Common Emitter Amplifier ("Simplified"): 
- What's common (ground) in a common emitter amp?
  - The emitter!
    - The emitter is connected (tied) to ground usually by a capacitor.
      - To an AC signal this looks like the emitter is connected to ground.

What use is a Common Emitter Amp?
- Amplifies the input voltage (the voltage at the base of the transistor).
- The output voltage has the opposite polarity as the input voltage.
- We want to calculate the following for the common emitter amp:
  - Voltage Gain $\equiv \frac{V_{out}}{V_{in}}$
  - Input Impedance
  - Output Impedance
DC Voltage Gain:
- The voltage gain we are about to derive is for small signals only.
  - A small signal is defined here to be in the range of a few mV.
- As in all of what follows we assume that the transistor is biased on at its DC operating point.
  \[ V_{\text{out}} = V_{cc} - I_C R_C \]
- Since \( V_{cc} \) is fixed (it's a DC power supply) we have for a change in output voltage \( V_{out} \)
  \[ \Delta V_{out} = -\Delta I_C R_C \]
  - \( \Delta \) stands for a small change in either the voltage or current.
- The input voltage is related the emitter voltage by a diode drop:
  \[ V_{\text{in}} = V_B = V_E + 0.6 \text{ V} \]
  \[ \Delta V_{\text{in}} = \Delta V_E \]
- We want to relate the emitter voltage to the emitter current \((I_E)\):
  \[ V_E = I_E R_E \]
  \[ \Delta V_E = \Delta I_E R_E \]
- We can relate the emitter and collector currents by remembering that for a transistor:
  \[ I_E \approx I_C \]
  \[ \Delta I_E \approx \Delta I_C \]
  \[ \Delta V_E = \Delta I_E R_E = \Delta I_C R_E \]
  \[ \Delta V_{\text{in}} = \Delta V_E = \Delta I_C R_E = (-\Delta V_{out} / R_C) R_E \]
DC voltage gain \((G)\) for a common emitter amp:

\[
\text{Gain} = \frac{\Delta V_{\text{out}}}{\Delta V_{\text{in}}} = -\frac{R_C}{R_E}
\]

- What happens if \(R_E = 0???\)
- Do we have infinite gain?
- No, we get a new model for the transistor.
- The base-emitter junction is a diode.
- Describe the behavior of the junction using the Ebers-Moll equation:
  \[
  I = I_s \left[ e^{qV/kT} - 1 \right]
  \]
- \(V = V_{BE}\)
- \(kT/q = 25 \text{ mV at } 20^\circ\text{C}\)
- Neglecting the -1 term:
  \[
  V_{BE} = \frac{kT}{q} \left[ \ln I - \ln I_s \right]
  \]
- Calculate the dynamic resistance of the base-emitter junction,
  \[
  r_{BE} = \frac{dV_{BE}}{dI} = \frac{kT}{qI} = 25 \times 10^{-3} / I
  \]
  \(r_{BE} = 25 \Omega\) for current of 1 mA

Gain = 
\[
-\frac{R_C}{r_{BE} + R_E \| X_{CE}}
\]
We can now write the gain for the case $R_E = 0$ (neglecting $X_{CE}$ too):

$$\text{Gain} = -\frac{R_C}{r_{BE}} = -\frac{R_C (I_C / 25)}{I_C} \text{ with } I_C \text{ measured in mA.}$$

Simpson (page 227) writes an equivalent formula for the gain using the transistor parameter $\beta$ and a slightly different temperature, $T = 300^\circ\text{K}$. 

In terms of the hybrid parameter model (we will see this model soon)

$$r_{BE} = \frac{h_{ie}}{h_{fe}}$$

Using $r_{BE}$ to design a circuit is a dangerous practice as it depends on temperature

- varies from transistor to transistor even for same type of transistor.

- Input impedance
  - Input impedance of the common emitter amp can be calculated from the equivalent circuit:

\[
\frac{1}{R_{in}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{tin}}
\]

\[
R_{tin} \approx \frac{\Delta V_B}{\Delta I_B}
\]

\[
= \frac{\Delta V_E}{\Delta I_E / \beta}
\]

\[
= \frac{\Delta I_E R_E}{\Delta I_E / \beta}
\]

\[
= \beta R_E
\]

- For AC case, we usually have $R_1$ and $R_2 > R_{tin}$

  \[R_{tin} = \beta R_E = \beta r_{BE} = 2500 \, \Omega \text{ for } 1 \text{ mA of collector current and } \beta = 100.\]
Output impedance
- Harder to calculate than the input impedance and only a hand waving argument will be given.
- The output impedance of the amp is the parallel impedance of $R_C$ and the output impedance of the transistor looking into the collector junction.
- The collector junction is reversed biased and hence looks like a huge resistor compared to $R_C$.
  - The output impedance is simply $R_C$.
  - Assume that the load impedance (the thing the amp is hooked up to) is less than $R_C$.

