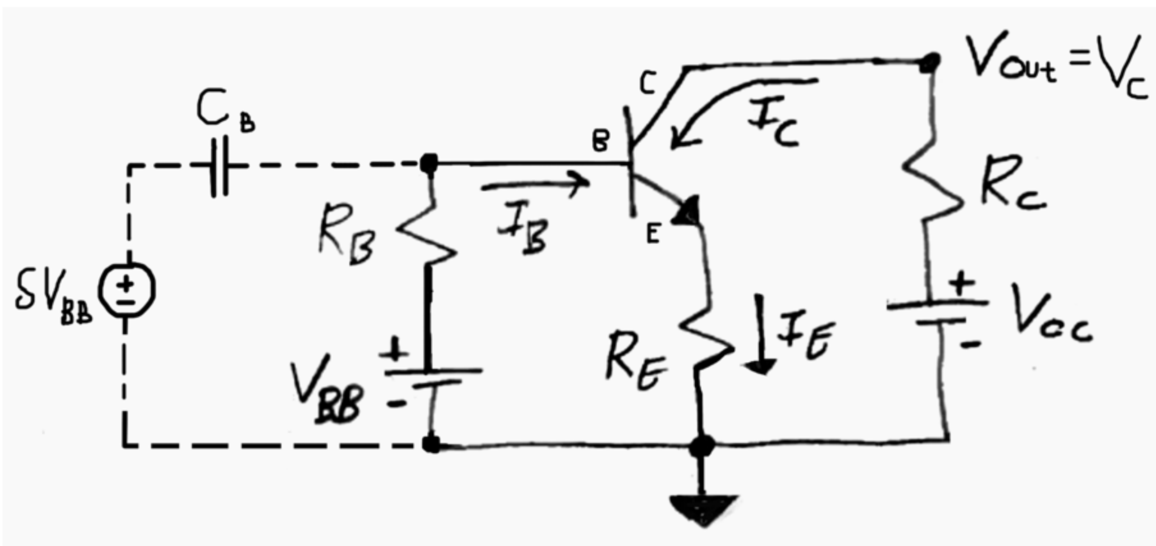
Physics 120 - David Kleinfeld - Spring 2015

Notes on common emitter transistor amplifier (accompanies Laboratory 8).

Here we use the transistor as a voltage amplifier. The idea is to turn a voltage at the input into a current through the base (B), and then turn the current flow through the transistor, *i.e.*, collector (C) to emitter (E) into a voltage drop. Since the dependent current source $I_C = \beta I_B$ can attain any voltage drop, the output is taken at the collector.

Our initial focus is on the DC properties, *i.e.*, setting up the bias to keep the transistor in the roughly "centered" in the active region. As an important technical aside, we use a nonzero value of R_E so that variations in the value of β can be removed to first approximation.



The left hand loop

$$-V_{BB} + I_B R_B + v_{BE} + I_E R_E = 0$$

but $\quad I_B = \frac{1}{\beta} I_c \quad$ and $\quad I_E = \frac{1+\beta}{\beta} I_C$

so $\quad I_C = \frac{\beta}{1+\beta} \, \frac{V_{BB} - v_{BE}}{R_E + R_B/(1+\beta)}.$

Recall that $\beta >> 1$ ($\beta \sim 200$ in this exercise) and choose $R_B << (1+\beta) R_E$. Then

$$I_C \simeq \frac{V_{BB} - v_{BE}}{R_E}$$

The right hand loop

$$-V_{CC} + I_C R_C + V_{CE} + I_E R_E = 0$$

but $\quad I_E = \frac{1+\beta}{\beta} I_C \simeq I_C$

so $I_C \simeq \frac{V_{CC} - V_{CE}}{R_E + R_C}$.

This equation defines the "load line" for the transistor, *i.e.*, the relation between I_C and V_{CE} that must be satisfied in addition to the intrinsic relation between I_C and V_{CE} that results from the transistor properties.

