DURATION 3 HOURS

Department Name & Course Number: Electronics ELEC 3509 A and ELEC 3509 B
Course Instructor(s): Prof. Q. J. Zhang and Prof. Calvin Plett

Students MUST count the number of pages in this examination question paper before beginning to write, and report any discrepancy immediately to a proctor. This question paper has 6 pages.

This examination question paper MAY be taken from the examination room.

Information and Instructions:

1. Attempt all questions.
2. Show all analysis.
3. The exam marks total 90.
4. Unless otherwise specified, use only the simplified transistor model for the BJT, i.e., take $r_x=0$, $r_o=\infty$, and $r_\mu=\infty$.

Possibly Useful Formulas

$$I_c = I_s e^{V_{BE}/V_T}, \quad r_x = \frac{\beta}{g_m}, \quad r_o = (\beta+1)r_x, \quad \alpha = \frac{\beta}{\beta+1}, \quad g_m = \frac{I_c}{V_T}, \quad V_T = 25mV \ @ \ 20^\circ C$$

$$i = C \frac{dv}{dt}, \quad V = IR$$

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

$Money = Power = VI = I^2R = \sqrt{Evi\ell}$

|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: $S'_x = \frac{dy}{dx} \cdot x$, \quad Low Pass Filter: $H(s) = \frac{H \omega_o^2}{s^2 + s \omega_o + \omega_o^2}$
**Question 1** (Total 17 Marks)

Answer the following questions.

3 marks (a) Draw the T model for a bipolar transistor including $C_\pi$, $C_\mu$, $r_o$, and $r_x$.

(b) A transistor has a collector current of 0.5 mA, $\beta$ of 100 and an Early Voltage of 100V. Determine $g_m$, $r_\pi$, $r_v$, $r_o$.

3 marks (c) State at least one advantage and one disadvantage for each of the following three amplifiers: CE, CB, and CC.

6 marks (d) For the following Class-A amplifier, determine the maximum efficiency under the following conditions and assumptions: the output voltage is undistorted, the input signal can be no larger than the power supply rails, the transistor $V_{BE}$ drop can be ignored, and the load resistor $R_L$ is not the optimum value, but instead is equal to 100Ω.

![Figure 1](image)

2 marks (e) A power transistor is required to dissipate 50W and the maximum allowable junction temperature is 150°C. The thermal resistance between the junction and case is 0.7°C/W, the thermal resistance between the case and heat sink is 0.2°C/W, and the thermal resistance between the heat sink and ambient is 1.1°C/W. Over what ambient temperature range will the transistor be able to dissipate 50W?

3 marks (f) Name six properties of real opamps that ideal opamps don’t have.
**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 $r_{o1}$ and $r_{o2}$).

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 $C_\pi$.

4 marks  (g) With $\beta_1 = \beta_2 = 100$, $V_{CC} = 15V$, determine values for $R_1$, $R_2$, $R_3$, $R_4$, and $R_5$, such that $V_{E2}$ is about 12V, the current in each of $Q_1$ and $Q_2$ is approximately 1 mA, the current through $R_1$ is approximately 0.1 mA, and so that the output voltage swing is approximately maximized.

![Figure 2](image-url)
**Question 3** (Total 20 Marks)

For the opamp circuit of Figure 3, all transistors are assumed to be matched. Perform the following analyses:

12 marks  (a) Draw the small signal model and use it to find expressions for:
   (i) The differential-mode gain $A_{DM}$.
   (ii) The common-mode gain $A_{CM}$.
   (iii) The differential mode input impedance $R_{DM}$.
   (iv) The common mode input impedance $R_{CM}$.

3 marks  (b) With $V_{CC} = 5V$ and $V_{EE} = -5V$, design a current mirror to replace $I_{EE}$ (and its impedance $R_{EE}$). Determine the required value of $R_{Bias}$ from the current mirror input to ground such that the opamp output voltage will be equal to zero when the two opamp input voltages are both zero.

2 marks  (c) Determine the minimum and maximum input common-mode voltage using the opamp with current mirror as designed for part (b).

3 marks  (d) With a capacitor $C = 10$ nF added from the opamp output to ground, determine the slew rate for both the positive edge and the negative edge.
**Question 4** (Total 20 Marks)

7 marks  (a) Derive the transfer function $v_o(s)/v_i(s)$ of the circuit shown in Figure 4. Note that there are two capacitors labeled $C$ and four resistors labeled $R$.

![Figure 4](Image)

4 marks  (b) For the following filter transfer function:

$$\frac{v_o(s)}{v_i(s)} = \frac{1 + \frac{R_3}{R_4}}{s^2 R_1 R_2 C_1 C_2 + s (R_1 C_2 + R_2 C_2 - \frac{R_3}{R_4} R_1 C_1) + 1}$$

find expressions for $H_0$, $\omega_o$ and $Q$.

3 marks  (c) For the filter in (b), given that $C_1 = 0.25 \, \mu F$, and $R_1 = R_4 = 1 \, k\Omega$, find values for the remaining components (that is for $R_2$, $R_3$, and $C_2$) to set $H_0 = 4$, $Q = 1.6$, and $\omega_o=2000$ rad/s.

4 marks  (d) For a second-order low-pass filter with $H_0 = 4$, $Q = 1.6$, and $\omega_o=2000$ rad/s, as in (b) and (c), sketch the transfer function approximately to scale and clearly identify $H_0$, $Q$, $\omega_o$, and the high-frequency rolloff.

2 marks  (e) For the filter in (b), derive an expression, (showing your steps) for the sensitivity for $\omega_o$ as a function of $C_2$, that is, determine $\delta \omega_o / \delta C_2$.
Question 5 (Total 11 Marks)

7 marks  (a) For the oscillator shown in Figure 5, determine the open-loop transfer function.

4 marks  (b) Apply Barkhausen criteria to the circuit in Figure 5 to find the oscillating frequency showing any necessary derivation. Then find out what is the necessary condition of $R_2$ to start the oscillator.