EE210: HW-10 Solution

Date: 12/03/2019

Unless stated otherwise, the BJT in the problems given below has the following characteristics

$I_S = 2.03 \times 10^{-15} A$; $\beta_F = 100$; $\beta_R = 1$; $V_A = \infty$; $r_{bb} = 200\Omega$; $V_T = 26mV$; $C_{jeo} = 1pF$; $C_{jco} = 0.5pF$;

$C_{jso} = 3pF$; $m = 0.5$; $V_{bi} = 0.85$; $\tau_F = 1ns$

(For simplicity, include r_{bb} only in high frequency analysis and ignore C_{js})

In all the solutions, we will assume and use directly coupled condition for V_B i.e. $V_B \leq V_{CC}$.

Q.1 Figure 1 shows a common-collector amplifier schematic. Determine voltage gain, input and output resistances, maximum output voltage swing, lower and upper cutoff frequencies.

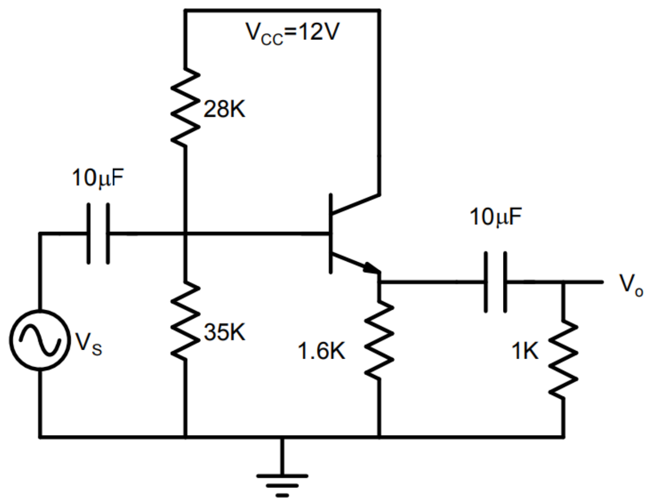


Fig. 1

Sol.

Dc analysis gives

$$I_{CQ} = 3.4mA; V_{CEQ} = 6.56V; V_E = 5.4V$$

Small signal analysis gives

$$g_m = 0.13\Omega^{-1}; r_\pi = 0.76k\Omega$$

$$A_V = \frac{g_m \times R_E||R_L}{1 + g_m \times R_E||R_L} = 0.988$$

$$R_{in} = (r_\pi + (\beta + 1) \times R_E||R_L)||R_{\boldsymbol{B}} = 12.45k$$

$$R_O = \frac{(r_\pi + R_B||R_S)}{1 + \beta}||R_E = 7.6\Omega$$

$$V_O \leq V_{CC} - V_{BE} - I_{CQ}R_E = 5.86V$$

$$V_O \leq I_{CQ}R_E||R_L = 2.1V$$

Thus,

$$V_{om} = 2.1V$$

$$f_L = \frac{1}{2\pi} \times \frac{1}{C_E \times (R_L + R_O)} = 15.8Hz$$

$$V_{BC} = V_{BE} - V_{CE} = -5.8V$$

$$C_{jc} = \frac{0.5pf}{\sqrt{1 - \frac{V_{BE}}{0.85}}} = 0.178pF; C_{je} = \frac{1pf}{\sqrt{1 - \frac{0.7}{0.85}}} = 2.38pF$$

$$C_\pi = g_m\tau_F + C_{je} = 133pF; C_\mu = 0.18pF$$

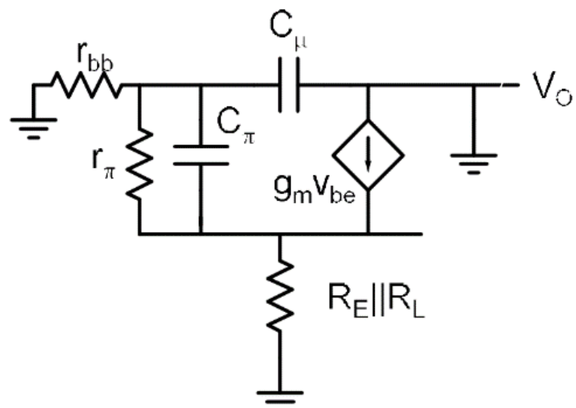
$$R_\pi = \left(1 + \frac{R'_E}{r_{bb}}\right)\left(r_\pi || \frac{r_{bb}}{1 + g_m R'_E}\right) = 9.1\Omega$$

