McGill University
Faculty of Engineering

Final Examination
Summer 2006

INTRODUCTION TO MICROELCTRONICS

ECSE334

Wednesday, April 25, 2007, 2:00pm

Examiner: prof. R. Khazaka
Signature: R. KHAZAKA

Associate Examiner: prof. G. Roberts
Signature: Gordon Roberts

STUDENT NAME: ______________________

McGill I.D. Number: ______________

INSTRUCTIONS

- The total number of points in this examination is 50
- This is a ***closed book*** examination.
- You are permitted **regular and translation dictionaries**.
- **Faculty standard calculator** permitted only.
- Answer all questions, and write your answers on the examination paper.
- This examination paper must be returned.
- A formula sheet is inluded at the end of the exam paper.

Question#	1	2	3	4
Weight	8	20	15	7
Score				

Total Score

QUESTION 1:(8 MARKS)

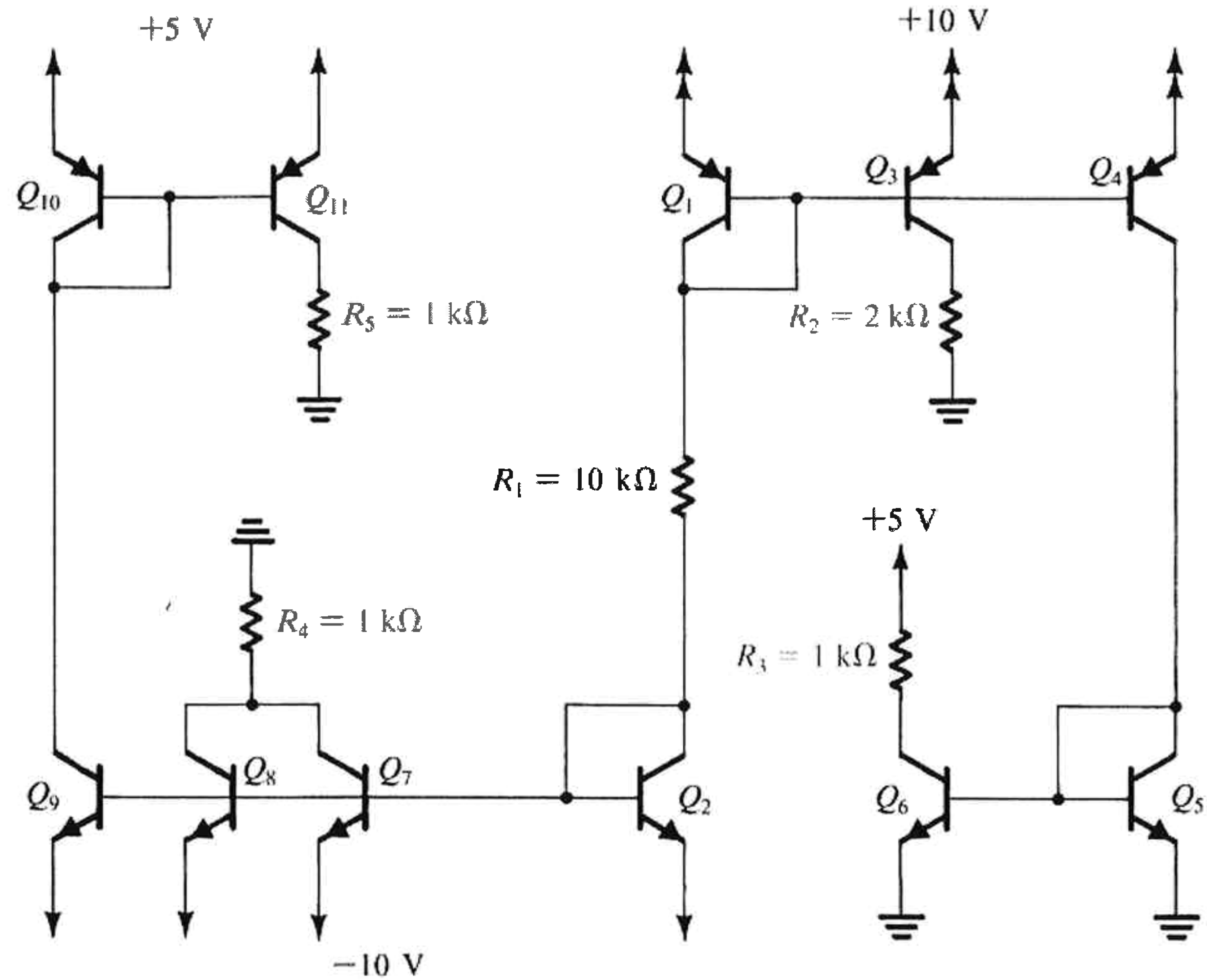

Figure Q1.1

Consider the circuit in Figure Q1.1. Find the current in all 5 resistors. Assume $|V_{BE}| = 0.7V$ and $\beta = \infty$.

