Day 3: Differential amplifiers to op-amps

A transistor amplifier:

\[ V_+ \]
\[ R_c \]
\[ V_{out} \]
\[ R_e \]
\[ V_- \]

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 \( R_e \):
\[ I_e = \frac{V_+ - V_{out} - V_{in}}{R_e} \]
Often we are interested in a voltage difference, not a voltage signal.

R.F. noise

How do we build such an amplifier?

Use 2 transistors!

\[
\begin{align*}
V_+ & \\
V_{in1} & \\
R_C & \\
R_e & \\
A & \\
R_e & \\
V_{in2} & \\
R_1 & \\
V_– & 
\end{align*}
\]
Support both \( V_{in1} \) & \( V_{in2} \) are the same.

- The voltage at A will vary with the applied voltage \( V_{in1} \) & \( V_{in2} \) "common-mode"

Then we can calculate the gain: \( G_{cm} = \frac{R_c}{(R_c + 2R_n)} \)

Now consider the case where we apply a perfectly symmetric signal \( V_{in1} = -V_{in2} \).

What is the voltage at point A? 0!

By symmetry, both AV's cancel out.
What is the gain?

\[ G_{\text{diff}} = \frac{R_c}{2R_E} \quad \text{From symmetry of voltage fluctuation.} \]

How well does this amp reject the common mode?

\[ \frac{G_{\text{diff}}}{G_{\text{cm}}} = \frac{R_c}{2R_E} \frac{(R_E+2R_1)}{R_c} \approx \frac{R_1}{R_E} \quad \text{when } R_1 \gg R_E. \]

\[ \text{"Common mode rejection ratio" } \text{CMRR}. \]

On to op-amps:

- Circuit diagrams:
  - Input stage
  - CE amplifier
  - Push-pull.
Op-amps have a lot of gain. They use **negative feedback** to obtain **consistent performance**.

Why negative feedback?
- Build in an excess of gain, feed that signal into the inputs so as to **decrease** the excess gain & stabilize the op-amp performance.

Feedback will close the loop unlike an **amplifier**, which are in open-loop. The excess gain is enormous. **Open-loop gain of LF411** is typically **200,000**.
"Golden rules" for op-amp operation:

1. The output does whatever it can to make the voltage difference at one input 0.

2. The inputs draw NO CURRENT. Supply is different: \( V_+ \), \( V_- \) must be powered to work.

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

```
V_{in} ───> "non-inverting input"

"inverting input" ───> V_{out}
```

Estimate:

- What is the input impedance, R_{in}?
- What is the voltage offset: V_{off} - V_{in}?
- Compare to emitter follower?
- What is the output impedance, R_{out}?

```
V_{in} ───> R_{in} ───> V_{out} (Apply ΔV = 1)
```

2. High swing output for low change (all amplify by use, and in enormous units).
Non-inverting amplifier:

What is the gain of this amplifier?

1. Apply 1V to the input.
   - At point A, \( V = 1V \).
   - Current to ground is \( \frac{1V}{R_1} \).

2. \( \frac{V_{out} - 1V}{R_2} = \frac{1V}{R_1} \Rightarrow V_{out} = 1 + \frac{R_2}{R_1} \cdot 1 \)

3. Amplifier when \( R_2 > R_1 \).
4. What is \( R_{in} \)? \( \infty \).
5. What is \( R_{out} \)? Very low (~0).
Inverting amplifier

![Circuit Diagram]

Apply IV @ input.
What is $V_A$?
"Virtual ground."

Current is \( \frac{1V}{R_1} \).

This current also goes through $R_2$:

\[
V_{out} = i \cdot R_2 = \frac{1V \cdot R_2}{R_1} = \frac{R_2}{R_1}
\]

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

What is $R_m$? \( \frac{R_2}{R_1} \). It's not "huge". Indeed, $R_1$. 

**Current Source**

\[ I = \frac{V_{ref}}{R} \]

Not an ideal current source, b/c V ref

**V_{ref}**

**Schmitt Trigger**: Very stable switch, where Swtch is set programmatically.

**Op amp improves transient behavor. The load is connected to ground.**

**Trans-impedance amplifier**: Amplifies current sources.

**Integrate & differentiates, filtets etc.**