- Name: Student Number: -

McGill University

Faculty of Engineering

Department of Electrical and Computer Engineering

Final Examination: Electronic Circuits I - ECSE-330B

April 11th 2006, 2:00 PM – 5:00 PM

Examiner: Dr. Ramesh Abhari; ________

Associate Examiner: Dr. Gordon Roberts; ________

Instructions:

1) This is a closed-book examination, no notes permitted. There are 2 pages of equations provided at the end of the questions.

2) The examination consists of 7 problems with the total possible points of 50. Partial point distribution is indicated in brackets.

3) The examination consists of 10 pages, including this page and the equation pages; please ensure you have a COMPLETE exam book.

4) Only the Faculty Standard Calculator is permitted.

5) Write your answers in the provided Answer Booklets.

6) Show your work: Answers without justification will not receive marks. State any assumption you find necessary to complete your answer.

Last Name	
First Name	
Student Number	

Question	1	2	3	4	5	6	7
Mark	/3	/6	/5	/7	/11	/8	/10
TOTAL	/50						

Question #1 (3 pts)

Two amplifier stages are connected in cascade to operate between a voltage source (v_s) with **1MΩ source resistance** and a **1kΩ load**. The first amplifier stage, which is a voltage amplifier, has an **input resistance of 500kΩ**, an **open circuit voltage gain of 200V/V**, and an **output resistance of 80kΩ**. The second stage, which is a transconductance amplifier, has an **input resistance of 100kΩ**, an **output resistance of 20kΩ**, and a **short circuit transconductance of 5mA/V**.

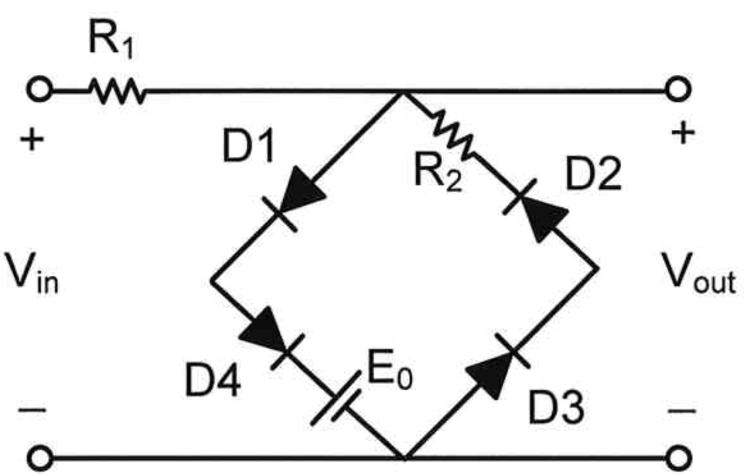
a) Draw the entire circuit model from the voltage source to the 1kΩ load. (1 pt)

b) What is the overall voltage gain, v_{out}/v_S. v_{out} is the voltage measured across the load.(1 pt)

c) Consider the output current is i_o. What is the overall transconductance gain, i_o/v_S, if we replace the 1kΩ load resistor with a short circuit? (1 pt)

Question #2 (6 pts)

In the following circuit, **R_1= 150Ω, R_2= 100Ω, E_0=1.6V**. All the diodes are the same with V_D(on)= 0.7V. The small signal resistance of each diode in forward bias is 25Ω.

