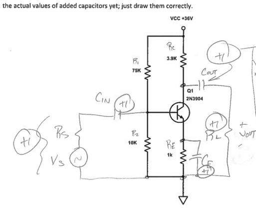
BME-ISE 3512 • Exam V • 12 April 2019 NAME SOLUTION

Determine the D.C. operating point of the following circuit (I_C and V_{CE}) if base current may be assumed negligible. Check P_{diss} and verify that the transistor is operating in the active region. Draw additional components on the circuit to create a common-emitter voltage amplifier with a source resistance of 600 Ω and a load resistance of 25 kΩ. Don't worry about the actual values of added capacitors yet; just draw them correctly.



$V_{BE} = 0.7V$
$V_{CE} > 0.2V$
positive I
✓ yes, active region (+1)

$$V_B = V_{CC}\left[\frac{R_2}{R_1+R_2}\right] = 36\left[\frac{10k}{10k+75k}\right] = 4.235\ V \quad (+1)$$

$V_{BE} = 0.7V$ (Si NPN) (+1)

$\therefore V_E = 4.235 - 0.7 = 3.535\ V$ (+2)

$I_E = \frac{3.535}{1k} = 3.535\ mA$ (+1)

high-β → $I_C = 3.535\ mA$ (+1)

$V_C = V_{CC} - I_C R_C = 36 - 3.535 \cdot 3.9 = 22.21\ V$ (+1)

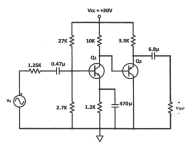
$V_{CE} = V_C - V_E = 22.21 - 3.535$

$V_{CE} = 18.68\ V$

$P_{diss} = I_C \cdot V_{CE} = 3.535 \cdot 18.68 = 66.02\ mW$ (+1)

EE 3310/3510 • Exam II • 5 October 2022 43 pts. NAME SOLUTION

1) Refer to the following circuit:



Which type of transistor is Q_1 (NPN or PNP), and in what amplifier configuration is it used (common-emitter, common-base, or common-collector)?

NPN (+1)

Common-emitter (+1)

Please answer the same questions for Q_2.

PNP (+1)

Common-collector (+1)

Determine V_{B1}, V_{E1}, I_{E1}, I_{C1}, V_{C1}, and V_{CE1} if base current may be assumed negligible due to high β. Check P_{diss1} and verify that the transistor is operating in the active region.

$V_{B_1} = 30\left[\frac{2.7}{2.7+27}\right] = 2.724\ V$ (+2)

$V_{E_1} = V_{B_1} - 0.7 = 2.027\ V$ (+1) NPN

$I_{E_1} = \frac{V_{E_1}}{R_{E_1}} = \frac{2.027}{1.2k} = 1.689\ mA$ (+2)

high-β → $I_{C_1} \sim 1.689\ mA$ (+1)

$V_{C_1} = V_{CC} - I_{C_1}R_{C_1} = 30 - 1.689 \cdot 10$

$V_{C_1} = 13.11\ V$ (+2)

$V_{CE_1} = V_{C_1} - V_{E_1} = 11.08\ V$ (+1)

$> 0.2V$; yes active region (+1)

$P_{diss_1} = V_{CE_1} \cdot I_{C_1} = 11.08 \cdot 1.689 = 18.71\ mW$ (+2)

Now determine V_{B2}, V_{E2}, I_{E2}, I_{C2}, V_{C2}, V_{CE2}, P_{diss2}, and verify active region under the same high-β assumption.

$V_{B_2} = V_{C_1} = 13.11\ V$ (+1)

$V_{E_2} = V_{B_2} + 0.7 = 13.81\ V$ (+1) PNP

$I_{E_2} = \frac{V_{CC} - V_{E_2}}{R_{E_2}} = \frac{30 - 13.81}{3.3k}$

$I_{E_2} = 4.906\ mA$ (+2)

$\therefore I_{C_2} \cong 4.906\ mA$ (+1)

$V_{C_2} = 0$ (ground) (+1)

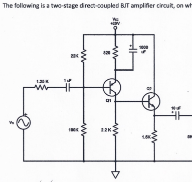
$V_{CE_2} = V_{C_2} - V_{E_2} = 0 - 13.81 = -13.81$ (+1)

$|-13.81| > 0.2V$; yes, active (+1)

$P_{diss_2} = |V_{CE_2}|\ I_{C_2} = 13.81 \cdot 4.906 = 67.75\ mW$ (+2)

BME-ISE 3512 • Exam V • Due 14 April 2021 60 pts. NAME SOLUTION

The following is a two-stage direct-coupled BJT amplifier circuit, on which we will perform full DC and AC analyses.



