Information and Instructions

1. Attempt all questions.
2. Show all analyses.
3. The exam marks total 77.
4. Unless otherwise specified, use only the simplified hybrid-pi model for the BJT, i.e.,
take $r_x = 0$, $r_o = \infty$, and $r_{\mu} = \infty$.

Useful Formulas

\[ r_x = \frac{\beta}{g_m}, \quad r_o = (\beta + 1) r_e, \quad \alpha = \beta / (\beta + 1), \quad g_m = I_C / V_T, \quad V_T = 25 mV @ 20^\circ C \]

\[ |\text{forward-biased } V_{BE}| = 0.7 \text{ volts} \]

\[ \omega_L \approx \omega_{L1} + \omega_{L2} + \ldots \]

\[ \frac{1}{\omega_H} \approx \frac{1}{\omega_{H1}} + \frac{1}{\omega_{H2}} \]

Miller's Theorem: $Y_1 = Y(1 - v_2/v_1)$, $Y_2 = Y(1 - v_1/v_2)$
Question 1 (Total 13 marks)

1 mark a) Draw the complete hybrid $\pi$ model of a BJT including $g_m, r_\pi, r_\mu, r_o, C_\pi$, $C_\mu$ and $r_x$.

2 mark b) Given $I_c = 1.25\,mA$, calculate the BJT transconductance $g_m$. Given $\beta = 100$, compute $r_\pi$.

3 marks c) Draw the circuit diagram of
   i) common emitter
   ii) common collector
   iii) common base
amplifiers by adding coupling and bypass capacitors to the bias scheme in Figure 1. Label $V_{in}$ and $V_{out}$ in the diagram.

![Figure 1]

3 marks d) State one major disadvantage and on major (relative) advantage of each of the following power amplifier configurations
   i) class A amplifier
   ii) class B amplifier
   iii) class C amplifier

4 marks e) A power BJT needs to dissipate up to $150\,W$ of power at room (ambient) temperature of $25^\circ C$. The maximum allowed junction temperature is $200^\circ C$. The junction to case thermal resistance is $\theta_{JC} = 0.4\,^\circ C/W$. What is the maximum allowable thermal resistance between case and ambient, i.e., $\theta_{CA} =$ ?
Question 2 (Total 24 marks)

Analyze the amplifier circuit in Figure 2 using appropriate and simplified models, to find general expressions (i.e. without component values unless specifically asked for).

![Amplifier Circuit Diagram]

Figure 2

3 marks  a) Draw the mid-band small signal equivalent circuit.

2 marks  b) Determine the mid-band input resistance $R_{in}$.

7 marks  c) Determine the mid-band gain $A_v = \frac{v_o}{v_s}$.

3 marks  d) Determine the mid-band $R_{out}$. Include $r_{02}$. Ignore $r_{01}$, $r_{\mu 1}$ and $r_{\mu 2}$.

4 marks  e) Determine the low frequency poles (i.e. $\omega_L$'s) for $C_1$ and $C_2$ only.

5 marks  f) Determine the high frequency poles (i.e. $\omega_H$'s). Assume that $R_4$ is shorted to ground at high frequencies in order to simplify calculations. Include $C_{\pi}$ and $C_{\mu}$ for both transistors.
Question 3 (Total 13 marks)

In this question:

i) All analysis to be performed at midband frequencies

ii) All transistors are matched and all $\beta$'s = 100.

iii) $R_s$, $r_o$ and $r_\mu$ may be ignored.

8 marks

a) Analyze the op amp shown in Figure 3, including $R_L$ to find general expressions (i.e., without component values) for

i) $R_{idm}$

ii) $R_{icm}$

iii) $A_{dm}$

3 marks

b) Use a current mirror to replace the current source $I_0$ (and its impedance $R_o$) such that the transistors $Q_1$ and $Q_2$ are biased at $I_{C1} = I_{C2} = 2mA$. Redraw the circuit including the new current mirror, $Q_1$-$Q_4$ and $R_L$.

2 marks
c) Find the common mode input swing range $V_{cm(max)}$ and $V_{cm(min)}$ for the amplifier in b)
Question 4 (Total 18 marks)

7 marks  a) Derive the voltage transfer function, $\frac{V_o(s)}{V_i(s)}$, of the high pass filter circuit shown in Figure 4.

![Figure 4](image)

4 marks  b) For the filter transfer function

$$\frac{V_o(s)}{V_i(s)} = \frac{K}{R_1 R_2 C_1 C_2 s^2 + (R_2 C_2 + R_1 C_2 + (1 - K) R_1 C_1) s + 1}$$

i) find the expression for $H_0$, $\omega_0$ and Q.

ii) Assume $R_1 C_1 = R_2 C_2$, and $R_1 = 25 \, \text{k}\Omega$. Find suitable component values ($K$, $R_1$, $C_1$, $R_2$, $C_2$) to make $H_0 = 2$, $\omega_0 = 4000 \, \text{Rad/second}$ and $Q = 2.5$.

2 marks  c) Plot the amplitude response of a 2\textsuperscript{nd} order low pass filter, clearly identify $H_0$, $\omega_0$ and Q and the high frequency roll-off rate for 2 cases:

i) case 1: $Q < 1$, ii) case 2: $Q > 1$

1 marks  d) What is the high frequency roll-off rate of a 8\textsuperscript{th} order low pass filter

4 marks  e) Show the form of the 2\textsuperscript{nd} order filter transfer function for each of the 4 cases:

i) low pass filter,  ii) high pass filter,

iii) bandpass filter,  iv) bandstop filter
Question 5 (Total 9 marks)

1 marks a) What is Barkhausen Criteria?

7 marks b) The circuit in Figure 5 can be connected to an op amp non-inverting amplifier of gain K, resulting in an oscillator circuit.

![Oscillator Circuit Diagram]

Figure 5

i) draw the complete oscillator circuit using resistors, capacitors and an op amp.

ii) Write any required conditions for oscillation, and the frequency of oscillation.

1 marks c) show the location of poles in the s-plane (complex frequency domain) for

i) a second order filter with $Q > 0.5$

ii) an oscillator