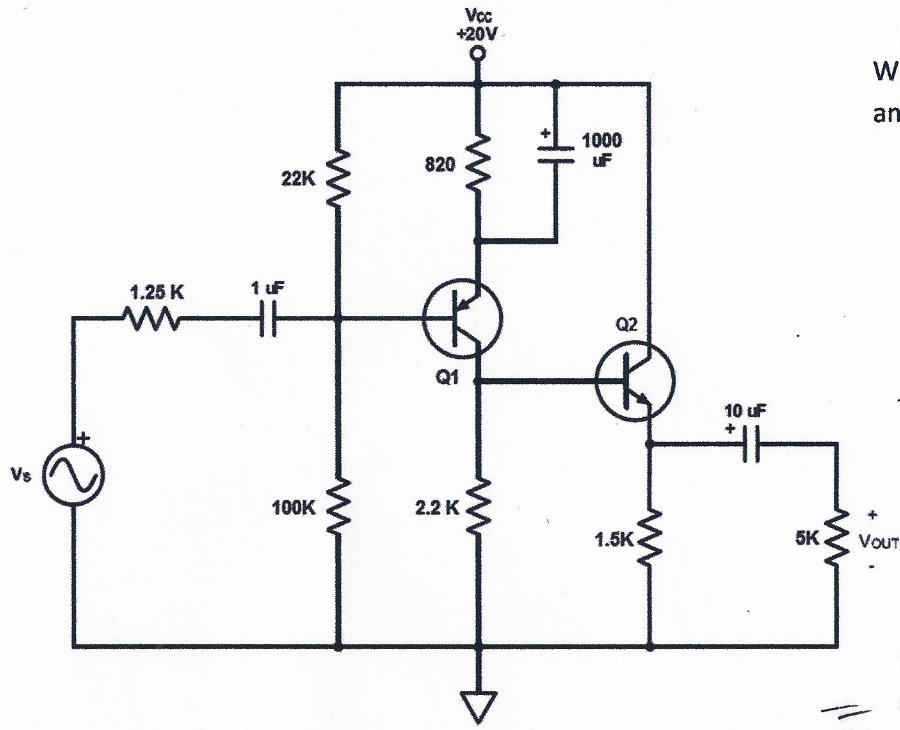
60 pts.

BME-ISE 3512 • Exam V • Due 14 April 2021 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_1, 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.

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

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

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

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

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

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

yes, active (+1)

$$V_{CE_1} = V_{C_1} - V_{E_1} = 7.807 - 17.09 = -9.283 \text{ V} \quad (+2)$$

15

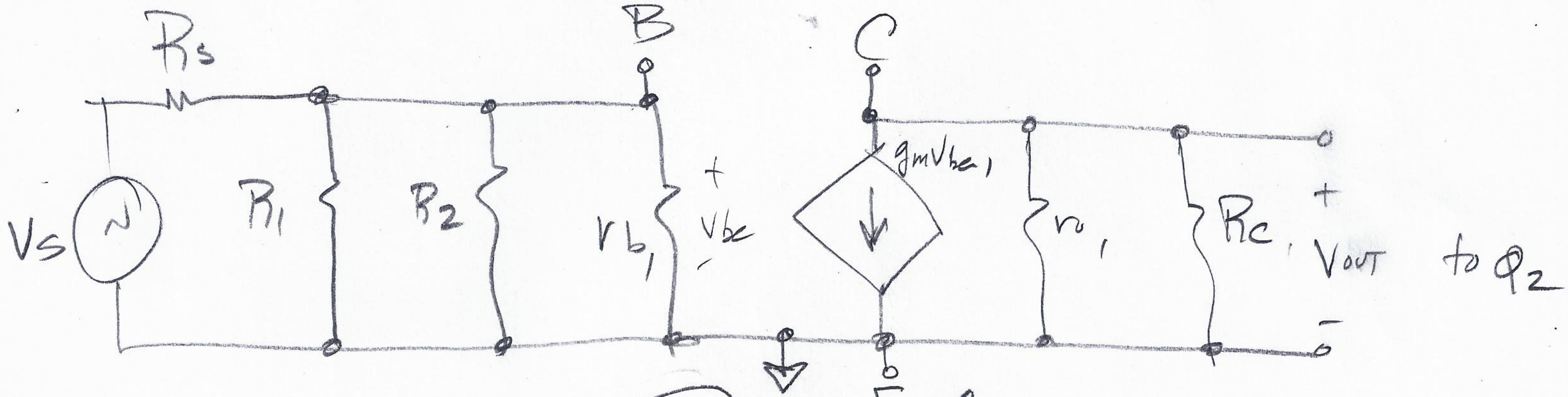
Calculate the parameters g_{m1}, r_{b1}, and r_{o1} if $\beta = 300$ and the Early voltage $|V_A|$ is 100 V. Include a <u>unit</u> with each answer.

