McGill University

Faculty of Engineering
Department of Electrical and Computer Engineering
ECSE-330A – Introduction to Electronics

Examiner: Dr. David V. Plant; ____________________
Associate Examiner: Dr. Mourad El-Gamal (signature on file)
Date: Friday, December 19, 2003
Time: 9:00 – 12:00
Calculator: Faculty Standard

Pertinent Information:

1) This is a closed-book examination, no notes permitted. There are 3 pages of equations provided at the back of the examination.

2) The examination consists of 7 problems; you must answer all 7 problems.

3) The examination is worth 77 total points

4) The examination consists of 12 pages, including this page and the equations pages; please ensure you have a COMPLETE examination paper.

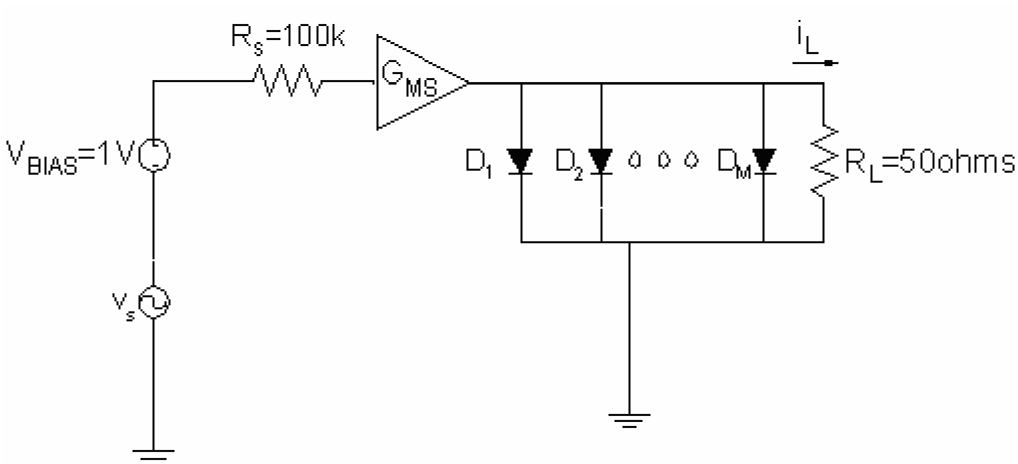
5) Only the Faculty Standard Calculator is permitted.

6) Questions may be completed in any order, however ensure that you clearly identify which part of which question you are attempting.

Do NOT turn in this exam with your exam booklet

Question 1 (9 pts)

The following circuit makes use of a transconductance (voltage-to-current) amplifier to create a current in $R_{L.}$ The amplifier has an input resistance of 1MO and an output resistance of 100O. There are M diodes (n=2) in parallel with the load R_L. You may use the constant voltage drop model for these diodes.



a) [2 pts] Find a condition on the short-circuit transconductance G_{MS} so that all the diodes can conduct.

For the remaining parts of this question, let G_{MS} = 50mA/V

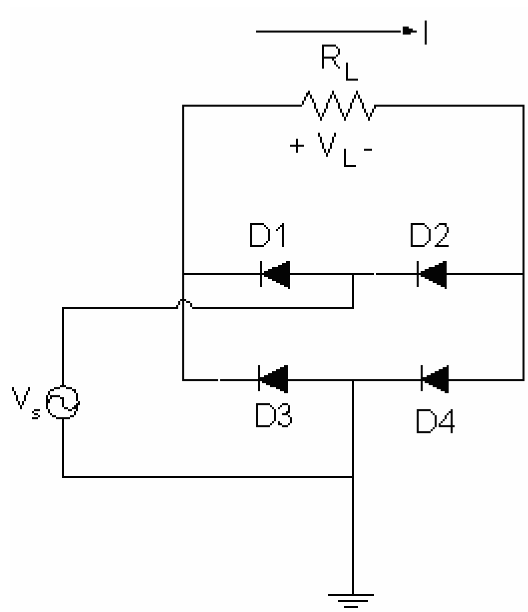
b) [2 pts] Determine the current in each diode as a function of M.

c) [2 pts] Draw the small-signal model for this circuit, assuming all diodes are conducting.

d) [3 pts] Assume there is a small input voltage ripple $v_s = |v_s|\sin(\omega t)$ as shown. What magnitude of v_s causes a corresponding current ripple in the load of $i_{load}(t) = 100\sin(\omega t)$ μA?

Question 2 (11 pts)

Consider the following circuit:



For this question, you may use the constant voltage drop model of a diode, and assume the diodes have n=1.

a) [2 pts] Which diodes are on and which are off when input Vs is 5V DC?

b) [2 pts] Which diodes are on and which are off when input Vs is -5V DC?