The output voltage is given by $V_C = V_{CE} + I_E R_E$. Thus

$$\begin{aligned} V_C &\simeq V_{CC} - I_C\left(R_E + R_C\right) + I_C R_E \\ &= V_{CC} - I_C R_C \\ &= V_{CC} - \frac{V_{BB} - v_{BE}}{R_E} R_C \\ &= \left(V_{CC} + \frac{R_C}{R_E} v_{BE}\right) - \frac{R_C}{R_E} V_{BB} \end{aligned}$$

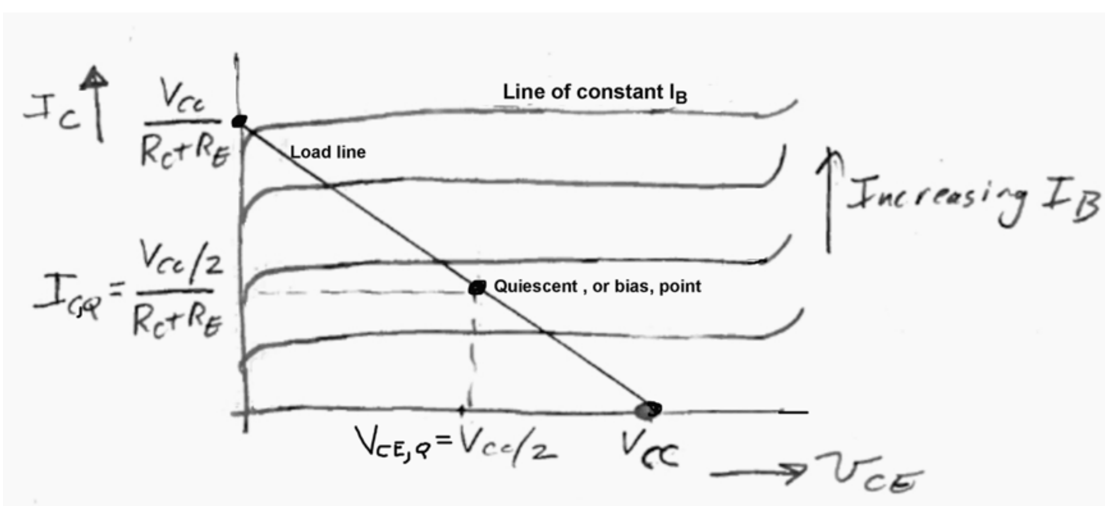
The term in the brackets is just a constant. The term proportional to V_{BB} contains a potential signal term. That is, if we change the base voltage source, such as by addition an AC current to the base through the inclusion of a time varying signals δV_{BB} (see previous figure), there is a corresponding change in the voltage at the collector, *i.e.*,

$$\delta V_C \simeq -\frac{R_C}{R_E} \delta V_{BB}$$
.

The ratio "- R_C / R_E" is the voltage gain. The minus means that the signal is inverted. Notice how β does not play a role (so long as β >>1)! This is the hallmark of good design - factor out the exact value of the gain since this is large but variable from device to device.

Load line and set point

The set-point are the values of I_C and V_{CE}, denoted $I_{C,Q}$ and $V_{CE,Q,}$ in the absence of AC input. We plot the load line equation (above) on top of the I_C versus V_{CE} curves for this transistor (see attached sheet for a small part of the measured relation) to establish the set-point.



The value of V_{CE} is bounded at the low end by the cut-off voltage of 0.2 V. From the load line equation $I_C \simeq \frac{V_{CC} - V_{CE}}{R_E + R_C}$, we see that V_{CE} is bounded from above to be V_{CC} (typically many Volts). Since V_{CC} >> 0.2 V, we choose $V_{CEQ} = V_{CC}/2$ to insure a (near) maximum voltage swing.

<u>Selecting values</u>

Choose the gain. For |Gain| = 10, $R_C = 10\ R_E$.

Satisfy $R_B << \beta R_E$. Since $\beta \geq 100$, select $R_B = 10\ R_E$.

Pick V_{CQ}. We choose V_{CQ} = 7.5 V. Then $V_{CC} = 2\ V_{CEQ}$ = 15V.

Pick $I_{CQ.}$ We choose I_{CQ} = 1 mA.

Satisfy the load-line relation $I_{CQ} \simeq \frac{V_{CC} - V_{CEQ}}{R_E + R_C} \simeq \frac{V_{CC}}{2R_C}$ which yields $R_C \simeq \frac{V_{CC}}{2I_{CQ}}$.