$$g_{m_1} = 35\, I_C = 35 \cdot 3.549 = 124.2 \ \text{mA/V}$$ +2

$$r_{b_1} = \frac{\beta}{g_m} = \frac{300}{124.2} = 2.415 \ \text{k}\Omega$$ +2

$$r_{o_1} = \frac{|V_A|}{I_C} = \frac{100}{3.549} = 28.18 \ \text{k}\Omega$$ +2

Draw the mid-frequency AC small-signal model for amplifier section pertaining to Q_1. Hint: due to the circuit configuration, R_L is no longer part of the first amplifier stage.



+2 (-1 if R_L is included)

Compute the input and output transfers A_{V1} and A_{V2} and use them to determine the overall mid-frequency gain A_V(dB).

$$R_b' = R_1 \| R_2 \| r_{b_1} = 22k \| 100k \| 2.415k = 2.130 \ \text{k}\Omega$$ +2

$$A_{V_1} = \frac{R_b'}{R_b' + R_s} = \frac{2.130}{2.130 + 1.25} = 0.6302$$ +2

$$A_{V_2} = -g_{m_1} \cdot (r_{o_1} \| R_c) = -124.2\,(\underbrace{28.18k \| 2.2k}_{2.041k}) = -253.5$$ +2

$$A_V = 0.6302 \cdot -253.5 = -159.7$$ +2

$\Rightarrow$ 44 dB inverting +2

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.

$$C_{BC(IN)} = C_{BC_1}(1 - A_{v_2}) = 5 \times 10^{-12}(1 - {}^{-}253.5)$$

$$= 1273 \text{ pF} \quad +1$$

$$f_{H(IN)} = \frac{1}{2\pi\,(C_{BE_1} + C_{BC(IN)})\,(R_S \parallel R_b')}$$

$C_{BE_1} \Rightarrow 22\text{p}$, $C_{BC(IN)} \Rightarrow 1273\text{p}$, $R_S \parallel R_b' \Rightarrow = 1250 \parallel 2130 = 787.7\,\Omega$

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

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

$$f_{C\,IN} = \frac{1}{2\pi\, C_{IN}\,(R_S + R_{b_1}')} = \frac{1}{2\pi \cdot 1 \times 10^{-6}(1.25k + 2.130k)}$$

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

no penalty if R_E is included

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

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

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

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}.

$$V_{B2} = V_{C_1} = 7.807\,V \quad +1$$

$$V_{BE_2} = 0.7\,V \quad (NPN)$$

$$V_{E_2} = V_{B_2} - V_{BE_2} = 7.807 - 0.7 = 7.107 \quad +2$$

$$I_{E_2} = \frac{V_{E2}}{R_{E2}} = \frac{7.107}{1.5k} = 4.738\ mA \quad +2$$

$$V_{CE_2} = \underbrace{V_{C_2}}_{=V_{CC}} - V_{E2} = 20 - 7.107 = 12.89\ V \quad +2$$

yes, active +1

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

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.

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

$$= 165.8 \text{ mA/V}$$

(+1)

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

(+1)

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

(+1)

$$\therefore f_{L(OUT)} = \frac{1}{2\pi \cdot C_{OUT} \cdot R_{C(OUT)}} = \frac{1}{2\pi \cdot 10\times10^{-6} \cdot 5k}$$

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

(+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)