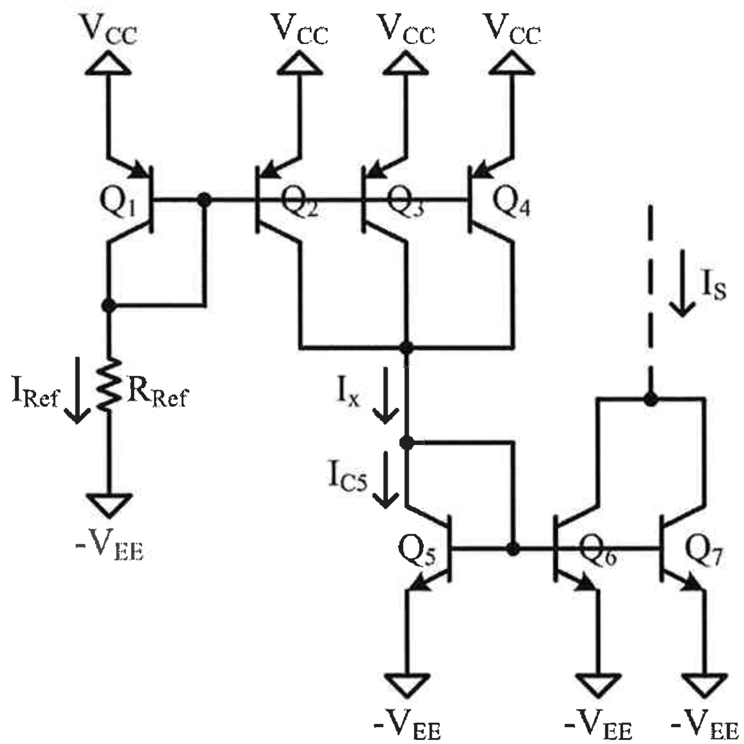


a) If the input voltage is $V_{in} = 5 + 0.001 \times \cos(2\pi t)\ \ V$, find the DC and AC output voltages, i.e. $V_{out} = V_{out}(DC) + V_{out}(AC)$. (3 pts)

b) If the DC level of the input voltage is changed to -5V as given in $V_{in} = -5 + 0.001 \times \cos(2\pi t)\ \ V$, find the DC and AC output voltages, i.e. $V_{out} = V_{out}(DC) + V_{out}(AC)$. (3 pts)

Question #3 (5 pts)

Consider the following BJT current steering circuit. All npn transistors are identical with $\beta_N = 100$, and all pnp transistors are identical with $\beta_P = 80$. The operating mode for all transistors are assumed to be the active mode, and $|V_{BE}| = 0.7$.



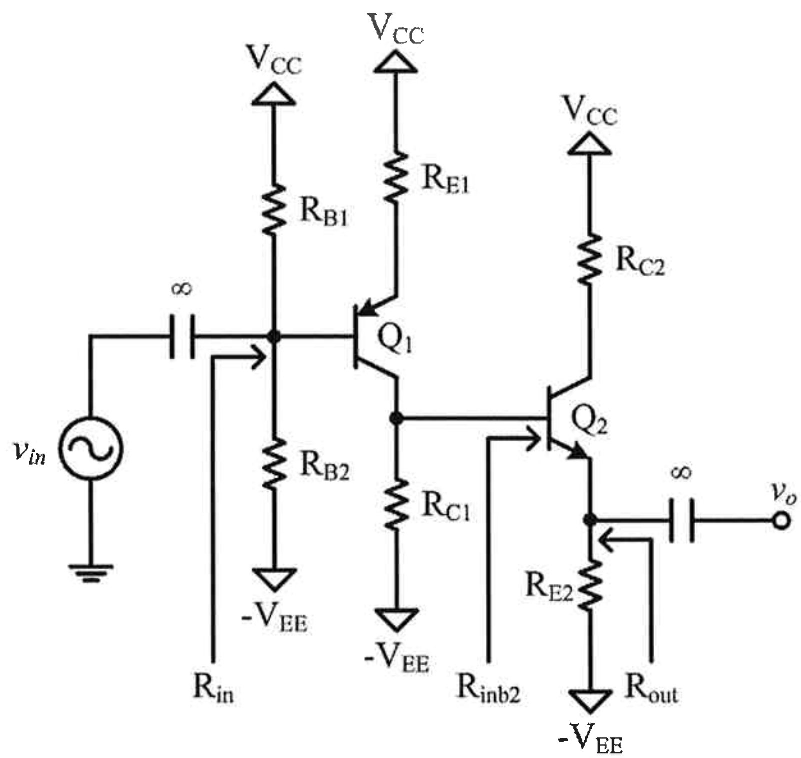
Considering $\mathbf{I_S = 8mA}$, $\mathbf{V_{CC} = 5V}$ and $\mathbf{V_{EE} = 5V}$,

a) Calculate I_{C5} and I_x. (2 pts)

b) Calculate I_{Ref} and R_{Ref}. (3 pts)

