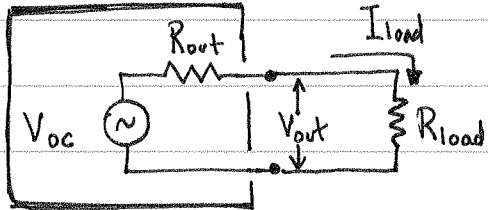


2.1 Output impedance of an emitter follower.

Definition of Output Impedance of a circuit:



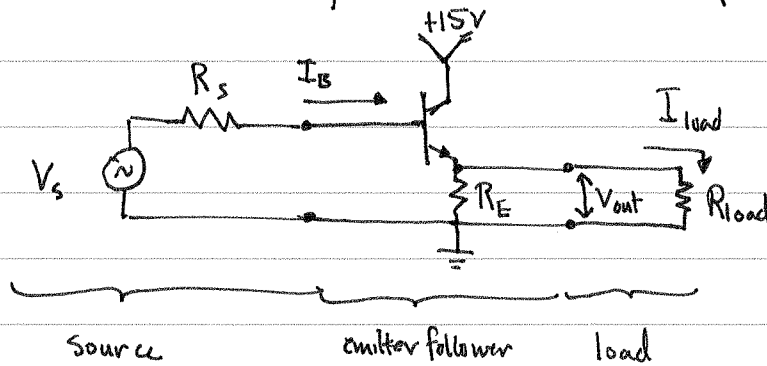
↳ "black box" .. general circuit

$$V_{out} = V_{oc} - I_{load} R_{out}$$

↳ "open circuit"

or... $R_{out} = - \frac{dV_{out}}{dI_{load}}$ Take this as the definition of output resistance.

Emitter follower driven by a source with its own output impedance, R_s .



$$V_{out} = V_s - I_B R_s - V_{diode}$$

↳ base current ↳ forward biased diode drop

Transistor action $I_B = \frac{I_E}{1+\beta}$ and $I_E = I_E' + I_{load}$

↳ current through R_E .

So,
$$V_{out} = V_s - \frac{(I_E' + I_{load}) R_s}{1+\beta} - V_{diode}$$

Assuming I_E' is roughly independent of V_{load} ... then

$$R_{out} = - \frac{dV_{out}}{dI_{load}} = \frac{R_s}{1+\beta}$$

Or, more generally,

$$Z_{out} = \frac{Z_s}{1+\beta}$$

Under what conditions is I_E' approximately independent of I_{load} ?

In fact... $V_{out} = I_E' R_E$ so...

$$V_{out} = V_s - \frac{1}{(1+\beta)} \left(\frac{V_{out}}{R_E} + I_{load} \right) R_s - V_{diode}$$

Solve for V_{out} ...

$$V_{out} \left(1 + \frac{R_s/R_E}{1+\beta} \right) = V_s - \frac{R_s}{(1+\beta)} I_{load} - V_{diode}$$

If this term is small compared to unity, then the above result is good...

Condition:

$$\frac{R_s}{(1+\beta)R_E} \ll 1$$

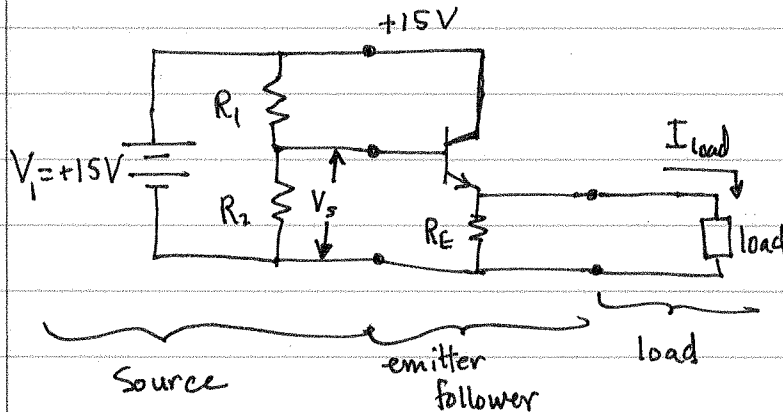
or..

$$\frac{R_s}{(1+\beta)} \ll R_E$$

↑
and this is the output resistance
calculated above.