Which type of transistor is Q_2, and in what amplifier configuration is it being used?

PNP (+1)

Common-emitter (+1)

$P_{diss} = |V_{CE}| \cdot I_C = 9.283 \cdot 3.549 = 32.94\ mW$ (+2)

Determine V_{B1}, V_{E1}, I_{C1}, V_{C1}, and V_{CE1} if base current may be assumed negligible due to high β. Check P_{diss1} and verify that the transistor is operating in the active region.

$V_{B_1} = 20\left[\frac{100k}{100k+22k}\right] = 16.39\ V$ (+2)

$V_{BE_1} = -0.7V$ (PNP)

$\therefore V_{E_1} = V_{B_1} - V_{BE_1} = 16.39 - -0.7 = 17.09\ V$ (+2)

$I_{C_1} = \frac{V_{CC} - V_{E_1}}{R_{E_1}} = \frac{20 - 17.09}{820} = 0.003549$

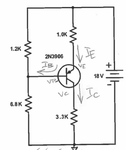
$\therefore I_{E_1} \cong I_{C_1} = 3.549\ mA$ (+2)

$V_{C_1} = I_{C_1} \cdot R_{C_1} = 3.549 \cdot 2.2 = 7.807\ V$ (+2)

$V_{CE_1} = V_{C_1} - V_{E_1} = 7.807 - 17.09 = -9.283\ V$ (+2) yes, active (+1)

BME-ISE 3512 • Exam V • 6 April 2018 NAME SOLUTION

1) Refer to the following circuit:



Compute V_B, V_C, V_E, V_{BE}, V_{CE}, I_B, I_C, I_E, and P_{diss} if β = 250. Compute V_B assuming base current is small compared to the current in the biasing resistors. Also verify that the transistor is operating in the active region.

$V_B = 18\left[\frac{6.8}{1.2+6.8}\right] = 15.3\ V$ (+2)

$V_{BE(ON)} = -0.7V$ (PNP) (+1)

$\therefore V_E = V_B - V_{BE}$ (+1)

$= 15.3 - -0.7 = 16V$ (+1)

$I_E = \frac{18 - V_E}{1k} = \frac{18-16}{1k} = 2\ mA$ (+1)

$I_B = \frac{I_E}{\beta+1} = \frac{2\ mA}{250+1} = 0.008\ mA$ or $8\ \mu A$ (+1)

$I_C \approx I_E$ (+1) ok to compute from I_C instead

$V_C \cong I_C \cdot 3.3k = 6.6V$ (+2)

$V_{CE} = V_C - V_E = 6.6 - 16 = -9.4\ V$ (+2) ← yes, active region (+1)

$P_{diss} = V_{CE} \cdot I_C = 9.4 \cdot 2 = 18.8\ mW$ (+2)

Determine the high-frequency input and output capacitances using Miller's Theorem if C_{BC} = 6 pF and C_{BE} = 22 pF. Compute the input and output HF cutoff frequencies and the approximate overall high-frequency cutoff, f_H.

$C_{BC(IN)} = C_{BC}(1 - A_V)$ (+1) eqn

$= 6 \cdot (1 - -246.9)$

$= 1487\ pF$ (+1)

$C_{BC(OUT)} = C_{BC}\left(1 - \frac{1}{A_V}\right) \approx C_{BC}$

$= 6\ pF$ (+1)

$\therefore C_{IN(HF)} = C_{BC(IN)} + C_{BE}$

$= 1487 + 22$

$= 1509\ pF$ (+1)

