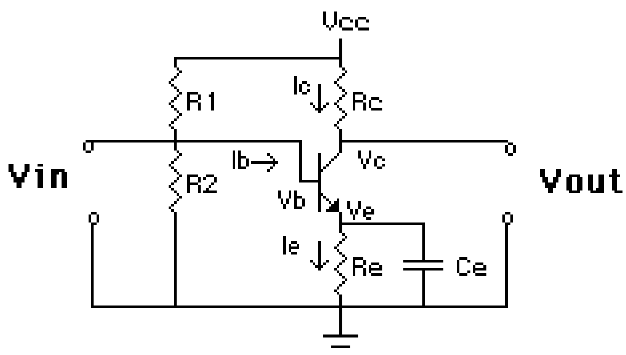
Transistors Amplifiers

<u>Common Emitter Amplifier ("Simplified")</u>

- 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.



- <u>What use is a Common Emitter Amp?</u>

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 $\equiv V_{out}/V_{in}$
Input Impedance
Output Impedance

- DC Voltage Gain:

The voltage gain we are about to derive is for <u>*small signals*</u> 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.

$$V_{out} = V_{cc} - I_C R_C$$

Since V_{cc} is fixed (its a DC power supply) we have for a change in output voltage V_{out}

$$\Delta V_{out} = -\Delta I_C R_C$$

In the above Δ stands for a small change in either the voltage or current. The input voltage is related the emitter voltage by a diode drop:

$$V_{in} = V_B$$
$$= V_E + 0.6\text{ V}$$
$$\Delta V_{in} = \Delta V_E$$

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:

$$I_E \approx I_C$$

$$\Delta I_E \approx \Delta I_C$$

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

$$\Delta V_E = \Delta I_E R_E = \Delta I_C R_E$$

We also have $\Delta V_E = \Delta V_{in}$ so we can write the above as:

$$\Delta V_{in} = \Delta I_C R_E = (-\Delta V_{out} / R_C) R_E$$

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

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

Note: the minus sign in the gain means that the output is the opposite polarity as the input (180^0 out of phase).

What happens if $R_E = 0$??? Do we have infinite gain?
(must consider the AC case where $X_{CE} << R$)

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:

$$I = I_s [e^{qV/kT} - 1]$$

with $V = V_{BE}$ and $kT/q = 25$ mV at 20^0C.

Neglecting the -1 term:

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

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

$$r_{BE} = \frac{dV_{BE}}{dI}$$

$$= \frac{kT}{qI}$$

$$= 25 \times 10^{-3} / I \qquad \text{(note : for 1 mA of current } r_{BE} = 25\ \Omega)$$

$$\text{Gain} = -\frac{R_C}{r_{BE} + R_E \,||\, X_{CE}}$$

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

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

Note: Simpson (page 227) writes an equivalent formula for the gain using the transistor parameter β and a slightly different temperature, $T = 300^0$K.

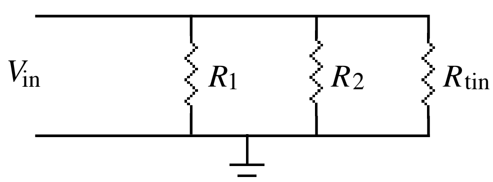
In terms of the hybrid parameter model (we will see this model soon)

$$r_{BE} = h_{ie} / h_{fe}$$

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:



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

$$R_{tin} \equiv \frac{\Delta V_B}{\Delta I_B}$$

$$= \frac{\Delta V_E}{\Delta I_E / \beta}$$

$$= \frac{\Delta I_E R_E}{\Delta I_E / \beta}$$

$$= \beta R_E$$

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

$R_{tin} = \beta R_E = \beta r_{BE} = 2500\ \Omega$ 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.

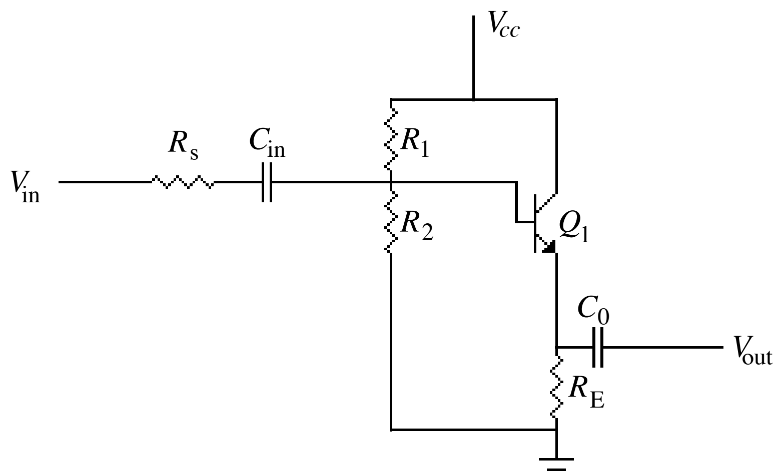
Thus the output impedance is simply R_C assuming that the load impedance (the thing the amp is hooked up to) is less than R_C.

