8.12. Circuit in the 2nd midterm

\[ V_{CC} = 5\text{V} \]
\[ R_C = 10\,\text{k}\Omega \]
\[ R_C = 35\,\text{k}\Omega \]
\[ I_C = 100\mu\text{A} \]

Improved circuit

\[ V_{CC} = 2.5\text{V} \]
\[ R_C = 25\,\text{k}\Omega \]
\[ I_C = 100\mu\text{A} \]

(a.) In both circuits

\[ V_{BE} = \frac{kT}{q} \ln \frac{I_c}{I_s} = 26\text{mV} \cdot \ln \frac{10^{-4}\text{A}}{10^{-10}\text{A}} = 718.4\text{mV} \]

\[ I_B = \frac{I_C}{\beta} = \frac{100\mu\text{A}}{100} = 1\mu\text{A} \]

In (A), \[ V_{BE} = I_B \cdot R_C + V_{BE} = 1\mu\text{A} \cdot 25\,\text{k}\Omega + 718.4\text{mV} = 743.4\text{mV} \]

In (B), \[ V_{BE} = I_B \cdot R_C + V_{BE} - 2.5\text{V} = -1.757\text{V} \]

(b.) Small signal model

\[ Y_C = \frac{I_C}{V_C} = \frac{100\mu\text{A}}{3.846\text{mS}} = 26\,\text{k}\Omega \]

\[ S_m = \frac{I_C}{I_V} = \frac{100\mu\text{A}}{26\text{mV}} = 3.846\text{mS} \]
For both circuits

\[ R_{in} = R_x = 26 \text{k}\Omega \]
\[ G_m = \beta = 3.846 \text{mS} \]

In (A),

\[ R_{out} = R_{load} R_C = \frac{10 \text{k}\Omega \cdot 200 \text{k}\Omega}{10 \text{k}\Omega + 200 \text{k}\Omega} = 9.524 \text{k}\Omega \]
\[ A_v = G_m \cdot R_{out} = 3.846 \text{mS} \cdot 9.524 \text{k}\Omega = 36.63 \]

In (B),

\[ R_{out} = R_o = 200 \text{k}\Omega \]
\[ A_v = -G_m \cdot R_{out} = -3.846 \text{mS} \cdot 200 \text{k}\Omega = -769.2 \]

Two port model for (A)  

Two port model for (B)

(C). Overall circuit small signal model

\[ R_o = 25 \text{k}\Omega \]
\[ V_o = 20 \text{V} \]

\[ V_i = 36.63 \text{V} \]
For (A),

\[ \text{Overall voltage gain} = \frac{V_{out}}{V_{in}} = \frac{26k\Omega}{25k\Omega + 26k\Omega} \cdot \frac{2k\Omega}{2k\Omega + 7.5\times4k\Omega} \]

\[ = -12.65 \]

For (B),

\[ \text{Overall voltage gain} = \frac{V_{out}}{V_{in}} = \frac{26k\Omega}{25k\Omega + 26k\Omega} \cdot \frac{20k\Omega}{20k\Omega + 20k\Omega} \]

\[ = -35.65 \]

(i) If \( V_{CE} > V_{CE\text{sat}} \), the bipolar transistor is in forward active region, \( I_c = \beta \cdot I_B \) and small signal \( I_c = \beta \cdot I_B \).

For (A) \( V_0 = I_c \cdot (R_L || R_c || V_0) = -\beta \cdot I_B \cdot (R_L || R_c || V_0) = -\beta \cdot \frac{V_0}{R_L + R_c} \cdot (R_L || R_c || V_0) \)

For (B) \( V_0 = -I_c \cdot (R_L || V_0) = -\beta \cdot I_B \cdot (R_L || V_0) = -\beta \cdot \frac{V_0}{R_L + R_c} \cdot (R_L || V_0) \)

\( V_0 \) is a linear function of \( V_i \).

(ii) If \( V_{CE} = V_{CE\text{sat}}, \) \( I_c \neq \beta \cdot I_B \), the overall voltage gain of both circuit will drop, the input signal is clipped.

For (A), the negative output swing will be 0.1V,
For (B), the negative output swing will be -2.4V.
(iii) For (A), the maximum positive output swing can be reached when \( I_c \) of the bipolar transistor becomes zero, it is determined by the voltage divider.

\[
\frac{5V}{\frac{20k\Omega}{10k\Omega + 20k\Omega}} = 3.333V
\]

For (B), the maximum positive output swing can be reached when \( I_c \) of the bipolar transistor becomes zero, all current from the current source will flow through \( R_c \).

\[
V_{out\_max} = 100 \mu A \cdot 20k\Omega = 2V
\]

- For (A) \( V_{out} \in (0.1V, 3.333V) \)
- For (B) \( V_{out} \in (-2.4V, 2V) \)