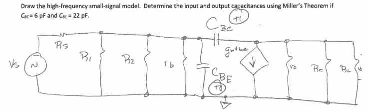
$f_{H(IN)} = \frac{1}{2\pi \cdot C_{IN}(R_b' \| R_S)} = \frac{1}{2\pi \cdot 1509 \times 10^{-12}(1.644k \| 600)} = 240\ kHz$ (+1) $= 440\ \Omega$

$C_{OUT(HF)} = 6\ pF$ (+1)

$f_{H(OUT)} = \frac{1}{2\pi\ C_{OUT} \cdot r_o \| R_C \| R_L} = \frac{1}{2\pi \cdot 6 \times 10^{-12} \cdot 2.724k} = 9.7\ MHz$ (+1)

$f_H \approx 240\ kHz$ (+1) (dominant pole; > 5x separation)

Draw the high-frequency small-signal model. Determine the input and output capacitances using Miller's Theorem if C_{BC} = 6 pF and C_{BE} = 22 pF.



$C_{BC(IN)} = C_{BC}(1 - A_V) = 6 \cdot (1 - -93) = 564\ pF$ (+1)

$\therefore C_{IN} = C_{BC(IN)} + C_{BE} = 564 + 22 = 586\ pF$ (+1)

$C_{OUT} = C_{BC(OUT)} = C_{BC}\left(1 - \frac{1}{A_V}\right) \cong 6\ pF$ (+1)

Compute the input and output HF cutoff frequencies and the approximate overall high-frequency cutoff, f_H.

$f_{H(IN)} = \frac{1}{2\pi \cdot C_{IN}(R_S \| R_1 \| R_2 \| r_b)}$ (+1) $= .762k \| 1k = 432\ \Omega$ (+1)

$= \frac{1}{2\pi \cdot 586 \times 10^{-12} \cdot 432}$

$f_{H(IN)} = 628.7\ kHz$ (+1)

$f_{H(OUT)} = \frac{1}{2\pi \cdot C_{OUT}(r_o \| R_C \| R_L)}$ (+1)

$f_{H(OUT)} = \frac{1}{2\pi \cdot 6 \times 10^{-12} \cdot .762k}$

$f_{H(OUT)} = 34.8\ MHz$ (+1)

$f_{H(IN)} \lll f_{H(OUT)}$

$\therefore f_{H(IN)}$ dominates (+1)

$f_H \approx 628.7\ kHz$ (+1)

Determine the mid-frequency gain A_V and A_V(dB). [struck-out text]

input network:

$R_b' = R_1 \| R_2 \| r_b = 10k \| 75k \| 2.021k = 1.644k$ (+1) (+1)

$v_{be} = V_S\left[\frac{R_b'}{R_b' + R_{IN}}\right] = V_S\left[\frac{1.644}{0.6 + 1.644}\right] = 0.7327\ V_S$ (+1)

output network:

$R_C' = r_o \| R_C \| R_L = 14.14k \| 3.9k \| 25k = 2.724k$ (+1)

$V_{OUT} = -g_m v_{be} \cdot R_C'$ (+1)

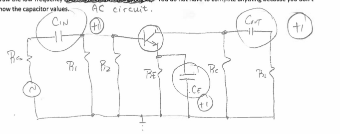
$= -123.7 \cdot 0.7327 V_S \cdot 2.724$

$V_{OUT} = -246.9\ V_S$

$A_V = -246.9$ (+1) or $+47.85\ dB$ (+1), inverting (+1)

Draw the low-frequency [struck-out text]. You do not have to compute anything because you don't know the capacitor values.

AC circuit.



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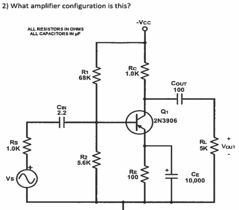
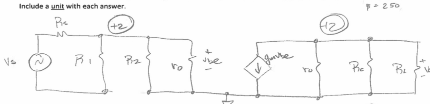
2) What amplifier configuration is this?

common-emitter (+1)



Draw the mid-frequency small-signal model. Calculate the dynamic parameters g_m, r_b, and r_o if I_C = 8 mA and $|V_A|$ = 80 V. Include a unit with each answer. β = 250