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.



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

$$V_E = V_B - 0.6\text{ V}$$

$$\Delta V_E = \Delta V_B$$

$$\Delta V_{out} = \Delta V_{in}$$

Thus 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 β is 100, there is lots of current gain.

- Input impedance:

By definition the input impedance is

$$R_{in} = \frac{\Delta V_{in}}{\Delta I_{in}}$$

$$= \frac{\Delta V_B}{\Delta I_B}$$

$$= \frac{\Delta V_E}{\Delta I_E / (\beta + 1)}$$

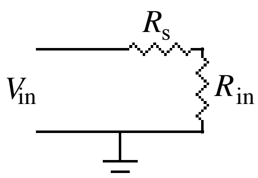
$$= \frac{\Delta I_E R_E}{\Delta I_E / (\beta + 1)}$$

$$R_{in} = (\beta + 1) R_E$$

Since R_E is usually a few kΩ and β 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:

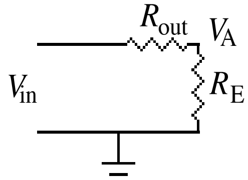


R_{in} is the input impedance of the transistor and V_{tin} is the voltage drop across it.

$$V_{tin} = \frac{V_{in} R_{in}}{R_{in} + R_s}$$

$$\approx \frac{V_{in} \beta R_E}{\beta R_E + R_s}$$

If we now look from the other (output) side of the amp with R_{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_{out}.



$$V_A = \frac{V_{in} R_E}{R_E + R_{out}}$$

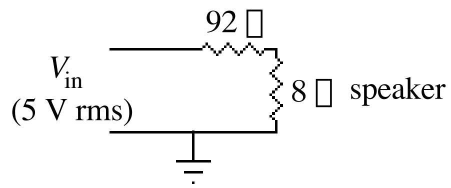
$$= V_{tin} = \frac{V_{in} \beta R_E}{\beta R_E + R_s} = \frac{V_{in} R_E}{R_E + R_s / \beta} \text{ or } R_{out} = \frac{R_s}{\beta}$$

Thus R_{out} is small since β 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 92 Ω voltage source. Lets look at 2 ways of driving the speakers and the power each method delivers to the speaker.

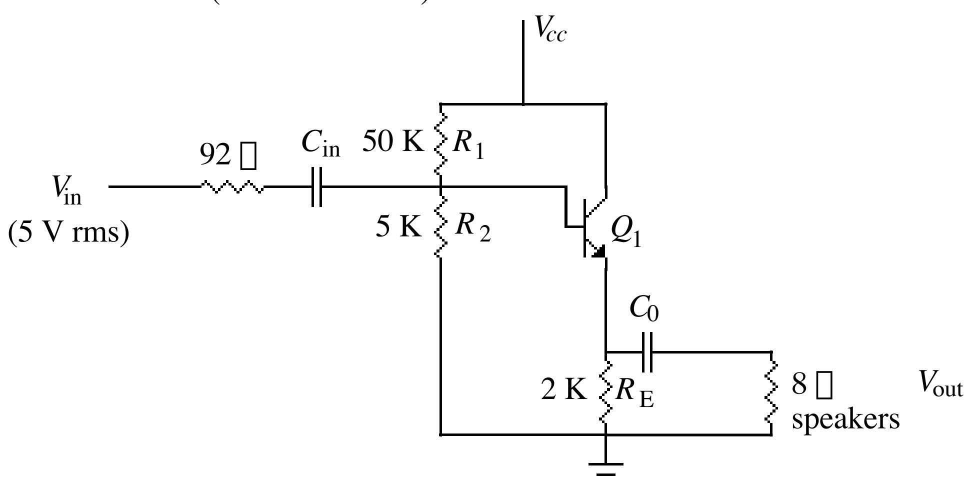
a) Hook the speakers directly to the voltage source:



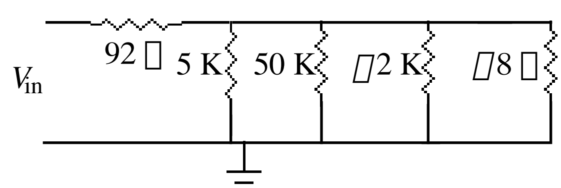
The voltage delivered to the speaker is $(8/100)V_{in}$. The power delivered is:

$$P = V^2 / R = (5 \times 8/100)^2 / 8 = 0.02 \text{ Watts} \text{ (not much power!)}$$

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 Ω/β or about 1 Ω. The power delivered to the speaker can now be calculated:

$$V_{sp} = (\beta 8\ \Omega\ V_{in}) / (\beta 8\ \Omega + 92\ \Omega) = 0.9 V_{in} \text{ (Volts)}$$

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

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

<u>Emitter Followers (common collectors) are used to match high impedances to low impedances.</u>