Information and Instructions:
1. Attempt all questions.
2. Show all analyses.
3. The exam marks total 87.
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

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

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

$$\omega_L = \omega_{L1} + \omega_{L2} + ...$$

$$\frac{1}{\omega_H} \approx \frac{1}{\omega_{H1}} + \frac{1}{\omega_{H2}}$$

Miller's Theorem: $Y_1 = Y(1 - 
\frac{v_2}{v_1}), \quad Y_2 = Y(1 - \frac{v_1}{v_2})$
**Question 1 (Total 23 Marks)**

![Amplifier Circuit Diagram](image)

Figure 1

Analyse the above amplifier circuit using appropriate models, to find generalized expressions (i.e. without component values unless specifically asked for).

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

2 marks b) Determine the mid-band input impedance.

5 marks c) Determine the mid-band gain $v_o/v_i$.

5 marks d) Determine the low frequency poles.

4 marks e) Determine the high frequency poles (consider only $c_{\mu1}$ and $c_{\mu2}$, ignore $c_{\pi1}$ and $c_{\pi2}$).

4 marks f) DC analysis: Calculate resistor values for $R_1$, $R_2$, $R_{C1}$, and $R_{C2}$ such that:

- $I_{C1} = I_{C2} = 1mA$
- $I_{R1} = 10I_{B1}$
- $V_{C2} = 3V$
- $V_{CEQ2} = 3V$

Note: $\beta_1 = \beta_2 = 100$, and $V_{BE1} = V_{EB2} = 0.7V$
Question 2 (Total 17 Marks)

In this question, all transistors are assumed to be matched.

6 marks  a) Quiescent analysis for the opamp show in Figure 2, assuming $V_{CE3} = V_{CE4} = 5.7V$, and voltages at both input terminals are zero at quiescent.
   i) what are the quiescent values of voltages across $R_{C1}$ and $R_{C2}$.
   ii) what is the collector current of transistor $Q2$.
   iii) find the value of resistor $R_A$.

2 marks  b) Draw the small-signal equivalent circuit for the sole purpose of computing the equivalent impedance $R_{EE}$. (Draw the equivalent circuit only. Do not solve it). Include $r_o$ and $r_{\mu}$ in your transistor models.

9 marks  c) Analyze the opamp show in Figure 2, using $R_{EE}$ to replace transistors $Q1$ and $Q2$, to find generalized expressions (i.e., without component values) for

   i) differential mode input resistance $R_{\text{in}}$
   ii) differential mode voltage gain $A_{\text{dm}}$
   iii) common mode input resistance $R_{\text{cm}}$

![Figure 2](image.png)
**Question 3** (Total 14 Marks)

10 marks  a) Derive the voltage transfer function $v_o(s)/v_i(s)$ of the band-pass filter circuit of Figure 3.

![Circuit Diagram](image)

**Figure 3.**

4 marks  b) Consider the transfer function:

$$\frac{v_o(s)}{v_i(s)} = \frac{K}{R_1R_2C_1C_2s^2 + (R_1C_1 + R_2C_1 + (1 - K)R_2C_2)s + 1}$$

Assume $R_1C_1 = R_2C_2$ and $R_2 = 20K\Omega$. Find suitable component values ($K$, $R_1$, $C_1$ and $C_2$) to make $H_0 = 2$, $Q = 4$ and $\omega_0 = 2000$ rad/s.
Question 4 (Total 11 Marks)

8 marks a) For the oscillator circuit in Figure 4, apply Barkhausen criteria to determine the conditions for oscillation and the oscillating frequency, showing necessary derivations.

![Oscillator Circuit Diagram](image)

Figure 4.

3 marks b) For the oscillator in a), find the sensitivity of the oscillating frequency $\omega_0$ with respect to capacitor C, i.e., find $S_{w0}$. 
Question 5 (Total 22 Marks)

12 marks a) Suppose you will design a circuit for each of your 6 clients. The primary objectives for each client are:

client 1: good voltage gain for short-wave radio signals
   (i.e., high-frequency signals, e.g., 15MHz)
client 2: good voltage gain for audio signals (e.g., 0.1 - 10 KHz).
client 3: to send a signal from a source with very-high
   source-impedance to a very-low-impedance load.
client 4: to drive large speakers for professional concerts held in
   mid-summer to large crowds gathered outdoors in a desert.
client 5: to extract low-frequency signals from a signal with mixed
   frequencies using minimum number of components
client 6: a 2nd order low-pass filter with user-adjustable bandwidth
   and user-adjustable Q-factors

From the following list, make ONE best choice for each client. (Choose only from the following list, and only one choice per client).

i) class A power amplifier ii) class B power amplifier
iii) class C power amplifier iv) class AB power amplifier
v) Sallen-Key circuit vi) Tow-Thomas circuit
vii) common emitter (CE) amplifier viii) common base (CB) amplifier
ix) common collector (CC) amplifier
(Hint: remember you always have a competitor in business: so do not complain the client, do not confuse the client, simply give your best choice).

4 marks b) Show locations of the poles in the s-plane of

i) a high-Q 2nd order filter ii) a low-Q 2nd order filter
iii) a 2nd order oscillator circuit iv) an unstable 2nd order circuit

3 marks c) Suppose the 4-resistor bias scheme in Figure 5 is used to design a common

emitter amplifier. There are 5 design criteria: high input impedance, low

output impedance, high gain, high bias stability (e.g., against temperature
change etc), and large output voltage swing range. State which design

criteria is helped and which criteria is sacrificed when the designer increases

i) resistors $R_E$, ii) resistor $R_C$, iii) resistors $R_1$, and $R_2$.

Figure 5:

3 marks d) Sketch the amplitude response (versus frequency) of a 6th order Chebyshev

and a 6th order Butterworth filters, showing responses in passband, at the

edge of pass band and beyond. Indicate the high-frequency roll-off rates.