2.2

Use an emitter follower with the base driven from a voltage divider to provide a stiff source of +5V (from a regulated +15V supply). The maximum load current is 25 mA. Choose resistors so that the output voltage doesn't drop by more than 5% under full load.



Treat the voltage divider as the source $V_s = \left(\frac{R_2}{R_1 + R_2} \right) V_{\pm}$

$$\text{We need } V_s = 5V + 0.6V = 5.6V$$

↑ base-emitter forward-biased junction.

$$\text{So... } \frac{R_1}{R_1 + R_2} = \frac{5.6V}{15V} = 0.373$$

The ~~output~~ output impedance of the voltage divider is $R_s = \frac{R_1 R_2}{R_1 + R_2} = \left(\frac{R_1}{R_1 + R_2} \right) R_2$
→ the parallel combination of R_1 and R_2 .
(solved earlier in the course for Thévenin equivalent of voltage divider) $= 0.373 \cdot R_2$

The ~~output of the~~ emitter follower has output resistance

$$R_{out} = \frac{R_s}{1 + \beta} \quad \text{from previous problem}$$

And the voltage drop is $\Delta V_{out} = I_{load} R_{out} < 0.05 \cdot V_{out} = 0.25V$
when $I_{load} = 25mA$

$$\text{So... need } R_{out} < \frac{0.25V}{0.025A} = \underline{\underline{10\Omega}}$$

$$\text{or... } \frac{R_s}{1+\beta} < 10\Omega \Rightarrow R_s \lesssim 1000\Omega \quad \text{since } \beta+1 \approx 100$$

$$\text{so... } \left(\frac{R_1}{R_1+R_2}\right) R_2 \lesssim 1k\Omega$$

$$\text{or } 0.373 R_2 \lesssim 1k\Omega$$

$$R_2 \lesssim 1k\Omega \cdot \frac{15}{5.6} = \underline{\underline{2.68 k\Omega}} \approx \underline{\underline{2.7 k\Omega}}$$

$$\text{And } \frac{R_1}{R_1+R_2} = \frac{5.6}{15} \quad \text{or... } \frac{R_1+R_2}{R_1} = \frac{15}{5.6}$$

$$1 + \frac{R_2}{R_1} = 2.68$$

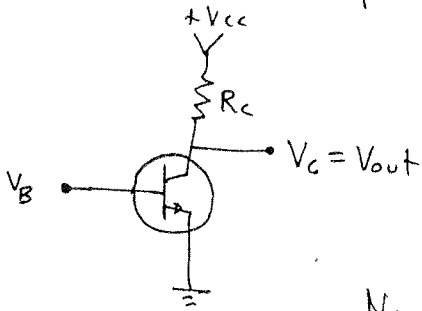
$$\frac{R_2}{R_1} = 1.68 \quad \text{or... } R_1 = \frac{R_2}{1.68} = \underline{\underline{1.6 k\Omega}}$$

Finally... R_E must be much larger than $\underline{\underline{10\Omega}}$ (the output resistance of the emitter follower)

$$\text{choose } \underline{\underline{R_E \approx 500\Omega}}$$

2.9

Common emitter amplifier with a grounded emitter.



Initial quiescent operating point has.. $V_{out} = \frac{V_{CC}}{2}$

$$V_{out} = V_{CC} - I_C R_C \quad \text{so...} \quad I_{C_0} R_C = \frac{V_{CC}}{2}$$

↑ initially.

Now, let temperature rise by 8°C

At fixed V_{BE} (fixed V_{in}), the collector current rises by a factor of 10 for a 30°C rise in temperature. (p.83)

$$\text{So...} \quad I_C = I_{C_0} \times 10^{\left(\frac{T-T_0}{30^\circ\text{C}}\right)}$$