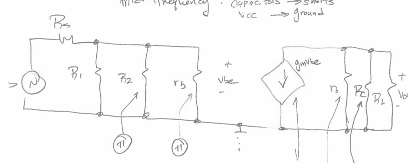
$g_m = 35\ I_C$ (+1) eqn. $= 35 \cdot 8 = 280\ mA/V$ (+1) unit

$r_b = \frac{\beta}{g_m}$ (+1) eqn. $= \frac{250}{280} = 0.893\ k\Omega$ (+1) unit

$r_o = \frac{|V_A|}{I_C}$ (+1) eqn. $= \frac{80}{8} = 10\ k\Omega$

Draw the mid-frequency AC small-signal model of the amplifier. Calculate the parameters g_m, r_b, and r_o if β = 250. and $|V_A|$ = 50V. Include a unit with each answer.

mid-frequency ∴ capacitors → shorts, Vcc → ground



$g_m = 35\ I_C$ (Ebers/Moll) (+1) eqn

$= 35 \cdot 3.535$

$g_m = 123.7\ mA/V$ (+1) unit

$r_b = \frac{\beta}{g_m}$ (+1) eqn $= \frac{250}{123.7} = 2.021\ k\Omega$ (+1) unit

$r_o = \frac{|V_A|}{I_C}$ (+1) eqn

$= \frac{50}{3.535} = 14.14\ k\Omega$ (+1) unit

Determine the high-frequency input capacitance using Miller's Theorem if C_{BC} = 4.0 pF and C_{BE} = 10 pF. Use it to compute the input HF cutoff frequency. You do not have to compute the output capacitance or cutoff frequency.

$$C_{BC(IN)}' = C_{BC}(1 - A_{V2})$$
$$= 4(1 - {-23.31}) = 97.24 \text{ pF} \quad (+2)$$

$$\therefore f_H = \frac{1}{2\pi \cdot C_{BC(IN)}' \cdot (R_S \| R_{IN}')} = \frac{1}{2\pi \cdot 97.24p \cdot (100k \| 30.39k)}$$
$= 23.3k$ (+1)

$$f_H = 70.25 \text{ kHz} \quad (+2)$$

Compute the LF cutoff frequencies due to the input and output capacitors.

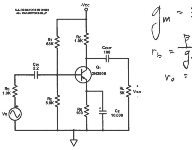
$$f_{C\,IN}' = \frac{1}{2\pi C_{IN}(R_S + R_{IN}')} = \frac{1}{2\pi \cdot 100n\,(100k + 30.39k)}$$

$$f_{C\,IN}' = 12.2 \text{ Hz} \quad (+2)$$

$$f_{C\,OUT}' = \frac{1}{2\pi C_{OUT}(R_C + R_L)} = \frac{1}{2\pi \cdot 100n\,(10k + 100k)}$$

$$f_{C\,OUT}' = 14.47 \text{ Hz} \quad (+2)$$

2) A silicon PNP transistor is used in a common-emitter amplifier configuration. Collector current is known to be 2.4 mA and the transistor has an Early voltage of 220 V and beta 320. Calculate the parameters g_m, r_b, and r_o.



$$g_m = 35 I_C = 35 \cdot 2.4 = 84 \frac{\text{mA}}{\text{V}} \quad (+2)$$

$$r_b = \frac{\beta}{g_m} = \frac{320}{84} = 3.81 \text{ k}\Omega \quad (+2)$$

$$r_o = \frac{|V_A|}{I_C} = \frac{220}{2.4} = 91.67 \text{ k}\Omega \quad (+2)$$

Determine the mid-frequency small-signal gains A_{V1} and A_{V2} and the overall gain of the amplifier in dB.

$$R_b' = r_b \| R_1 \| R_2 = 3.81 \| 5.6 \| 68 = 2.194 \text{ k}\Omega \quad (+1)$$

$$A_{V1} = \frac{V_{be}}{V_S} = \frac{R_b'}{R_b' + R_S} = \frac{2.194}{2.194 + 1} = 0.6869 \quad (+2)$$
or -3.3 dB

$$A_{V2} = \frac{V_{OUT}}{V_{be}} = -g_m (r_o \| R_C \| R_L) = -84\,(91.67 \| 1 \| 5) = -69.37 \quad (+2)$$
$\hookrightarrow = .8258k$ (+1)
or $+36.8$ dB

overall midband gain : $-3.3 + 36.8 = 33.5$ dB (inverting) (+1)

Determine the high-frequency input capacitance using Miller's Theorem if C_{BC} = 4.5 pF and C_{BE} = 12 pF. Use it to compute the input HF cutoff frequency. You do not have to compute the output capacitance or cutoff frequency.

