**Transistors Amplifiers**

**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.

![Transistor Amplifier Diagram](image)

- 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.
  - Since \( V_{cc} \) is fixed (it’s a DC power supply) we have for a change in output voltage \( V_{out} \)
    - \( \Delta V_{out} = \Delta I_C R_C \)
  - In the above \( \Delta \) stands for a small change in either the voltage or current. The input voltage is related the emitter voltage by a diode drop:
    - \( V_{in} = V_B \)
    - \( \Delta V_{in} = 0.6 \text{ V} \)
  - 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:

\[ I_E = \frac{1}{D} I_C \]
\[ D I_E = D I_C \]

For now we assume that the currents are equal and rewrite the above equation for the emitter in terms of the collector current.

\[ D V_E = D I_E R_E = D I_C R_E \]

We also have \[ D V_E = D V_{in} \] so we can write the above as:

\[ D V_{in} = D I_C R_E = \left( D D V_{out} / R_C \right) R_E \]

Finally we can write the DC voltage gain \( (G) \) for a common emitter amp as:

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

Note: the minus sign in the gain means that the output is the opposite polarity as the input \((180^\circ \text{ out of phase})\).

What happens if \( R_E = 0 \)?? Do we have infinite gain?

\( \text{NO} \), we get a new model for the transistor.

Remember that the base-emitter junction is a diode. We can describe the behavior of the junction using the Ebers-Moll equation:

\[ I = I_s \left( e^{qV_{BE}/kT} - 1 \right) \]

with \( V = V_{BE} \) and \( kT/q = 25 \text{ mV at } 20^\circ \text{C} \).

Neglecting the -1 term:

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

We wish to find the dynamic resistance of the base-emitter junction,

\[ r_{BE} = \frac{dV_{BE}}{dI} = \frac{kT}{ql} \]

\[ = 25 \times 10^{-3} / I \] (note: for 1 mA of current \( r_{BE} = 25 \square \))

\[ \text{Gain} = \frac{R_C}{r_{BE} + R_e \| X_{CE}} \]

We can now write the gain for the case \( R_E = 0 \) (neglecting \( X_{CE} \) too):

\[ \text{Gain} = D R_C / r_{BE} = D R_C (I_C / 25) \text{ with } I_C \text{ measured in mA.} \]
Note: 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 and varies from transistor to transistor (even if they are the same type of transistor).

- **Input impedance**

  The input impedance of the common emitter amp can be calculated from the following equivalent circuit:

  ![Input impedance diagram]

  $$\frac{1}{R_{\text{in}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{\text{tin}}}$$

  $$R_{\text{tin}} = \frac{\frac{\partial V_B}{\partial I_B}}{\frac{\partial V_E}{\partial I_E}} = \frac{\frac{\partial V_E}{\partial I_E}}{\frac{\partial I_E R_E}{\partial I_E}} = \frac{\partial R_E}{\partial I_E}$$

  For AC case $R_1$ and $R_2$ are usually $> R_{\text{tin}}$, so the input impedance is given by

  $$R_{\text{tin}} = \frac{\partial R_E}{\partial I_E} = \frac{\partial r_{BE}}{\partial I_E} = 2500 \Omega$$

  for 1 mA of collector current and $\beta = 100$.

- **Output impedance**

  This is harder to calculate than the input impedance and only a hand waving argument for its value will be given here. 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 $R_C$.

  Thus the output impedance is simply $R_C$ assuming that the load impedance (the thing the amp is hooked up to) is less than $R_C$.  

The 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.

![Common Collector Amplifier Diagram]

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
  
  \[ V_E = V_B - 0.6 \text{ V} \]
  
  \[ \frac{\Delta V_E}{\Delta V_B} = 1 \]
  
  \[ \frac{\Delta V_{out}}{\Delta V_{in}} = 1 \]

  Thus the amp has *unity gain*!

- **Current Gain:** As always we can use Kirchhoff’s current rule.
  
  \[ I_E = I_B + I_C \]
  
  \[ I_E = I_B (\beta + 1) \]

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

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

  Since a typical value for \( \beta \) is 100, there is lots of current gain.
• Input impedance: By definition the input impedance is
\[ R_{\text{in}} = \frac{V_{\text{in}}}{I_{\text{in}}} \]
\[ = \frac{V_B}{I_B} \]
\[ = \frac{V_E}{I_E / (\beta + 1)} \]
\[ = \frac{I_E R_E}{I_E / (\beta + 1)} \]
\[ R_{\text{in}} = (\beta + 1) R_E \]
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:

\[ V_{\text{in}} \]
\[ \frac{R_s}{R_{\text{in}}} \]
\[ \frac{1}{R_{\text{in}}} \]

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

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

If we now 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 a common collector amp has unity gain. We can rewrite the equation into a voltage divider equation to find \( R_{\text{out}} \):

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

\[ V_A = \frac{V_{\text{in}} R_{\text{in}}}{R_E + R_{\text{out}}} \]
\[ = V_{\text{in}} \frac{R_E}{R_E + R_s} = \frac{V_{\text{in}} R_E}{R_E + R_s / \beta} \] or \( R_{\text{out}} = \frac{R_s}{\beta} \)

Thus \( R_{\text{out}} \) is small since \( \beta \) is typically 100.
• What good is the common collector amp?
Example: In stereo systems very often loud speakers have 8 $\Omega$ input impedance. Assume that you want to drive the speakers with a 5 Volt 92 $\Omega$ voltage source. Lets 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:

\[ P = \frac{V^2}{R} = \frac{(5 \, V \text{ rms})^2}{8} = 0.02 \text{ Watts} \] (not much power!)

b) Use a common collector (emitter follower):

An AC signal at the input sees \( R_{sp} = 8 \, \Omega = 800 \, \Omega \).

From the speakers point of view the amp impedance looks like 92 $\Omega$ or about 1 $\Omega$. The power delivered to the speaker can now be calculated:

\[ V_{sp} = \frac{(8 \, \Omega V_{in})}{(8 + 92 \, \Omega)} = 0.9V_{in} \, \text{(Volts)} \]

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

Thus there is more than a factor of a hundred times more power delivered to the speaker with an emitter follower amp.

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