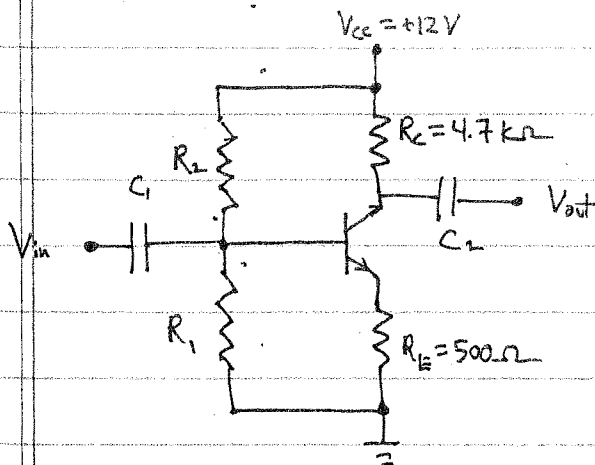
$$\text{An } 8^\circ\text{C temp. rise makes } I_C = I_{C_0} \times 10^{\left(\frac{8}{30}\right)} = 1.85 \times I_{C_0}$$

$$\text{So...} \quad V_{out} = V_{CC} - I_C R_C = V_{CC} - 1.85 I_{C_0} R_C$$

$$= V_{CC} - \frac{1.85}{2} V_{CC}$$

$$\boxed{V_{out} = 0.08 V_{CC}} \quad \leftarrow \text{close to ground --- transistor is saturated.}$$

Simpson Ch 5 [13] Common-emitter Amplifier



a) Calculate R_1 and R_2 if $I_E = 1.5 \text{ mA}$, $\beta = 100$.

Find the quiescent emitter voltage $V_E = I_E R_E = 1.5 \times 10^{-3} \text{ A} \cdot 500 \Omega$
 $= 0.75 \text{ V}$

The quiescent base voltage is one forward-biased diode drop higher than this

$$V_B = V_E + 0.6 \text{ V} = 1.35 \text{ V}$$

The base voltage is provided by the output of a voltage divider ...

$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} \quad \text{or...} \quad \frac{V_{CC}}{V_B} = 1 + \frac{R_2}{R_1}$$

$$\text{so...} \quad \frac{R_2}{R_1} = \frac{12 \text{ V}}{1.35 \text{ V}} - 1 = \underline{\underline{7.89}}$$

In order that the voltage divider not be loaded down, the base current $I_B = \frac{I_E}{\beta + 1}$ must be much less than the current through R_1 ... $I_1 = \frac{V_B}{R_1}$

$$\text{so...} \quad \frac{V_B}{R_1} \gg \frac{I_E}{\beta + 1} \quad \text{or...} \quad R_1 \ll \frac{(\beta + 1) V_B}{I_E} = \frac{101 \cdot 1.35 \text{ V}}{1.5 \times 10^{-3} \text{ A}}$$

$$R_1 \ll \underline{\underline{90.9 \text{ k}\Omega}}$$

Choose $R_1 = 5 \text{ k}\Omega$

and $R_2 = 7.89 \cdot R_1 = \underline{\underline{39.45 \text{ k}\Omega}}$

(b) Calculate the voltage gain.

$$\text{approximately } A_v = -\frac{R_c}{R_E} = \frac{-4.7 \times 10^3 \Omega}{500 \Omega} = \boxed{-9.4}$$

being a little more careful $A_v = -\frac{R_c}{(R_E + r_e)}$ where $r_e = \frac{25 \text{ mV}}{I_c (\text{mA})} \Omega$
is the Ebers-Moll resistance.

$$r_e = \frac{25 \text{ mV}}{1.5 \text{ mA}} = 16.7 \Omega$$

$$\text{so } A_v = \frac{-4.7 \times 10^3 \Omega}{516.7 \Omega} = \boxed{-9.1}$$

(c) Estimate the input and output impedances.

Input impedance is the parallel combination of R_1, R_2 and βR_E

$$\frac{1}{R_{in}} = \frac{1}{5 \times 10^3} + \frac{1}{39.45 \times 10^3} + \frac{1}{100,500} = 2 \times 10^{-3} + 2.5 \times 10^{-5} + 2 \times 10^{-5}$$
$$\approx 2 \times 10^{-3}$$

$$R_{in} \approx R_2 = \underline{\underline{5 \text{ k}\Omega}} \quad \text{in this case}$$

Output impedance is approximately equal to R_c

$$R_{out} \approx R_c = \underline{\underline{4.7 \text{ k}\Omega}}$$