QUESTION 2: (20 MARKS)

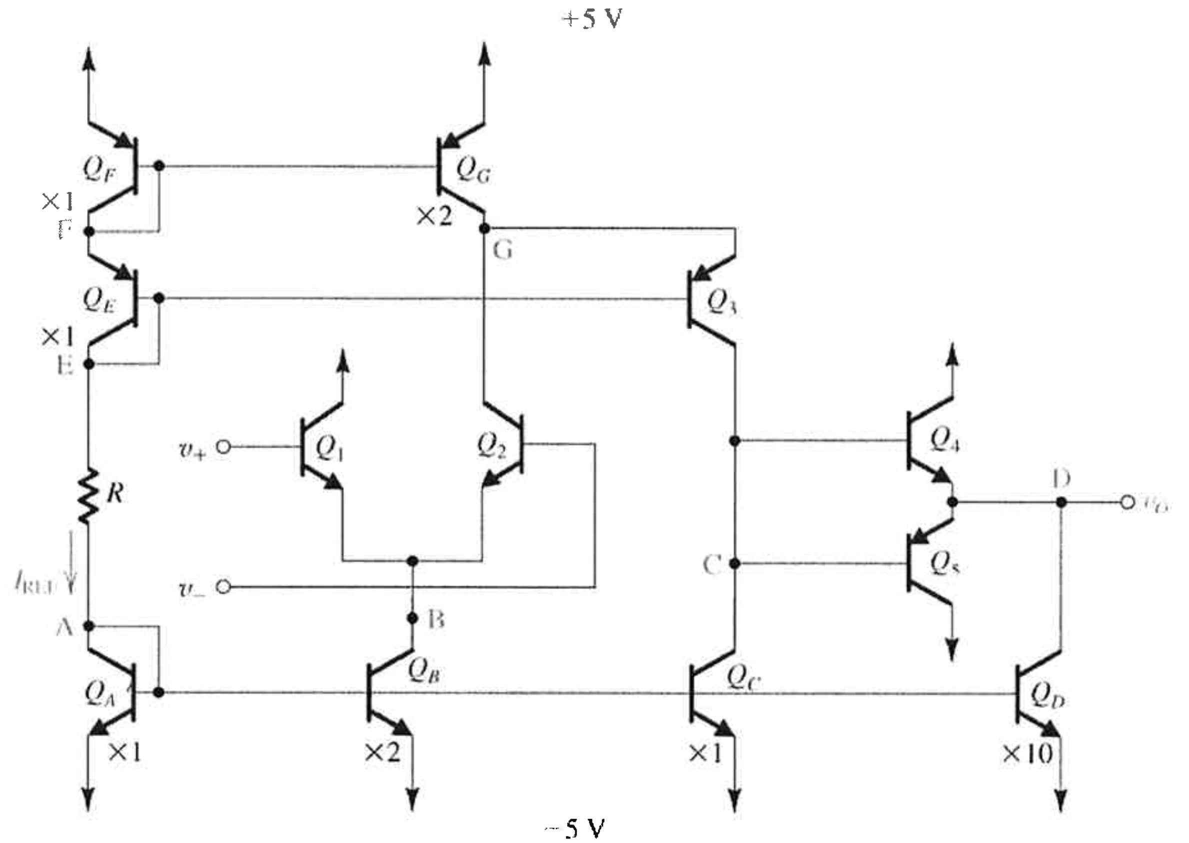

Figure Q2.1

The circuit shown in Figure Q2.1, is a multistage amplifier with a differential input stage. It uses a folded cascode involving transistor Q_3. Note that transistor Q_5 operates in class B mode and is off at the quiescent point, while Q_4 is ON at the quiescent point with Q_D sinking its bias current. All transistors have $|V_{BE}| = 0.7V$, $V_A = 200V$, and $\beta = 100$.