Common Collector Amplifier:
- Sometimes this amp is called an *emitter follower*.
- What's common (ground) in a common collector amp?
  - The collector!
  - The collector is connected (tied) to a DC power supply.
  - To an AC signal this *looks* like the collector is connected to ground.
- We want to calculate: voltage and current gain, and input and output impedance.
- Voltage Gain:
  - The input is the base and the output is taken at the emitter
    
    $V_E = V_B - 0.6 \, \text{V}$
    $\Delta V_E = \Delta V_B$
    $\Delta V_{\text{out}} = \Delta V_{\text{in}}$
  - The amp has *unity* gain!
Current Gain: As always we can use Kirchhoff's current rule.

\[ I_E = I_B + I_C \]
\[ = I_B(\beta + 1) \]

\[ \frac{\Delta I_E}{\Delta I_B} = \beta + 1 \]

\[ \frac{\Delta I_{out}}{\Delta I_{in}} = \beta + 1 \]

Since a typical value for \( \beta \) is 100, there is lots of current gain.

Input impedance:

By definition the input impedance is

\[ R_{in} = \frac{\Delta V_{in}}{\Delta I_{in}} \]
\[ = \frac{\Delta V_B}{\Delta I_B} \]
\[ = \frac{\Delta V_E}{\Delta I_E / (\beta + 1)} \]
\[ = \frac{\Delta I_E R_E}{\Delta I_E / (\beta + 1)} \]
\[ R_{in} = (\beta + 1)R_E \]

Since \( R_E \) is usually a few k\( \Omega \) and \( \beta \) is typically 100

the input impedance of the common collector amp is large.
Output impedance: This is trickier to calculate than the input impedance.

- In the figure below we are looking into the amp:

\[ V_{\text{in}} = \frac{V_{\text{in}} R_{\text{in}}}{R_{\text{in}} + R_s} \]

\[ \approx \frac{V_{\text{in}} \beta R_E}{\beta R_E + R_s} \]

- \( R_{\text{in}} \) is the input impedance of the transistor and \( V_{\text{tin}} \) is the voltage drop across it.

- If we look from the other (output) side of the amp with \( R_{\text{out}} \) the output impedance of the transistor

  - The voltage drop at A is the same as the voltage at the base (\( V_B \)) since the amp has unity gain.

  - We can rewrite the equation into a voltage divider equation to find \( R_{\text{out}} \):

\[ V_A = \frac{V_{\text{in}} R_E}{R_E + R_{\text{out}}} \]

\[ = \frac{V_{\text{tin}}}{\beta R_E + R_s} = \frac{V_{\text{in}} R_E}{R_E + R_s / \beta} \]

\[ R_{\text{out}} = \frac{R_s}{\beta} \]

- \( R_{\text{out}} \) is small since \( \beta \) is typically 100.
What good is the common collector amp?

Example: In stereo systems very often loud speakers have 8 Ω input impedance. Assume that you want to drive the speakers with a 5 Volt voltage source with 92 Ω of serious resistance. Let's look at 2 ways of driving the speakers and the power each method delivers to the speaker.

a. Hook the speakers directly to the voltage source:

\[
\begin{align*}
V_{\text{in}} & \quad 92 \, \Omega \\
(5 \text{ V rms}) & \quad 8 \, \Omega \text{ speaker}
\end{align*}
\]

- The voltage delivered to the speaker is \((8/100)V_{\text{in}}\).
- The power delivered is:
  \[P = V^2/R = (5 \times 8/100)^2/8 = 0.02 \text{ Watts}\]

\[\text{not much power!}\]
b. Use a common collector (emitter follower):

- An AC signal at the input sees \( \beta R_{sp} = \beta 8 \, \Omega = 800 \, \Omega \)
- From the speakers point of view the amp impedance looks like 
  \( 92 \, \Omega / \beta \approx 1 \, \Omega \)
- The power delivered to the speaker can now be calculated:
  \[ V_{sp} = (\beta 8 \, \Omega V_{in}) / (\beta 8 \, \Omega + 92 \, \Omega) = 0.9 V_{in} \]
  \[ P_{sp} = V_{sp}^2 / R_{sp} = (0.9 \times 5)^2 / 8 = 2.5 \text{ Watts (rms)} \]

\( \Rightarrow \) over a hundred times more power delivered to the speaker.

Emitter Followers (common collectors) are used to match high impedances to low impedances.