Picking standard values of resistors gives:

$R_C \simeq \frac{15\text{V}}{2\text{mA}}$ ~ 6.8 kΩ,

$R_E \simeq \frac{R_C}{10}$ ~ 680 Ω,

and

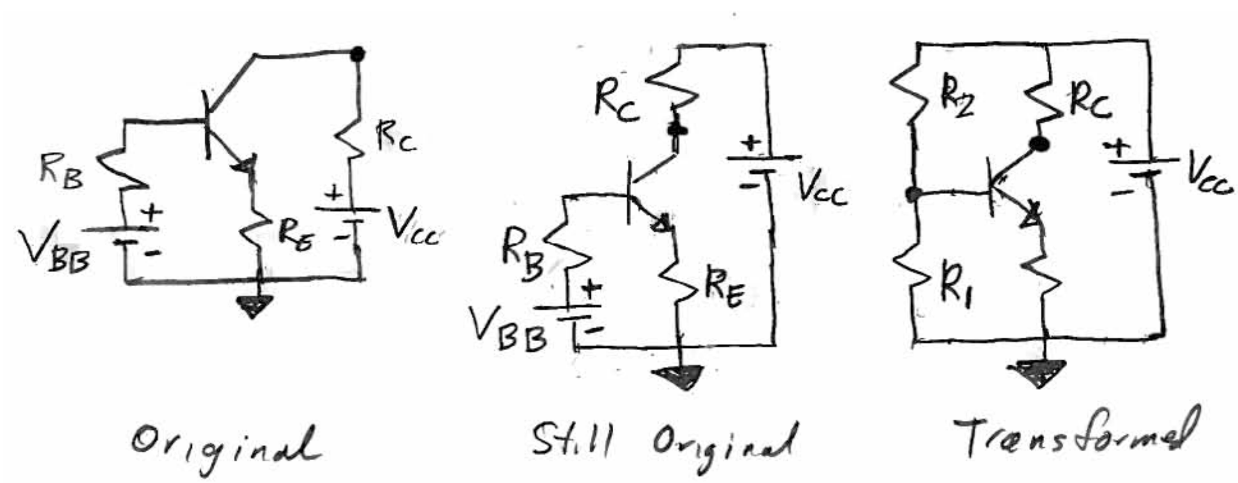
$R_B \simeq 10\ R_E$ ~ 6.8 kΩ.

Lastly,

$V_{BB} \simeq v_{BE} + I_E R_E$ ~ 1.5 V.

<u>Convert from dual to single power supply</u>

Rather than have two batteries, we use one battery for both V_{BB} and V_{CC}. Since V_{CC} is the larger voltage, we use it as the supply. and build a voltage divider to replace V_{BB} and R_B.



From the diagrams above,

$$R_B \simeq \frac{R_1 R_2}{R_1 + R_2} \quad \text{and} \quad V_{BB} \simeq \frac{R_1}{R_1 + R_2} V_{CC}$$

so that

$$R_1 \simeq R_B \frac{V_{CC}}{V_{CC} - V_{BB}} \quad \text{and} \quad R_2 \simeq R_B \frac{V_{CC}}{V_{BB}}.$$

Substituting in values and using standard components gives:

$$R_1 \simeq 5.6\text{k}\Omega \frac{15\text{V}}{15\text{V} - 1.5\text{V}} \sim 5.6\text{k}\Omega \quad \text{and} \quad R_2 \simeq 5.6\ \text{k}\Omega \frac{15\text{V}}{1.5\text{V}} \sim 56\ \text{k}\Omega.$$

Lastly, must also satisfy $R_1 << R_{in}$, *i.e.*, $R_1 << \beta R_E$, so that the input resistance does not contribute to the voltage divider. Our choises lead to self-consistency with 5.6kΩ << 200x680Ω or 5.6kΩ << 140kΩ, so all is fine.

Coupling of the AC signal, δV_{BB}.

This signal is high pass filtered with a cut-on frequency of $1/(2\pi R_B C_B)$. The desired cut-on frequency, f_C, sets the value of C_B, by $C_B = 1/(2\pi f_C R_B)$.

Fini!