a) Perform a dc bias calucation at the quiescent point ($v_+ = v_- = 0V$, and v_o is stabilized by external feedback to $0V$) and determine R so that the reference current I_{REF} is $100\mu A$. For this DC bias calculation you may assume $|V_{BE}| = 0.7V$, infinite β, and $V_A = \infty$. What are the dc voltages at all the labled nodes (A, B, C, D, E, F, G).

b) Provide in tabular form the bias current for all transistors. Provide g_m and r_o for the signal transistors (Q_1, Q_2, Q_3, Q_4, and Q_5), and r_o for Q_C, Q_D and Q_G.

c) Using $\beta = 100$, find the voltage gain $v_o/(v_+ - v_-)$ at the quiescent point, and in the process verify the polarity of the inputs.

d) Find the input and output resistances at the quiescent point ($v_+ = v_- = 0V$, and v_o is stabilized by external feedback to $0V$) .

e) Find the input common mode range for linear operation.

f) Under what conditions does transistor Q_5 turn on?

QUESTION 3:(15 MARKS)

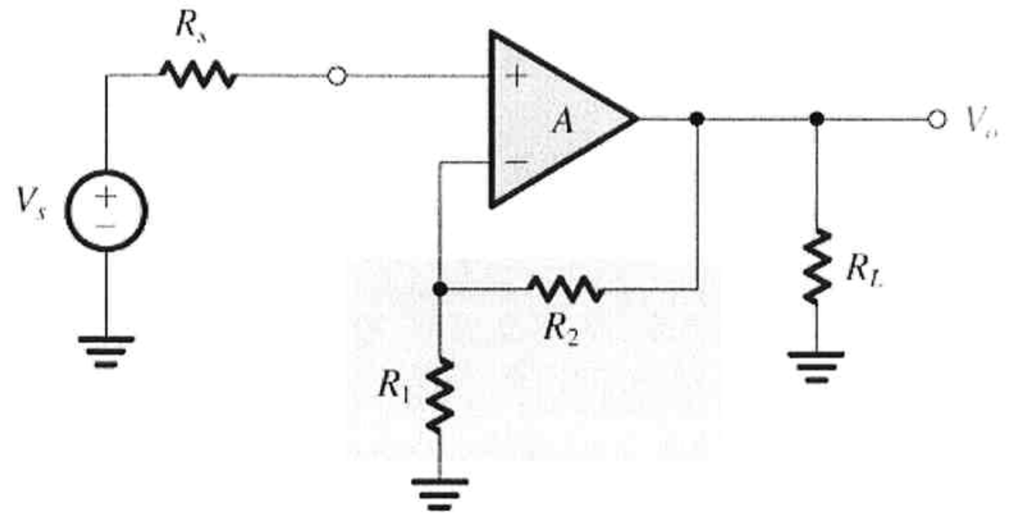

Figure Q3.1: OpAmp Circuit

Consider the circuit in series-shunt feedback configuration shown in Figure Q3.1. Assume that the opamp has infinite input resistance, zero output resistance and a base-band gain of $A = 10^5$.

a) Find an expression for the feedback factor β.

b) Find the ratio R_2/R_1 to obtain a closed loop volage gain of $A_f = \frac{V_o}{V_s} = 10$.

c) If A decreases by 20%, what is the corresponding decrease in A_f.

d) If the opamp has poles at $f_{p1} = 10^4 Hz$, $f_{p2} = 10^7 Hz$ and $f_{p3} = 10^8 Hz$, find the ratio R_2/R_1 that results in at least a 45 degree phase margin.

QUESTION 4: (7MARKS)

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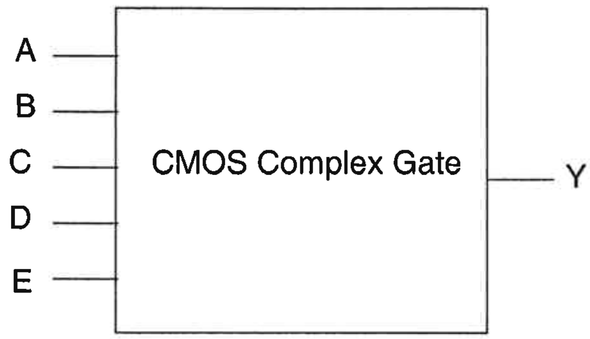

Figure Q4.1

Draw the general topology of a complex CMOS gate that realizes the following logic function: $Y = \overline{A \cdot B + C \cdot (D + E)}$.

