CARLETON UNIVERSITY

FINAL
EXAMINATION
December 2004

DURATION 3 HOURS — No. of Students 150

Department Name & Course Number: Electronics ELEC 3509
Course Instructor(s): Prof. John W. M. Rogers and Calvin Plett

AUTHORIZED MEMORANDA: Calculators Only

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 77.
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

$r_\pi = \dfrac{\beta}{g_m}$, $r_\pi = (\beta+1)r_e$, $\alpha = \dfrac{\beta}{\beta+1}$, $g_m = \dfrac{I_C}{V_T}$, $V_T = 25mV$ @ 20°C

|forward biased V_{BE}| = 0.7 Volts

$\omega_L \approx \omega_{L1} + \omega_{L2} + \omega_{L3} + \ldots$ and $\dfrac{1}{\omega_H} \approx \dfrac{1}{\omega_{H1}} + \dfrac{1}{\omega_{H2}} + \dfrac{1}{\omega_{H3}} + \ldots$

Miller's Theorem: $Y_1 = Y\left(1 - \dfrac{v_2}{v_1}\right)$, $Y_2 = Y\left(1 - \dfrac{v_1}{v_2}\right)$

Sensitivity: $S_x^y = \dfrac{dy}{dx} \cdot \dfrac{x}{y}$

Question 1 (Total 13 Marks)

Answer the following questions.

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

4 marks (b) For the class A 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 the is maximum symmetric voltage swing possible in this circuit? Therefore what should the load resistor be chosen as to provide this swing? What is the efficiency in this case?

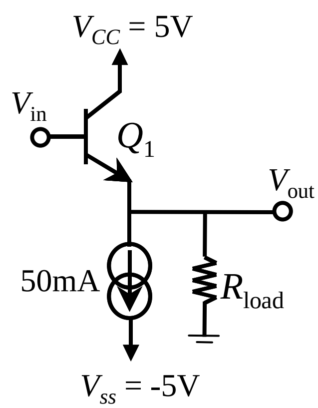

Figure 1

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 0.7°C/W, 0.2°C/W, and θ°C/W respectively. If the ambient temperature is 25°C, the transistor junction temperature is 150°C, and the power dissipated in the transistor is 50W, what is the value of θ?

2 marks (d) If three amplifier stages are connected in series (Al --- A2 --- A3), with the voltage gains, A_{v1} = 10dB, A_{v2} = 2dB, A_{v3} = 7dB, what will the overall gain of the series configuration be?

3 marks (e) The collector current as a function of base emitter voltage is given by $I_C = I_S e^{\frac{V_{BE}}{V_T}}$ find the sensitivity of the collector current to the base-emitter voltage. Under normal operating conditions what is its numerical value?

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).

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

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

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

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

4 marks (e) Find the low frequency poles (ω_L's).

4 marks (f) Find the high frequency poles (ω_H's) for the circuit. You may ignore $C_{\pi1}$.

3 marks (g) Assume that V_{cc} = 5V, I_{C1}= 1mA, I_{C2} = 2mA, V_{CEsat} = 0.5V, R_3 = 1 kΩ and β = 100, determine R_1, R_2, R_4, and R_5 so that I_{R2} is 10 times the base current of Q_1, and I_{R5} is 10 times the base current of Q_2. Choose R_6, so that the output swing is maximized.

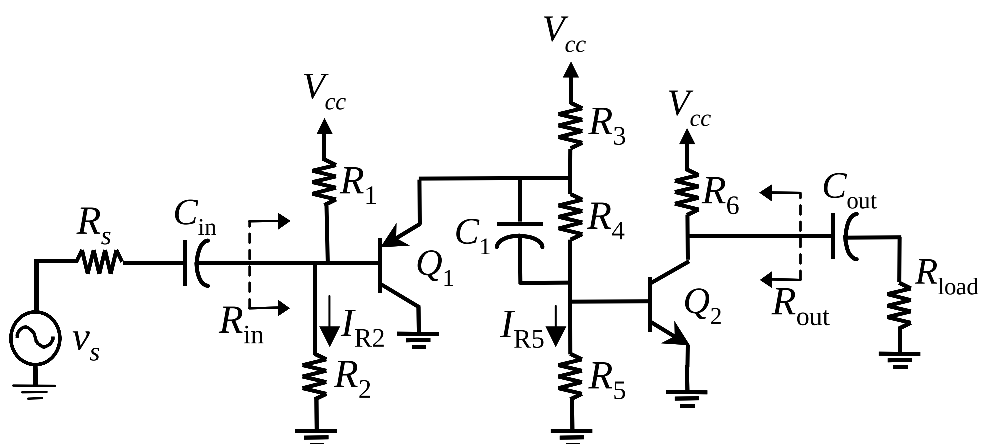

Figure 2

Question 3 (Total 16 Marks)

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

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

4 marks (b) Assume that V_{cc} = 15V, and V_{EE} = -15V
- (i) Use a current mirror and input bias resistor R_{Bias} to replace the current source I_{EE} (and its impedance R_{EE}) such that $I_{C1} = I_{C2}$ = 500 μA.
- (ii) Also use a current mirror and input bias resistor R_{Bias5} to replace current source I_5 (and its impedance R_5) with an appropriate current such that the quiescent value for v_{out} is 0V.
- (iii) Find the minimum and maximum input common-mode voltage $v_{icm,Min}$ and $v_{icm,Max}$, assuming $|V_{Cesat}|$ = 0.5V.

2 marks (c) Find the slew rate of the opamp using the circuit shown in Figure 3 (b) with a load capacitance C_L of 1 nF.