Miller Time!

$$C_{BC(IN)} = C_{BC}(1 - A_{V2}) = 4.5(1 - {-69.37}) = 316.7 \text{ pF} \quad (+2)$$

$$C_{IN} = C_{BC(IN)} + C_{BE} = 316.7 + 12 = 328.7 \text{ pF} \quad (+1)$$

$$f_{H(IN)} = \frac{1}{2\pi\, C_{IN} \cdot R_b' \| R_S} = \frac{1}{2\pi \cdot 328.7 \times 10^{-12}\,(1k \| 2.194k)}$$
$\hookrightarrow 686.9\,\Omega$

$$f_{H(IN)} = 704.9 \text{ kHz} \quad (+2)$$

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Determine the LF cutoff frequency caused by the output capacitor. Hint: we know the output resistance of the amplifier, so we can compute the resistance "seen" by C_{OUT}. Finally, determine the approximate overall cutoff frequency f_L.

$$g_{m2} = 35\, I_{C2} = 35 \cdot 4.738$$
$\approx I_{E2}$

$$= 165.8 \text{ mA/V} \quad (+1)$$

$$\therefore R_{OUT} \approx \frac{1}{g_{m2}} = \frac{1}{165.8 \times 10^{-3}} = 6.030\,\Omega \quad (+1)$$

$$R_{C(OUT)} = R_{OUT} + R_L = 6.030 + 5k \approx 5k \quad (+1)$$

$$\therefore f_{L(OUT)} = \frac{1}{2\pi \cdot C_{OUT} \cdot R_{C(OUT)}} = \frac{1}{2\pi \cdot 10 \times 10^{-6} \cdot 5k}$$

$$f_{L(OUT)} = 3.183 \text{ Hz} \quad (+2)$$

not 5x !

f_L dominated by $f_{C(IN)}$ [eh, maybe ...]

$\therefore f_L \approx$ 47-ish Hz (+2)

(in reality a little higher)

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Compute the three LF cutoff frequencies and the approximate overall low-frequency cutoff, f_L.

$$R_{CE} = \frac{1}{g_m} \| R_E = \frac{1}{67m} \| 332 = 14.28\,\Omega \quad (+1)$$

$$f_{CE} = \frac{1}{2\pi \cdot 14.28 \cdot 1000 \times 10^{-6}} = 11.14 \text{ Hz} \quad (+1)$$

$$R_{C\,OUT} = R_L + (R_C \| r_o) = 10k + (4.75k \| 130.6k)$$
$$= 14.58k \quad (+1)$$

$$f_{C\,OUT} = \frac{1}{2\pi \cdot 14.58k \cdot 10\mu} = 1.091 \text{ Hz} \quad (+1)$$

$$R_{C\,IN} = R_S + R_b' = .04938k + 1.520k = 1.569k \quad (+1)$$

$$f_{C\,IN} = \frac{1}{2\pi \cdot 1 \times 10^{-6} \cdot 1.569k} = 101.4 \text{ Hz} \quad (+1)$$

= dominant pole; $f_L \approx 101.4$ Hz (+1)

Determine the high-frequency input capacitance using Miller's Theorem if C_{BC1} = 5.0 pF and C_{BE1} = 22 pF. Use it to compute the input HF cutoff frequency. You do not have to compute the output capacitance or cutoff frequency.

$$C_{BC(IN)} = C_{BC_1}(1 - A_{V_2}) = 5 \times 10^{-12}(1 - {-253.5})$$
$$= 1273 \text{ pF} \quad (+1)$$

$$f_{H(IN)} = \frac{1}{2\pi\,(C_{BE_1} + C_{BC(IN)})\,(R_S \| R_b')}$$
$\Downarrow$ 22 p, $\Downarrow$ 1273 p, $\Rightarrow = 1250 \| 2130 = 787.7\,\Omega$

$$f_{H(IN)} = 156.0 \text{ kHz} \quad (+2)$$

Compute the LF cutoff frequencies due to the input and emitter capacitors.

