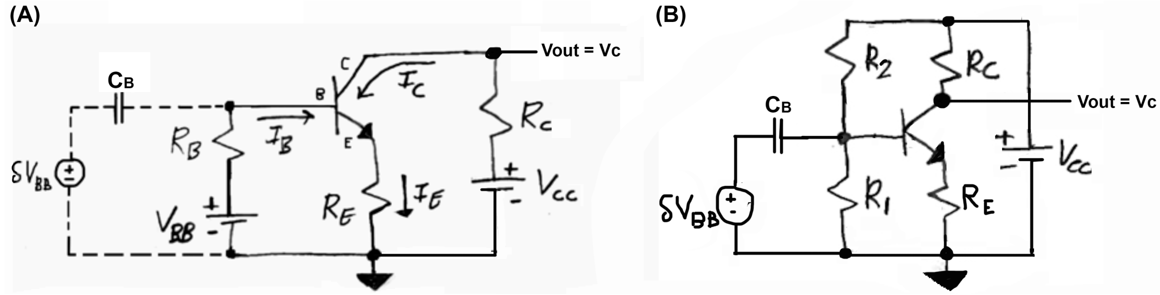
Your name: Your student number:

Physics 120 - Final exam - 14 June 2018

Complete the design of the common emitter transistor amplifier using a 2N3904 NPN BJT, demonstrate that it operates as planned in terms of gain, dynamic range, and bandwidth.



<u>The left hand loop (**Fig. A**)</u>

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

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

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

Recall that $\beta >> 1$ ($\beta \sim 100$ in this case) and choose $R_B << (1+\beta)R_E$. Then

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

<u>The right hand loop (**Fig. A**)</u>

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

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

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

This equation defines the "load line" for the transistor.

Gain: The output voltage is given by

$$V_C = V_{CC} - I_C R_C = V_{CC} - \frac{V_{BB} - V_{BE}}{R_E} R_C = \left(V_{CC} + \frac{R_C}{R_E} V_{BE} \right) - \frac{R_C}{R_E} V_{BB}.$$

The output is equal to the collector voltage, V_C, and is linear in V_{BB}. The voltage V_{BB} contains a constant as well as a signal component, δV_{BB} (**Fig. A,B**). The change δV_{BB} leads to a proportional change in the output, δV_C, *i.e.*,

$$\delta V_C \simeq -\frac{R_C}{R_E} \delta V_{BB}.$$ where the ratio "- R_C / R_E" is the voltage gain of the circuit.

Load line: The set-point, denoted $I_{C,Q}$ and $V_{CE,Q}$, are the values of I_C and V_{CE} with $\delta V_{BB} = 0$. The value of V_{CE} is bounded at by $V_{CE,Sat} = 0.2$ V and $V_{CC} = 15$ V.

Design constraints:

Choose $V_{CEQ} = V_{CC}/2$ to insure a (near) maximum voltage swing.

Choose $I_{CQ} = 10$ mA, the optimum current for this BJT

Choose |Gain| = 10, so $R_C = 10\ R_E$

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 $R_C \simeq \frac{V_{CC}}{2I_{CQ}}$.

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

Calculate $V_{BB} \approx V_{BE} + I_{C,Q} R_E$.

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Realization (*note*: confirm the value of all components prior to construction)

(1a-c) Pick standard values of resistors:

$R_C \approx$ **750 Ω** $R_E \approx$ **75 Ω**

$R_B \approx$ **750 Ω**

(1d) Calculate V_{BB}:

$V_{BB} \approx$ **1.2 V**

Convert from dual to single power supply with a voltage divider (**Fig. B**) to replace V_{BB} and R_B:

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

(1e,f) Pick standard values of resistors:

$R_1 \approx$ **810 Ω** $R_2 \approx$ **10 kΩ**

(1g) Show that your choice satisfies $R_1 << R_{input}$, i.e., $R_1 << \beta R_E$, so that the input resistance does not contribute to the voltage divider.

810 Ω << 100*75 Ω = 7500 Ω

Testing (*recall:* the oscilloscope and DMM inputs are not differential)

(2a) Measure and record the actual value of $V_{CE,Q}$ (how?):

$V_{CE,Q} \approx$ *(Call for a TA to demonstrate your measurement)*

Differential voltage from collector to emitter. This could be successive measurements.

(2b) Measure and record the actual value $I_{C,Q}$ (how?):

$I_{C,Q} \approx$ *(Call for a TA to demonstrate your measurement)*

Series current along collector OR along emitter leg OR via voltage drop across R_C or across R_E. Drop across R_E is a single probe measurement and simplest.

(2c) Pick a standard value of capacitor, or combined capacitors, to couple δV_{BB} through a high-pass filter with cut-on frequency of $f_{High\text{-}pass}$ ~ 1.0 kHz (**Fig A,B**) (*recall*: $f_{High\text{-}pass} = 1/(2\pi R_B C_B)$):

$C_B \approx$ **0.21 μF OR two 0.1 μF capaciters in parallel**

(2d) Show that the output δV_C spans the full range of positive and negative values of δV_{BB} for an ~ 1 $V_{peak\text{-}to\text{-}peak}$ sine input at ~ 10 kHz (*note*: ensure Z_{out} = High for the function generator).

Call for a TA to observe your demonstration (show δV_{BB} and δV_C on the oscilloscope)

(2e) Measure the output δV_C as a function of frequency (*hint*: use "AC" coupling on the oscilloscope for ease). What is the actual value of the cut-on frequency, i.e., f_{3dB} for high-pass?

$f_{High\text{-}pass} \approx$

(2f) What is the value of the cut-off frequency, i.e., f_{3dB} for low-pass?

$f_{Low\text{-}pass} \approx$

(2g) What is the origin of the high-frequency filtering for $f_{Low\text{-}pass}$?

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