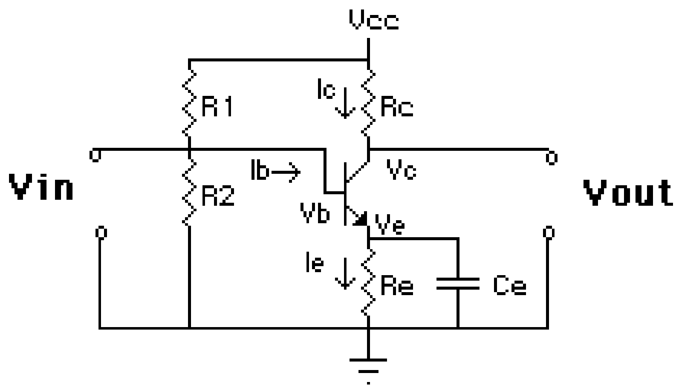
Lecture 6: Transistors Amplifiers

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.



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

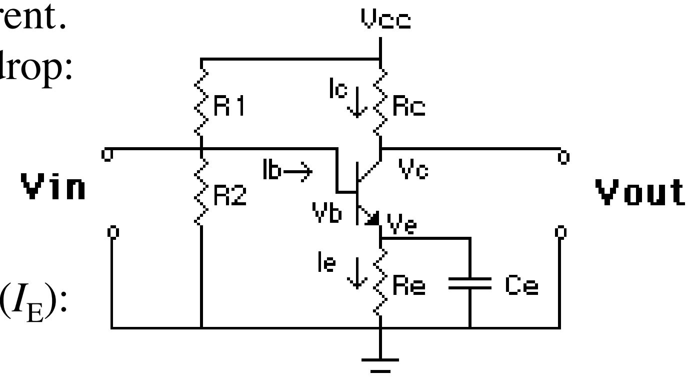
- DC Voltage Gain:
  - The voltage gain we are about to derive is for small signals only.
    - A small signal is defined here to be in the range of a few mV.
  - As in all of what follows we assume that the transistor is biased on at its DC operating point.

$$V_{\text{out}} = V_{cc} - I_{\text{C}} R_{\text{C}}$$

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

$$\Delta V_{\text{out}} = -\Delta I_{\text{C}} R_{\text{C}}$$

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



$$V_{\text{in}} = V_{\text{B}}$$
$$= V_{\text{E}} + 0.6 \text{ V}$$
$$\Delta V_{\text{in}} = \Delta V_{\text{E}}$$

  - We want to relate the emitter voltage to the emitter current (I_{E}):

$$V_{\text{E}} = I_{\text{E}} R_{\text{E}}$$
$$\Delta V_{\text{E}} = \Delta I_{\text{E}} R_{\text{E}}$$

  - We can relate the emitter and collector currents by remembering that for a transistor:

$$I_{\text{E}} \approx I_{\text{C}}$$
$$\Delta I_{\text{E}} \approx \Delta I_{\text{C}}$$
$$\Delta V_{\text{E}} = \Delta I_{\text{E}} R_{\text{E}} = \Delta I_{\text{C}} R_{\text{E}}$$
$$\Delta V_{\text{in}} = \Delta V_{\text{E}} = \Delta I_{\text{C}} R_{\text{E}} = (-\Delta V_{\text{out}} / R_{\text{C}}) R_{\text{E}}$$

- DC voltage gain (G) for a common emitter amp:

$$\text{Gain} = \frac{\Delta V_{\text{out}}}{\Delta V_{\text{in}}} = -\frac{R_{\text{C}}}{R_{\text{E}}}$$

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

- What happens if $R_{\text{E}} = 0$???
- 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:

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

  - $V = V_{\text{BE}}$
  - $kT/q = 25$ mV at 20$^{\text{o}}$C
- Neglecting the -1 term:

$$V_{\text{BE}} = \frac{kT}{q}[\ln I - \ln I_{\text{s}}]$$

- Calculate the dynamic resistance of the base-emitter junction,

$$r_{\text{BE}} = \frac{dV_{\text{BE}}}{dI} = \frac{kT}{qI} = 25\times 10^{-3}/I$$

