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 (its a DC power supply) we have for a change in output voltage \( V_{\text{out}} \)
  \[ \Delta V_{\text{out}} = -\Delta I_C R_C \]
  - \( \Delta \) 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:
  \[ I_E \approx I_C \]
  \[ \Delta I_E \approx \Delta I_C \]
  \[ \Delta V_E = \Delta I_E R_E = \Delta I_C R_E \]
  \[ \Delta V_{\text{in}} = \Delta V_E = \Delta I_C R_E = (-\Delta V_{\text{out}} / R_C) R_E \]
DC voltage gain ($G$) for a common emitter amp:

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

The minus sign in the gain means that the output is the opposite polarity as the input (180° out of phase).

- 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:

\[ I = I_s \left[ e^{qV/kT} - 1 \right] \]

- $V = V_{\text{BE}}$
- $kT/q = 25 \text{ mV at 20°C}$

Neglecting the -1 term:

\[ V_{\text{BE}} = \frac{kT}{q} \left[ \ln I - \ln I_s \right] \]

Calculate the dynamic resistance of the base-emitter junction,

\[ r_{\text{BE}} = \frac{dV_{\text{BE}}}{dl} = \frac{kT}{ql} = 25 \times 10^{-3} / I \]

$\quad r_{\text{BE}} = 25 \Omega$ for current of 1 mA

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

\[
\text{Gain} = -\frac{R_C}{r_{BE}} = -\frac{R_C}{I_C / 25} \text{ with } I_C \text{ measured in mA.}
\]

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

\[\text{ varies from transistor to transistor even for same type of transistor.}\]

- 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
    \[
    V_E = V_B - 0.6 \text{ V} \\
    \Delta V_E = \Delta V_B \\
    \Delta V_{out} = \Delta V_{in} \\
    \]  
  - The amp has *unity* gain!
● Current Gain: As always we can use Kirchhoff’s current rule.
\[
I_E = I_B + I_C = I_B(\beta + 1)
\]
\[
\frac{\Delta I_E}{\Delta I_B} = \beta + 1
\]
\[
\frac{\Delta I_{\text{out}}}{\Delta I_{\text{in}}} = \beta + 1
\]
- Since a typical value for $\beta$ is 100, there is lots of current gain.

● Input impedance:
- By definition the input impedance is
\[
R_{\text{in}} = \frac{\Delta V_{\text{in}}}{\Delta I_{\text{in}}}
\]
\[
= \frac{\Delta V_B}{\Delta I_B}
\]
\[
= \frac{\Delta V_E}{\Delta I_E/(\beta + 1)}
\]
\[
= \frac{\Delta I_E R_E}{\Delta I_E/(\beta + 1)}
\]
\[
R_{\text{in}} = (\beta + 1)R_E
\]
- Since $R_E$ is usually a few kΩ 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:

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

\[ \approx \frac{V_{\text{in}}\beta R_{E}}{\beta R_{E} + R_{s}} \]

- \( R_{\text{in}} \) is the input impedance of the transistor and \( V_{\text{in}} \) 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 \( R_{\text{out}} \).

\[ V_{\text{A}} = \frac{V_{\text{in}}R_{E}}{R_{E} + R_{\text{out}}} \]

\[ = V_{\text{tin}} = \frac{V_{\text{in}}\beta R_{E}}{\beta R_{E} + R_{s}} = \frac{V_{\text{in}}R_{E}}{R_{E} + R_{s} / \beta} \]

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

- \( R_{\text{out}} \) 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:

- The voltage delivered to the speaker is \((8/100)V_{in}\).
- The power delivered is:
  \[ P = \frac{V^2}{R} = \frac{(5 \times 8 /100)^2}{8} = 0.02 \text{ Watts} \]
  - 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
\[ 92 \, \Omega / \beta \sim 1 \, \Omega \]

The power delivered to the speaker can now be calculated:
\[ V_{sp} = (\beta 8 \, \Omega V_{in}) / (\beta 8 \, \Omega + 92 \, \Omega) = 0.9 V_{in} \]

\[ P_{sp} = V_{sp}^2 / R_{sp} = (0.9 \times 5)^2 / 8 = 2.5 \text{ Watts (rms)} \]

\[ \Rightarrow \text{ over a hundred times more power delivered to the speaker.} \]

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