Question 4 (7 pts)

Consider the following two-stage BJT amplifier. You can assume that all transistors are in active mode and that they have the same β. The early effect for both transistors can be ignored.



a) Draw the small signal model of the above circuit. (2 pts)

b) Find an expression for R_{in}. (1 pt)

c) Find an expression for R_{inb2}. (1 pt)

d) Find an expression for R_{out}. (1 pt)

e) Derive an expression for v_o/v_{in}. (2 pts)

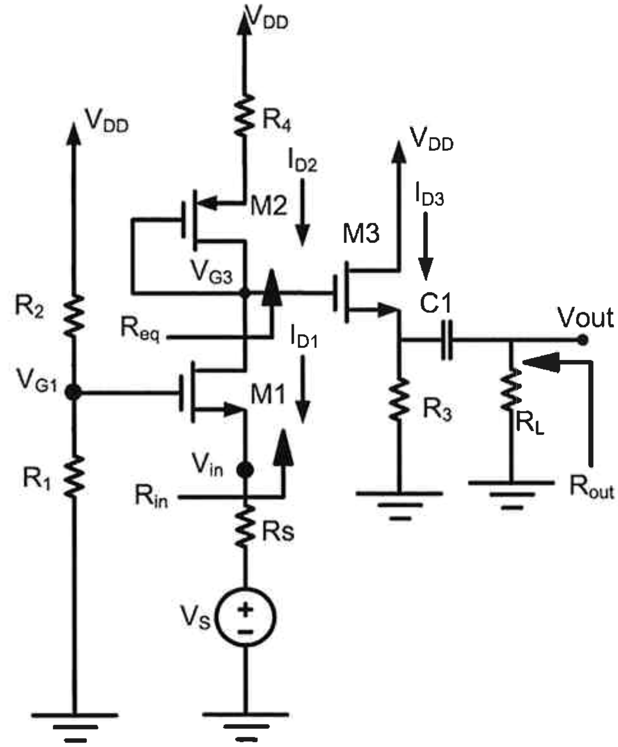
Question #5 (11 pts)

In the following circuit, all NMOS and PMOS transistors are operating in the saturation region. Assume **R_1 = 200kΩ, R_2 = 400kΩ, R_3 = 2kΩ, R_4 = 1kΩ, R_L = 3kΩ, R_S = 1kΩ.**

The transistor parameters are **$\mu_n C_{OX} = 100\mu A/V^2$, $\mu_p C_{OX} = 50\mu A/V^2$, $V_{tn} = -V_{tp} = 0.5V$, $(W/L)_1 = (W/L)_3 = 10$,** and **$(W/L)_2 = 20$.**

The supply voltage is **V_{DD} = 6 V**. The DC voltage at the source of M1 is zero, i.e. **Vin(DC) = V_{S1} (M1) = 0.**

Note that the body effect and channel length modulation can be ignored in DC and small signal analysis.