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

$$\text{Gain} = -\frac{R_C}{r_{\text{BE}} + R_{\text{E}} \parallel X_{\text{CE}}}$$

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

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

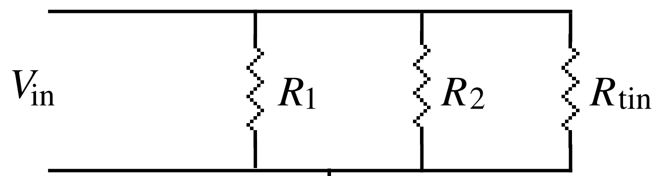
  Simpson (page 227) writes an equivalent formula for the gain using the transistor parameter β and a slightly different temperature, $T = 300^O$K.

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

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

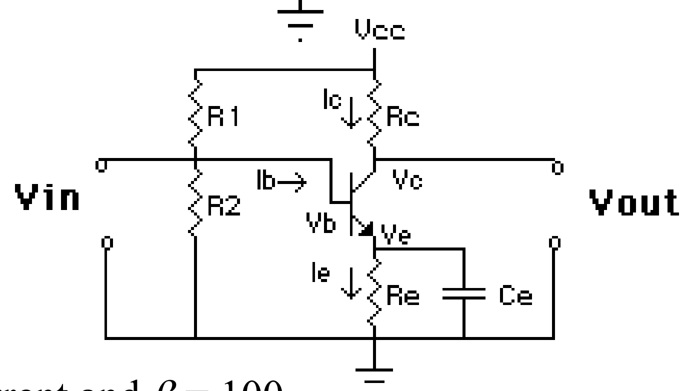
- Using r_{BE} to design a circuit is a dangerous practice as it depends on temperature
  - varies from transistor to transistor even for same type of transistor.

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



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

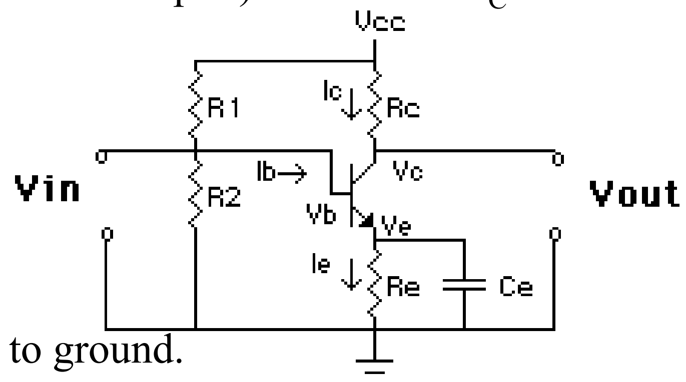
$$R_{tin} \approx \frac{\Delta V_B}{\Delta I_B} = \frac{\Delta V_E}{\Delta I_E / \beta} = \frac{\Delta I_E R_E}{\Delta I_E / \beta} = \beta R_E$$



  - For AC case, we usually have R_1 and $R_2 > R_{tin}$
    - ☞ $R_{tin} = \beta R_E = \beta r_{BE} = 2500\ \Omega$ for 1 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.

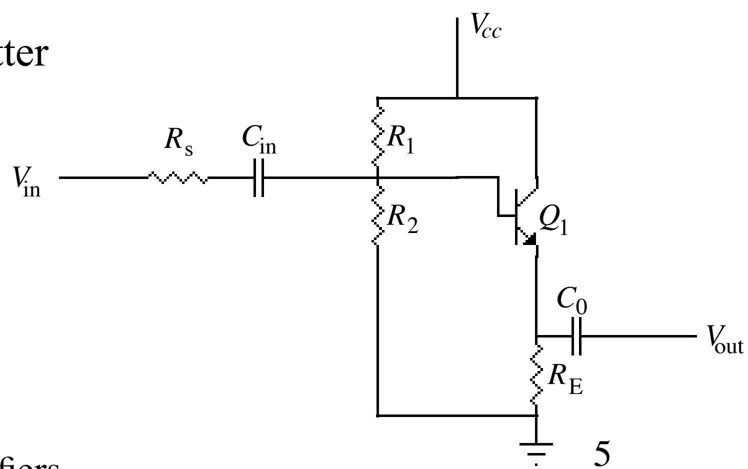
Common Collector Amplifier:



- 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!