Table 4.2 SUMMARY OF THE BJT CURRENT–VOLTAGE RELATIONSHIPS IN THE ACTIVE MODE

$$i_C = I_S e^{v_{BE}/V_T}$$

$$i_B = \frac{i_C}{\beta} = \left(\frac{I_S}{\beta}\right) e^{v_{BE}/V_T}$$

$$i_E = \frac{i_C}{\alpha} = \left(\frac{I_S}{\alpha}\right) e^{v_{BE}/V_T}$$

Note: For the *pnp* transistor, replace v_{BE} with v_{EB}.

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

$$i_C = \beta\, i_B \qquad i_E = (\beta+1) i_B$$

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

$$V_T = \text{thermal voltage} = \frac{kT}{q} \simeq 25 \text{ mV at room temperature}$$

Table 4.3 RELATIONSHIPS BETWEEN THE SMALL-SIGNAL MODEL PARAMETERS OF THE BJT

Model Parameters in Terms of DC Bias Currents:

$$g_m = \frac{I_C}{V_T} \qquad r_e = \frac{V_T}{I_E} = \alpha\left(\frac{V_T}{I_C}\right)$$

$$r_\pi = \frac{V_T}{I_B} = \beta\left(\frac{V_T}{I_C}\right) \qquad r_o = \frac{V_A}{I_C}$$

In terms of g_m:

$$r_e = \frac{\alpha}{g_m} \qquad r_\pi = \frac{\beta}{g_m}$$

In terms of r_e:

$$g_m = \frac{\alpha}{r_e} \qquad r_\pi = (\beta+1) r_e \qquad g_m + \frac{1}{r_\pi} = \frac{1}{r_e}$$

Relationships between α and β:

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

Table 5.4 SUMMARY OF IMPORTANT MOSFET EQUATIONS

Current-Voltage Relationships

■ For NMOS Devices:

- *Triode region* ($v_{GS} \geq V_t$, $v_{DS} \leq v_{GS} - V_t$)

$$i_D = k_n'\left(\frac{W}{L}\right)\left[(v_{GS} - V_t)v_{DS} - \frac{1}{2}v_{DS}^2\right]$$

For small v_{DS}: $r_{DS} = \frac{v_{DS}}{i_D} = \left[k_n'\left(\frac{W}{L}\right)(v_{GS} - V_t)\right]^{-1}$

- *Saturation region* ($v_{GS} \geq V_t$, $v_{DS} \geq v_{GS} - V_t$)

$$i_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)(v_{GS} - V_t)^2(1 + \lambda v_{DS})$$

- $k_n' = \mu_n C_{ox}$ (see Table 5.1)

$V_t = V_{t0} + \gamma\left[\sqrt{2\phi_f + |V_{SB}|} - \sqrt{2\phi_f}\right]$

$\gamma = \sqrt{2qN_A\varepsilon_s}/C_{ox}$, $q = 1.6 \times 10^{-19}$ coulomb, $\varepsilon_s = 1.04 \times 10^{-12}$ F/cm

$\lambda = 1/V_A$, $V_A \propto \alpha L$

■ For PMOS Devices: V_t, γ, λ and V_A are negative

- For triode region, $v_{GS} \leq V_t$ and $v_{DS} \geq v_{GS} - V_t$
- For saturation region, $v_{GS} \leq V_t$ and $v_{DS} \leq v_{GS} - V_t$

■ For Depletion Devices (refer to Fig. 5.23):

- n channel: V_t is negative
- p channel: V_t is positive
- $I_{DSS} = \frac{1}{2}k'\left(\frac{W}{L}\right)V_t^2$

Small-Signal Model (Fig. 5.67)

$g_m = \sqrt{2k'(W/L)}\sqrt{I_D}$ $\qquad r_o = \frac{|V_A|}{I_D}$

$g_m = k'(W/L)(V_{GS} - V_t)$

$g_m = \frac{2I_D}{V_{GS} - V_t}$ $\qquad V_{GS} - V_t \equiv V_{eff}$

$g_{mb} = \chi g_m$, $\qquad \chi = \gamma/\left[2\sqrt{2\phi_f + |V_{SB}|}\right]$

$C_{gs} = \frac{2}{3}WLC_{ox} + WL_{ov}C_{ox}$ $\qquad C_{gd} = WL_{ov}C_{ox}$

$C_{sb} = \frac{C_{sb0}}{\sqrt{1 + \frac{|V_{SB}|}{V_0}}}$ $\qquad C_{db} = \frac{C_{db0}}{\sqrt{1 + \frac{|V_{DB}|}{V_0}}}$

$f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})}$