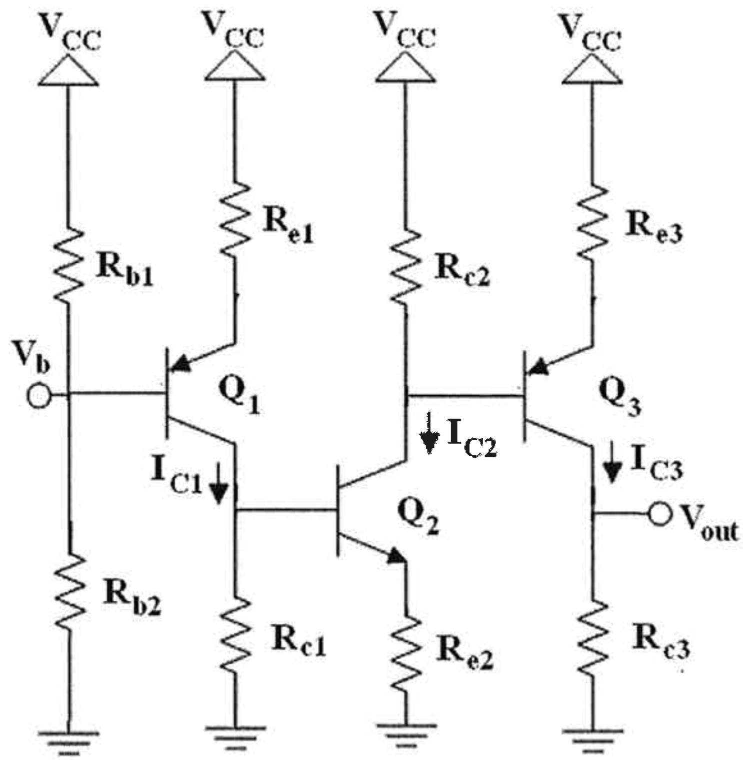
a) Calculate V_{G1}, I_{D1}, I_{D2}, V_{G3}, and I_{D3} and verify that all transistors are operating in the saturation mode.(5 pts)

b) Derive an expression for R_{eq} and draw the small signal model of the entire circuit. No need to calculate the numerical values. (2 pts)

c) Derive expressions for R_{out}, R_{in} and V_{out}/V_S. No need to calculate the numerical values. (4 pts)

Question 6 [8 pts]:

In the following circuit:
R_{b1} = 3kΩ, R_{b2} = 7kΩ, R_{e1} = 2.25kΩ, R_{c1} = 5kΩ, R_{e2} = 2.25kΩ, R_{c2} = 2kΩ, R_{e3} = 3.3kΩ, R_{c3} = 2kΩ, V_{CC} = 10V, and β = 50 for all transistors. The Early effect can be ignored for all transistors.

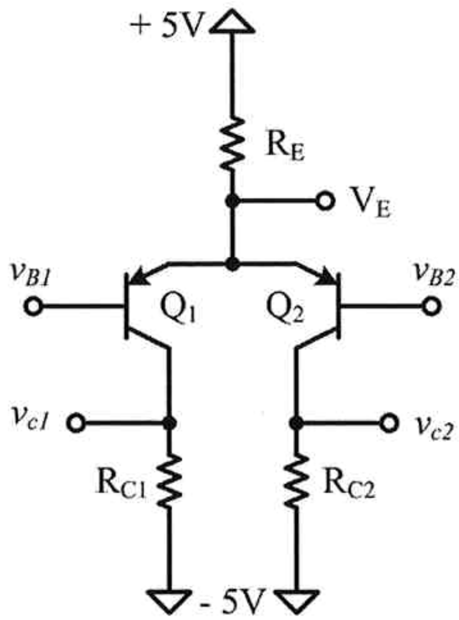


Find the values for V_b, I_{C1}, I_{C2}, I_{C3}, and V_{out} and verify your assumption about the mode of operation of all transistors. (8 pts)

Question 7 [10 pts]:

Consider the following differential amplifier circuit. Assume that all BJTs are identical and have $|V_{BE}| = 0.7$ V. The Early effect can be ignored for all transistors. The input terminals are v_{B1} and v_{B2}, the differential input is $v_d = v_{B1} - v_{B2}$ and the output terminals are v_{C1} and v_{C2}.