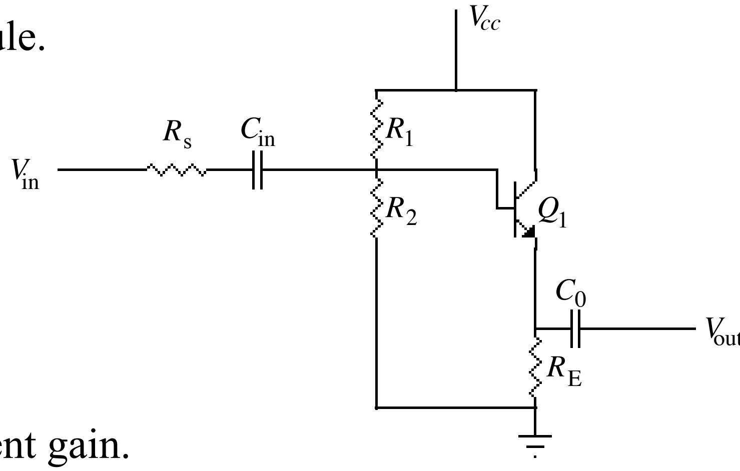


- Current Gain: As always we can use Kirchhoff's current rule.

$$
\begin{aligned}
I_E &= I_B + I_C \\
&= I_B(\beta + 1)
\end{aligned}
$$

$$\frac{\Delta I_E}{\Delta I_B} = \beta + 1$$

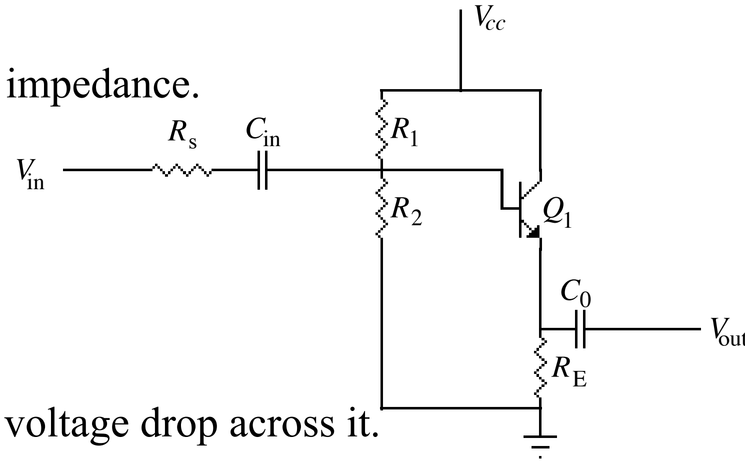
$$\frac{\Delta I_{out}}{\Delta I_{in}} = \beta + 1$$



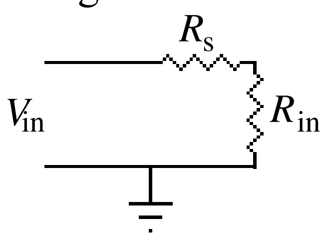
  - Since a typical value for β is 100, there is lots of current gain.
- Input impedance:
  - By definition the input impedance is

$$
\begin{aligned}
R_{in} &= \frac{\Delta V_{in}}{\Delta I_{in}} \\
&= \frac{\Delta V_B}{\Delta I_B} \\
&= \frac{\Delta V_E}{\Delta I_E/(\beta+1)} \\
&= \frac{\Delta I_E R_E}{\Delta I_E/(\beta+1)} \\
R_{in} &= (\beta+1)R_E
\end{aligned}
$$

    - 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.