$$R_\mu = r_{bb}(1 - x) + R_C \times (1 + x\beta) = 200\Omega$$

$$x = \frac{r_{bb}}{r_{bb} + r_\pi + \beta R'_E} = 2 \times 10^{-3}$$

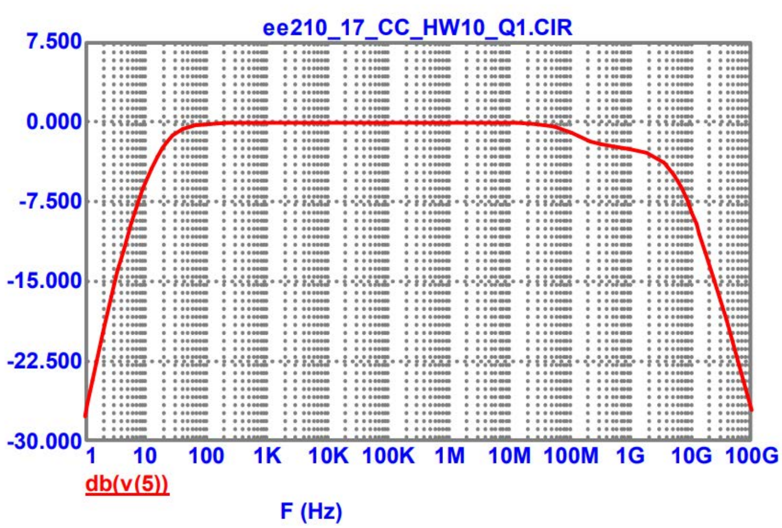
$$f_{p1} \cong \frac{1}{2\pi \times (R_\pi C_\pi + R_\mu C_\mu)} = 127.7MHz$$

$$f_z \cong \frac{1}{2\pi \times \frac{C_\pi}{g_m}} = 156MHz$$



$$f_{p2} \cong \frac{1}{2\pi \times (r_{bb} + R_S||R_B)C_\mu} = 4.4GHz$$

$$f_H = f_{p2} = 4.4GHz$$



Simulation shows 2.2GHz

Q.2 Repeat the calculations for the amplifier shown in Fig. 2, which has a current source biasing.

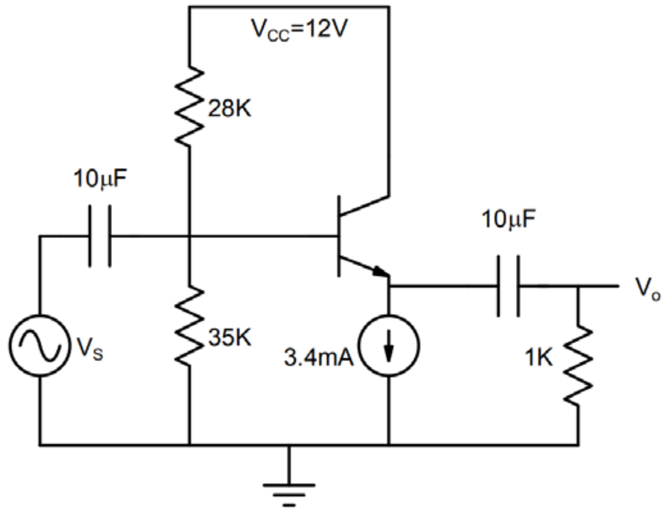


Fig. 2

Sol.

Dc analysis

$$I_{CQ} = 3.4mA; V_{CEQ} = 6.56V; V_E = 5.4V$$

Small signal analysis gives

$$g_m = 0.13\Omega^{-1}; r_\pi = 0.76k\Omega$$

$$A_V = \frac{g_m \times R_L}{1 + g_m \times R_L} = 0.992$$

$$R_{in} = (r_\pi + (\beta + 1) \times R_L)||R_{\boldsymbol{B}} = 13.5k$$

$$R_O = \frac{(r_\pi + R_B||R_S)}{1 + \beta}||R_E = 7.6\Omega$$

$$V_O \leq V_{CC} - V_{BE} - I_{CQ}R_E = 5.86V$$

$$V_O \leq I_{CQ}R_L = 3.4V$$

$$V_{om} = min.\{V_{CC} - V_{BE} - I_{CQ}R_E, I_{CQ}R_L\} = 3.4V$$

$$f_L = \frac{1}{2\pi} \times \frac{1}{C_E \times (R_L + R_O)} = 15.8Hz$$

$$V_{BC} = V_{BE} - V_{CE} = -5.8V$$

$$C_{jc} = \frac{0.5pf}{\sqrt{1 - \frac{V_{BE}}{0.85}}} = 0.178pF; C_{je} = \frac{1pf}{\sqrt{1 - \frac{0.7}{0.85}}} = 2.38pF$$

