Information and Instructions:

1. Attempt all questions.
2. Show all analysis.
3. The exam marks total 82.
4. Unless otherwise specified, use only the simplified transistor model for the BJT, i.e., take $r_x=0$, $r_o=\infty$, and $r_\mu=\infty$.

**Useful Formulas**

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

$$g_m = \sqrt{2\mu C_{ox}(\frac{W}{L})I_{DS}}, \quad \Gamma = \frac{Z_L-Z_o}{Z_L+Z_o}, \quad \nabla \times \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t}$$

The average of a half sine wave with amplitude of 1 is $1/\pi$.

$$a = \frac{dv}{dt} = \frac{d^2 x}{dt^2}, \quad Money = Power = VI = I^2 R = \sqrt{Evil}$$

|forward biased $V_{BE}| = 0.7$ Volts

$$\omega_L \approx \omega_{L1} + \omega_{L2} + \omega_{L3} + ... \quad \text{and} \quad \frac{1}{\omega_H} \approx \frac{1}{\omega_{H1}} + \frac{1}{\omega_{H2}} + \frac{1}{\omega_{H3}} + ...$$

Miller’s Theorem: $$Y_1 = Y \left(1 - \frac{V_2}{V_1}\right), \quad Y_2 = Y \left(1 - \frac{V_1}{V_2}\right)$$

Sensitivity: $$S^y_x = \frac{dy}{dx} \cdot \frac{x}{y}$$
Question 1 (Total 14 Marks)

Answer the following questions.

2 marks  (a) A transistor is biased at 10µA, has an early voltage of 100V and β =100. What are the values of $r_e$, $r_π$, $r_o$, and $g_m$?

4 marks  (b) For the class B amplifier shown in figure 1, assuming that you cannot ignore the 0.7V $V_{BE}$ drop in the transistor, and also assuming that the input cannot go above the rails, what is maximum voltage swing possible in this circuit? What is the output power in this case? What is the average current drawn from the supplies? What is the efficiency?

2 marks  (c) A power transistor in a case has a heat sink attached. The junction to case, case to heat sink and heat sink to air thermal resistances are 0.9°C/W, 0.1°C/W, and 1.2°C/W respectively. If the ambient temperature is 25°C and the transistor is dissipating 100W what is the junction temperature?

2 marks  (d) In the s plane, draw the poles for a 2nd order filter, an unstable circuit with growing amplitude, and an unstable circuit with constant amplitude.

4 marks  (e) In a completely fictional transistor the collector current as a function of base emitter voltage is given by $I_C = 10^{-3} \cdot e^{l_e}$ where $l_e$ is the emitter length. What is the $g_m$ of this device?
**Question 2** (Total 22 Marks)

When analyzing the amplifier circuit in Figure 2, use appropriate models, to find generalized expressions (i.e. without component values unless specifically asked for).

4 marks  (a) Draw the small-signal equivalent circuit.

3 marks  (b) Find the mid-band gain $A_v$.

2 marks  (c) Find the mid-band $R_{in}$.

2 marks  (d) Find the mid band $R_{out}$ (include $r_{o1}$, $r_{o2}$ and $r_{\mu2}$).

3 marks  (e) Find the low frequency poles ($\omega_L$’s).

4 marks  (f) Find the high frequency poles ($\omega_H$’s) for the circuit. You may ignore $C_{o2}$.

4 marks  (g) With $V_{CC} = 15V$, $R_3 = 2 \, k\Omega$, determine $R_1$, $R_2$, $R_{C1}$, and $R_{E2}$, such that $I_{C1} = 1mA$ and $I_{C2} = 2mA$ and the voltage on the collector of $Q_1$ is 10V. Set the current through $R_2$ to be 10 times the base current of $Q_1$, (assume $\beta = 100$), but for all other calculations, you may ignore base current.

![Figure 2](image-url)
**Question 3** (Total 18 Marks)

In this question, all transistors are assumed to be matched. Perform the following analysis on the op amp circuit of Figure 3(a). Assume that $r_e = \infty$ for all transistors.

10 marks  
(a) Draw the small signal model and use it to find:
   (i) The differential mode gain $A_{DM}$ with output at $v_x$.
   (ii) The differential mode input impedance $R_{DM}$.
   (iii) The common mode input impedance $R_{CM}$.

5 marks  
(b) With $V_{cc} = 5V$, and $V_{EE} = -5V$
   (i) Design a current mirror to replace the current source $I_0$ (and its impedance $R_0$). Calculate the required value of $R_{Bias}$ (at the input of the current mirror to ground) such that $I_{C1} = I_{C2} = 250 \ \mu A$. Redraw the circuit to show the current mirror, $Q_1$, $Q_2$, $Q_3$, $Q_4$, and $R_x$.
   (ii) Find the minimum and maximum input common-mode voltage $v_{icm,Min}$ and $v_{icm,Max}$.

3 marks  
(c) Now consider Figure 3(b) which shows the resistor $R_x$ replaced with a class AB output stage.
   (i) Determine the value of $R_E$ such that the output transistors $Q_5$ and $Q_6$ are biased at $I_{C5} = I_{C6} = 4 mA$.
   (ii) Determine the voltage $v_x$ when the output voltage is 0 V.
Question 4 (Total 17 Marks)

8 marks (a) Derive the transfer function \( \frac{v_{out}(s)}{v_{in}(s)} \) of the circuit shown in Figure 4.

\[ R(s) = \frac{1}{s^2 + 2s + 1} \]

9 marks (b) Consider the following circuit:

Where the voltage transfer functions for each of the boxes is \( v_1/v_{in} = R(s) \) and \( v_2/v_{in} = S(s) \) respectively. Sketch each of these two transfer functions (include corner frequency gains, Qs, and gain in flat regions, and drop off rates), and then sketch in a reasonable amount of detail the overall magnitude response \( v_{out}/v_{in} \) of the circuit.
Question 5 (Total 11 Marks)

7 marks (a) For the oscillator shown in Figure 6, apply Barkhausen criteria to find the oscillating frequency showing any necessary derivation. Then find out what is the necessary value of $K$ to start the oscillator.

![Oscillator Diagram]

4 marks (b) The opamps used above are powered from $\pm15V$ supplies. How big would you expect the oscillator output to get assuming that the zener diodes each have a reverse breakdown of $5V$? What is the change in the loop gain when the zener diodes become active?