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

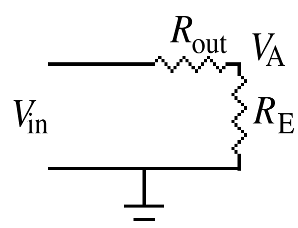
$$\approx \frac{V_{in} \beta R_E}{\beta R_E + R_s}$$

  - If we 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 the amp has unity gain.
    - ☞ We can rewrite the equation into a voltage divider equation to find R_{out}.

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

$$= V_{tin} = \frac{V_{in} \beta R_E}{\beta R_E + R_s} = \frac{V_{in} R_E}{R_E + R_s / \beta}$$

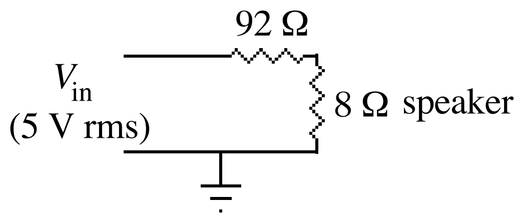
$$R_{out} = \frac{R_s}{\beta}$$



    - ☞ 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 voltage source with 92 Ω of serious resistance. 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:

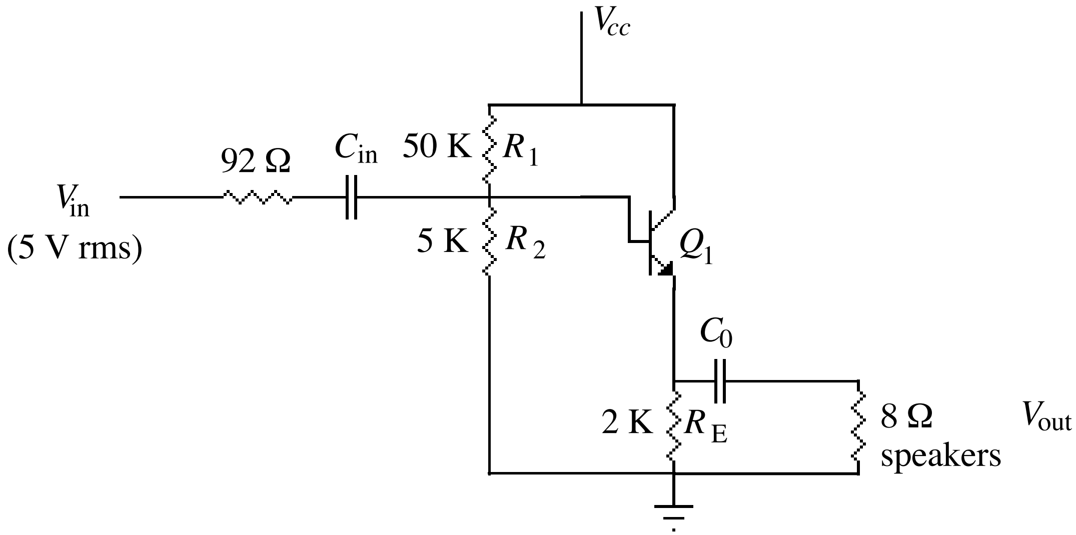


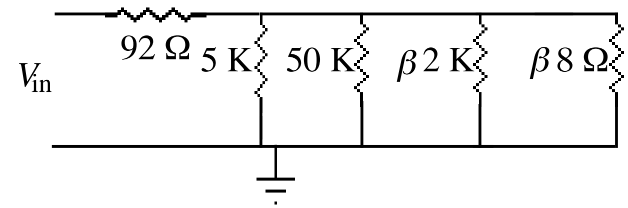
    - The voltage delivered to the speaker is $(8/100)V_{in}$.
    - The power delivered is:

      $P = V^2/R = (5 \times 8/100)^2/8 = 0.02$ 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:
  $V_{sp} = (\beta 8\ \Omega V_{in})/(\beta 8\ \Omega + 92\ \Omega) = 0.9V_{in}$

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

☞ over a **hundred** times more power delivered to the speaker.

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