$$C_\pi = g_m\tau_F + C_{je} = 133pF; C_\mu = 0.18pF$$

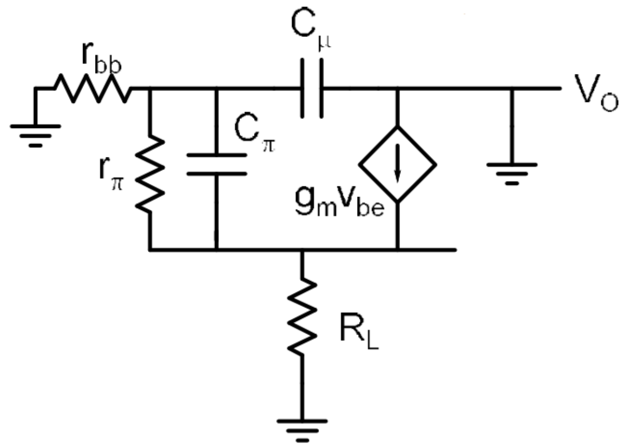
$$R_\pi = \left(1+\frac{R'_E}{r_{bb}}\right)\left(r_\pi || \frac{r_{bb}}{1+g_m R'_E}\right) = 9.1\Omega$$

$$R_\mu = r_{bb}(1-x) + R_C \times (1+x\beta) = 200\Omega;$$

$$x = \frac{r_{bb}}{r_{bb}+r_\pi+\beta R'_E} = 2\times 10^{-3}$$

$$f_{p1} \cong \frac{1}{2\pi \times (R_\pi C_\pi + R_\mu C_\mu)} = 127.7MHz$$

$$f_z \cong \frac{1}{2\pi \times \frac{C_\pi}{g_m}} = 156MHz$$



$$f_{p2} \cong \frac{1}{2\pi \times (r_{bb} + R_S||R_B)C_\mu} = 4.4GHz$$

$$f_H = f_{p2} = 4.4GHz$$

Q.3 Figure 3 shows one implementation of the current source biased CC amplifier. Determine the maximum output voltage swing that can be obtained? What is the flaw in the design of the amplifier?

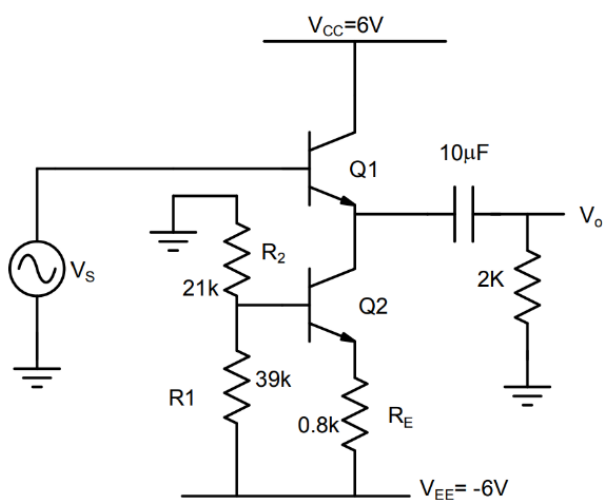


Fig. 3

Sol.

