac{R_2}{R_1}$$

- Amplifier when $R_2 > R_1$.
- What is $R_{in}$? $\infty$.
- What is $R_{out}$? very low ($\sim 0$).

* Inverting amplifier




Apply 1V @ input.
what is $V_A$? (0V, =)
"virtual ground".

Current is $\dfrac{1V}{R_1}$.

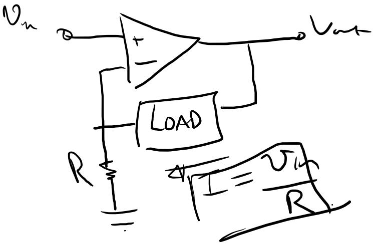
This current also goes through $R_2$:

$$v_{out} = i \cdot R_2 = \frac{1V\,R_2}{R_1} = \frac{R_2}{R_1}$$

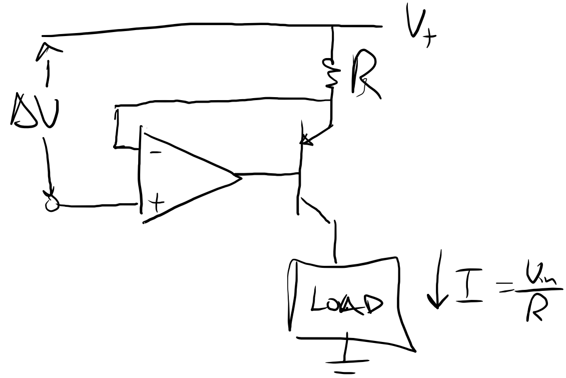
$$G = \frac{v_{out}}{v_{in}} = \frac{R_2}{R_1}.$$

* What is $R_{in}$? $\cancel{R_2}$. it's not "huge" infact, $\underline{R_1}$.

* Current Source:




not an ideal current source, b/c V @ inverting input is not 0.




Op amp improves transistor behavior. The load is connected to ground.

* Schmitt Trigger: very stable switch, where switch is set programmatically.
* Trans-impedance amplifier: Amplifies current sources.
* Integrators & differentiators, filters etc.