$$f_{C\,IN} = \frac{1}{2\pi\, C_{IN}\,(R_S + R_b')} = \frac{1}{2\pi \cdot 1 \times 10^{-6}\,(1.25k + 2.130k)}$$

$$f_{C\,IN} = 47.09 \text{ Hz} \quad (+2)$$

no penalty if R_E is included !

$$R_{CE} \approx \frac{1}{g_m} = \frac{1}{124.2 \times 10^{-3}} = 8.052\,\Omega \quad (+1)$$

$$f_{CE} = \frac{1}{2\pi \cdot C_E \cdot R_{CE}} = \frac{1}{2\pi \cdot 1000 \times 10^{-6} \cdot 8.052}$$

$$f_{CE} = 19.77 \text{ Hz} \quad (+2)$$

Determine the mid-frequency gain A_V and A_V(dB).

$$r_b' = 46.4k \| 3.32k \| 2.985k$$
$$= 1.520k \quad (+1)$$

$$R_S = 4.75k \| 49.9 = 0.04938\,k \quad (+1)$$

$$\therefore V_{be} = V_S \left(\frac{1.520}{1.520 + 0.04938}\right) = 0.9685\,V_S \quad (+1)$$

$$R_C' = 130.6k \| 4.75k \| 10k = 3.143k \quad (+1)$$

$$V_{OUT} = -g_m V_{be} R_C' = -67 \cdot 0.9685 V_S \cdot 3.143k$$

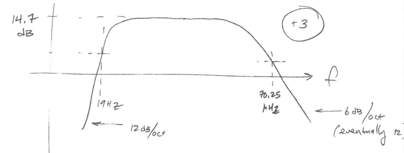
$$A_V = \frac{V_{OUT}}{V_S} = -203.9 \quad (+1)$$

or 46.2 dB inverting (+1)

Finally, determine the approximate overall cutoff frequency f_L and sketch the overall magnitude response of the Electro Harmonix LPB-1.

$$f_L \overset{N}{=} \sqrt{12.2^2 + 14.47^2}$$

$$= 18.93 \text{ Hz} \quad (+1)$$



What type of transistor is Q_2, and in what amplifier configuration is it being used?

NPN (+1)

common-collector / emitter follower (+1)

Determine V_{B2}, V_{E2}, I_{E2}, [redacted], and V_{CE2} if base current may be assumed negligible due to high β. Check P_{diss2} and verify that the transistor is operating in the active region. Note: we already know V_{B2} due to the direct-coupled connection to Q_1. Also determine g_{m2}.

$$V_{B2} = V_{C_1} = 7.807\text{V} \quad (+1)$$

$$V_{BE2} = 0.7\text{V} \quad (\text{NPN})$$

$$V_{E2} = V_{B2} - V_{BE2} = 7.807 - 0.7 = 7.107 \quad (+2)$$

$$I_{E2} = \frac{V_{E2}}{R_{E2}} = \frac{7.107}{1.5k} = 4.738 \text{ mA} \quad (+2)$$

$$V_{CE2} = V_{C2} - V_{E2} = 20 - 7.107 = 12.89 \text{ V} \quad (+2)$$
$\Downarrow$ $= V_{CC}$; yes, active (+1)

$$P_{diss2} = I_{E2} \cdot V_{CE2} = 4.738 \cdot 12.89 = 61.09 \text{ mW} \quad (+2)$$

Calculate the parameters g_m, r_b, and r_o if β = 200 and the Early voltage $|V_A|$ is 250 V. Include a unit with each ansv

$$g_m = 35 I_C = 35 \cdot 1.914 = 67 \text{ mA/V} \quad (+2)$$

$$r_b = \frac{\beta}{g_m} = \frac{200}{67} = 2.985 \text{ k}\Omega \quad (+2)$$

$$r_o = \frac{|V_A|}{I_C} = \frac{250}{1.914} = 130.6 \text{ k}\Omega \quad (+2)$$