<u>Dc analysis</u>

$$I_{CQ} = 3.4mA;\ V_{B1} = 0;\ V_{E1} = -0.7V;\ V_{CEQ} = 6.7V;$$

$$V_{E2} = -3.26V;\ V_{CE2} = 2.56V$$

Like Q.2

$$V_O \leq V_{CC} - V_{BE} - V_E = 6V$$

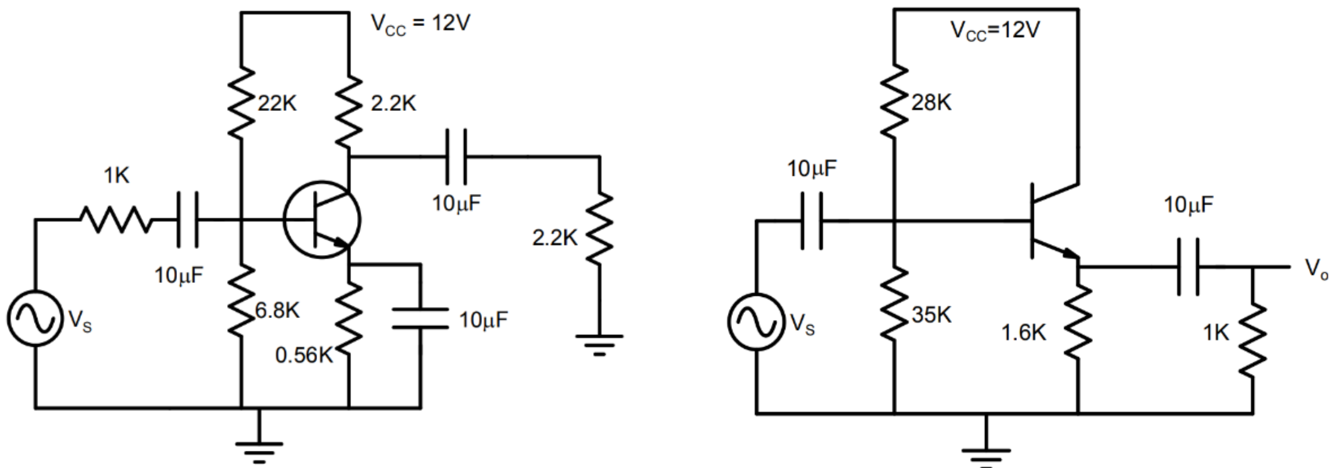
$$V_O \leq I_{CQ}R_L = 6.8V$$

We also need to ensure that Q2 stays out of saturation,

$$V_{CE2} - V_o \geq 0.2V \Rightarrow V_O \leq 2.54V$$

Thus $V_o \sim 2.54V$. The flaw in the design is that V_{CE2} has been designed to be too low. We should reduce V_{E2} to lower value.

Q.4 Figure 4 shows a CE amplifier; whose voltage gain and upper cutoff frequency are 58 and 2MHz respectively. Show that use of the CC amplifier shown in Fig. 1 in the combination of CC-CE can result in significant improvement in both gain as well as upper cutoff frequency.



Sol.

For CE Stage only:

Dc analysis

$$I_{CQ} = 3.48mA; V_{CEQ} = 2.38V;$$

Small signal analysis

$$g_m = 0.13\Omega^{-1}; r_\pi = 0.74k\Omega$$

$$R_{in} = r_\pi||R_{\boldsymbol{B}} = 0.65k;\ R_O = R_C = 2.2k\Omega$$

$$A_V = \left(\frac{R_{in}}{R_{in} + R_S}\right)(g_m \times R_C||R_L) = 0.395 \times 147.5 = 58$$

$$V_{BC} = V_{BE} - V_{CE} = -1.68V$$

$$C_{jc} = \frac{0.5pf}{\sqrt{1 - \frac{V_{BC}}{0.85}}} = 0.29pF; C_{je} = \frac{1pf}{\sqrt{1 - \frac{0.7}{0.85}}} = 2.38pF$$

$$C_\pi = g_m\tau_F + C_{jc} = 136.5pF$$

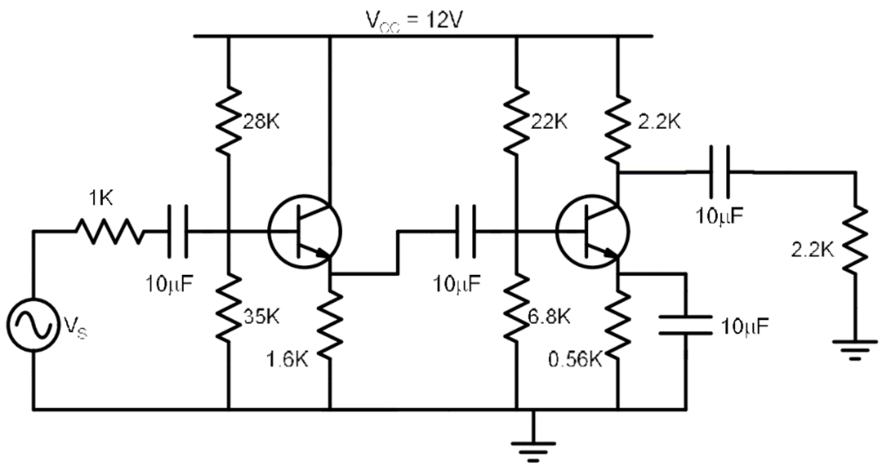
$$C_\mu = 0.29pF$$

$$R_\pi = \left(1 + \frac{R'_E}{r_{bb} + R_S||R_B}\right)\left(r_\pi || \frac{r_{bb} + R_S||R_B}{1 + g_m R'_E}\right) = 0.43k\Omega$$