$R_{C1} = R_{C2} = 2k\Omega$
$R_E = 5k\Omega$
$\beta = 99$ for all BJTs



a) If V_{B1}= -0.8V and V_{B2}= 0.2V, find V_E, V_{C1} and V_{C2} . (2 pts)

b) If V_{B1}= 0.5V and V_{B2}= 0.5V, find V_E, V_{C1} and V_{C2} . (2 pts)

c) Draw the small signal model for this circuit. (2 pts)

d) Derive expressions for the *differential voltage gain, differential input resistance, differential output resistance* and the *Common mode gain.* Considering the base voltages indicated in part (b), calculate the numerical values for these four parameters. (3 pts)

e) If the output is connected to a resistive load R_L= 20 kΩ, i.e. R_L is connected between v_{c1} and v_{c2} terminals, calculate the new differential voltage gain. (1 pt)

Diodes:

$i=I_s(\exp(v/nV_T)-1)$

FETs:

NMOS:

Cutoff: $V_{GS} < V_t$ $\quad I_D = 0$ $\quad k'_n = \mu_n C_{ox}$

Triode: $V_{GS} > V_t$, $V_{DS} < V_{GS} - V_t$ $\quad I_D = k'_n \frac{W}{L}\left[(V_{GS} - V_t)V_{DS} - \frac{1}{2}V_{DS}^2\right]$

Saturation: $V_{GS} > V_t$, $V_{DS} > V_{GS} - V_t$ $\quad I_D = \frac{1}{2}k'_n \frac{W}{L}(V_{GS} - V_t)^2(1 + \lambda V_{DS})$

Body effect: $V_t = V_{t0} + \gamma\left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right)$

PMOS:

Cutoff: $V_{GS} > V_t$ $\quad I_D = 0$ $\quad k'_p = \mu_p C_{ox}$

Triode: $V_{GS} < V_t$, $V_{DS} > V_{GS} - V_t$ $\quad I_D = k'_p \frac{W}{L}\left[(V_{GS} - V_t)V_{DS} - \frac{1}{2}V_{DS}^2\right]$

Saturation: $V_{GS} < V_t$, $V_{DS} < V_{GS} - V_t$ $\quad I_D = \frac{1}{2}k'_p \frac{W}{L}(V_{GS} - V_t)^2(1 + \lambda V_{DS})$

Body effect: $|V_t| = |V_{t0}| + \gamma\left(\sqrt{2\phi_f + |V_{SB}|} - \sqrt{2\phi_f}\right)$

SMALL SIGNAL

$$g_m = \frac{2 \cdot I_D}{V_{GS} - V_t}$$

$$g_m = k'_n \frac{W}{L}(V_{GS} - V_t)(1 + \lambda \cdot V_{DS})$$

$$g_m = \sqrt{2k'_n}\sqrt{\frac{W}{L}}\sqrt{1 + \lambda \cdot V_{DS}}\sqrt{I_D}$$

$$r_o = \frac{1}{\lambda \cdot I_D}$$

$$g_{mb} = \chi \cdot g_m$$

$$\chi = \frac{\gamma}{2} \cdot \frac{1}{\sqrt{2\phi_f + V_{SB}}}$$

Two - Page
Formula Sheet

BJTs:

$$i_C = I_S \exp(v_{BE}/V_T)$$

$$i_B = \frac{i_C}{\beta}$$

$$i_E = \frac{i_C}{\alpha}$$

$$i_B = (1-\alpha) i_E = \frac{i_E}{\beta+1}$$

$$i_E = (\beta+1) i_B$$

$$g_m = \frac{I_C}{V_T} \quad r_e = \frac{V_T}{I_E} = \alpha \frac{V_T}{I_C} = \frac{\alpha}{g_m}$$

$$r_\pi = \frac{V_T}{I_B} = \frac{\beta}{g_m} \quad r_o = \frac{V_A}{I_C}$$

$$r_\pi = (\beta+1) r_e$$

$$\beta = \frac{\alpha}{1-\alpha} \quad \alpha = \frac{\beta}{\beta+1} \quad \beta+1 = \frac{1}{1-\alpha}$$

Two-page formula sheet