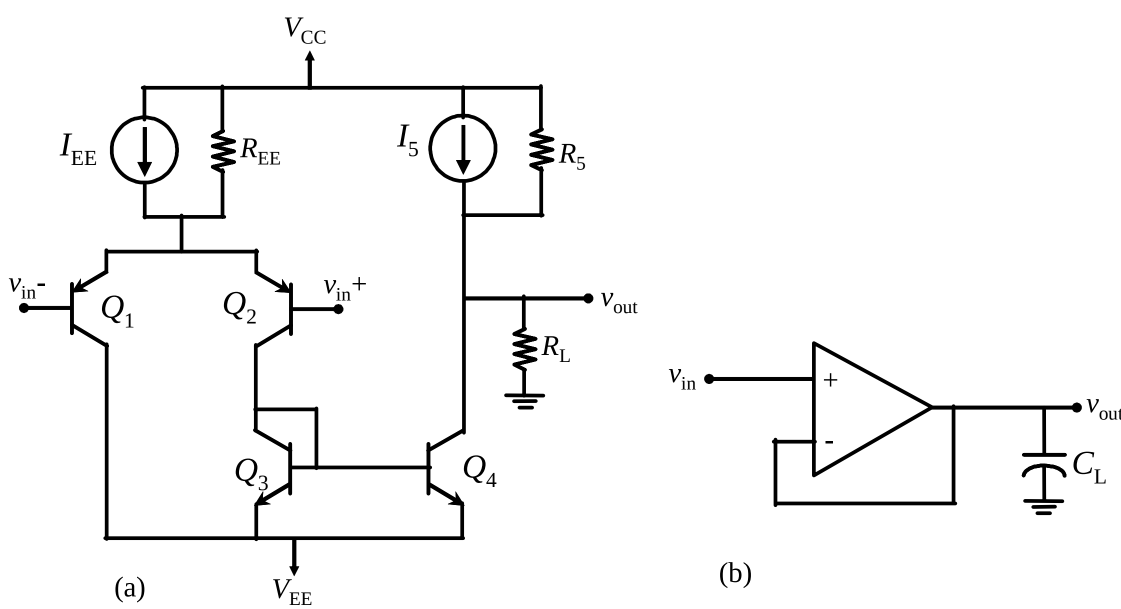

Figure 3

<u>Question 4</u> (Total 17 Marks)

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

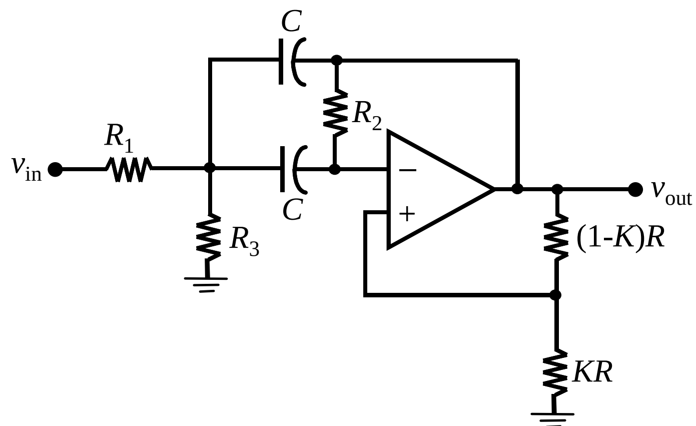

Figure 4

9 marks (b) Consider the following circuit:

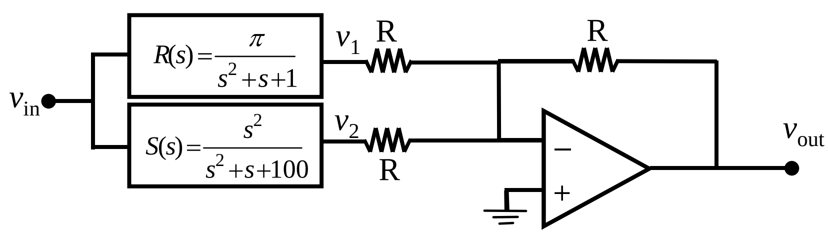

Figure 5

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, and then sketch in a reasonable amount of detail the overall magnitude response v_{out}/v_{in} of the circuit.

Question 5 (Total 9 Marks)

6 marks (a) For the oscillator shown in Figure 5, apply Barkhausen criteria to find the oscillating frequency showing necessary derivation.

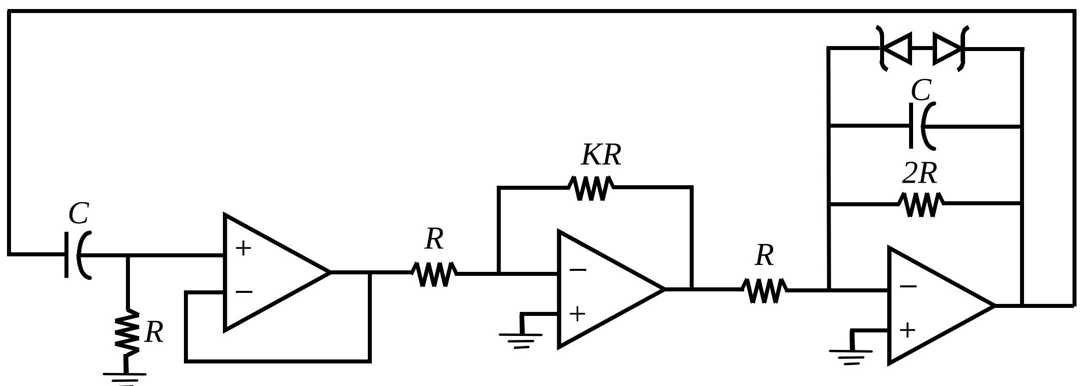

Figure 5

3 marks (b) The opamps used above are powered off ±15V supplies. How big would you expect the oscillator output to get? Note assume that the zener diodes break down at 5V.