$$f_H \cong \frac{1}{2\pi \times (R_\pi C_\pi + R_\mu C_\mu)} = 2MHz$$

$$R_\mu = (r_{bb} + R_S||R_B)(1 - x) + R'_C \times (1 + x\beta) = 65.6k\Omega;$$

$$x = \frac{r_{bb} + R_S||R_B}{r_{bb} + R_S||R_B + r_\pi + \beta R'_E} = 0.58$$



For CC stage:

$$R_L = R_{in2} = 0.65k\Omega$$

$$A_V = \left(\frac{g_m \times R_E||R_L}{1 + g_m \times R_E||R_L}\right) = 0.984$$

$$R_O = \frac{(r_\pi + R_B||R_S)}{1 + \beta}||R_E = 16.88\Omega$$

This (R_0 of CC stage) serves as R_S for CE stage.

For CE stage:

$$R_S = R_{O1} = 16.88k\Omega$$

$$A_V = \left(\frac{R_{in}}{R_{in} + R_S}\right)(g_m \times R_C||R_L) = 0.975 \times 147.5 = 143.7$$

$$R_\pi = 168\Omega;\ R_\mu = 26k\Omega$$

$$f_H \cong \frac{1}{2\pi \times (R_\pi C_\pi + R_\mu C_\mu)} = 5.2MHz$$

Q.5 Determine the values of resistors R_B and R_E to obtain a maximum output voltage swing of 1V first and then for 2V.

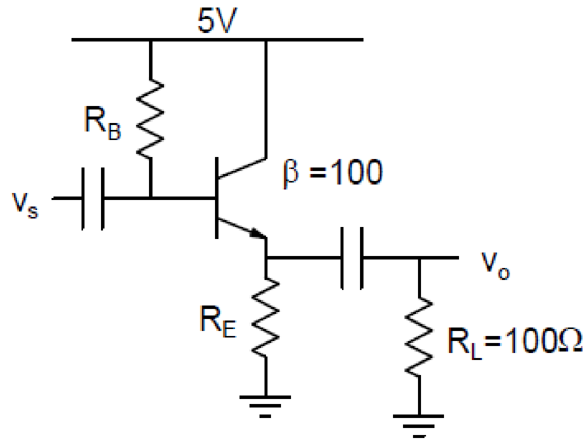


Fig. 5

Sol 5(a).

$$V_E \geq V_o \times \left(1 + \frac{R_E}{R_L}\right) = 1 + \frac{R_E}{R_L}$$

$$V_E \leq V_{CC} - V_{BE} - V_O = 3.3V$$

$$1 + \frac{R_E}{R_L} \leq V_E \leq V_{CC} - V_{BE} - V_O = 3.3V \implies R_E \leq 2.3 * R_L$$

$$I_{CQ} = \frac{V_E}{R_E} \geq \frac{1}{R_E} + \frac{1}{R_L}$$

Choose R_E to be large to minimize the I_{CQ} but leave some margin. Let's choose, $R_E = 2R_L = 200\Omega$

$$V_E = 3.1V; \; I_{CQ} = 15.5mA$$

$$I_{CQ} = \frac{V_{CC} - 0.7 - V_E}{R_B} \times \beta \Rightarrow R_B = 7.7k\Omega$$

Sol 5(a).

$$V_E \geq V_o \times \left(1 + \frac{R_E}{R_L}\right) = 2 + \frac{2R_E}{R_L}; \; V_E \leq V_{CC} - V_{BE} - V_O = 2.3V$$

$$2 + \frac{R_E}{R_L} \leq V_E \leq V_{CC} - V_{BE} - V_O = 2.3V \implies R_E \leq 0.15 * R_L$$

$$I_{CQ} = \frac{V_E}{R_E} \geq \frac{2}{R_E} + \frac{2}{R_L}$$

Choose R_E to be large to minimize the I_{CQ} but leave some margin. Let's choose, $R_E = 0.1R_L = 10\Omega$

$$V_E = 2.25V; \; I_{CQ} = 225mA \; (very\ large)$$

$$I_{CQ} = \frac{V_{CC} - 0.7 - V_E}{R_B} \times \beta \Rightarrow R_B = 0.9k\Omega$$