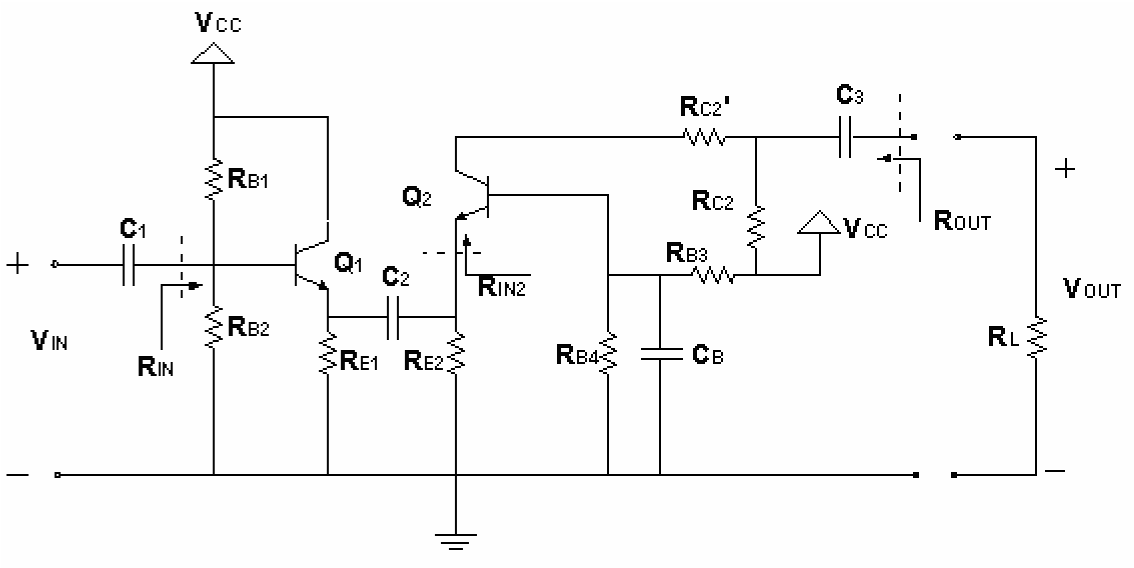
c) [3 pts] Consider the AC input $V_s = 5\sin(?t)$ V. Sketch a plot of this input. On the same sketch, plot the output V_L carefully, indicating any relevant voltages.

d) [2 pts] Consider a small-signal input $v_s = 10\sin(?t)$ mV. What is the corresponding output V_L?

e) [2 pts] What is the output if the input is $V_s = 5$ V + $10\sin(?t)$ mV instead? Provide numerical answers (do not sketch).

Question 3 (11 pts)

The following figure shows a CC-CB two-stage amplifier. Transistors Q_1 and Q_2 are identical with the same ß. All capacitors are infinite.



For the following parts, assume: V_{CC} = 12V, R_{B1} = 120kO, R_{B2} = 40kO, R_{B3} = 120kO, R_{B4} = 20kO, R_{E1} = 3kO, R_{E2} = 1kO, R_{C2} = 10kO, $R_{C2'}$ = 0 and ß = 49.

a) [2 pts] Find the DC operating point of this amplifier by calculating the values of the collector current and emitter voltage for both Q_1 and Q_2. You may neglect the Early effect.

b) [2 pts] Draw the small signal equivalent circuit (you do not need to enter numerical values for small-signal parameters).

For parts c)-e), leave your answers in terms of small signal parameters (g_m, r_p, r_o, r_e and ß) and the resistors shown in the schematic. You should decide where to consider the Early effect. You may use the expressions R_{IN}, R_{IN2} and R_{OUT} in your answers.

c) [2 pts] Find an expression for R_{IN}

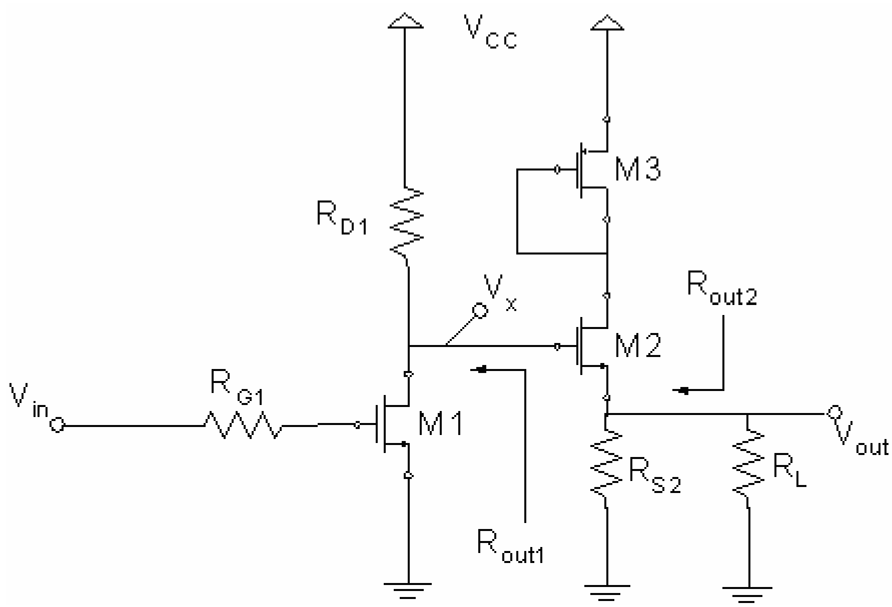
d) [1 pts] Find an expression for R_{IN2}

e) [1 pts] Find an expression for R_{OUT}

f) [3 pts] Assume $I_{C1} = I_{C2}$ = 0.8mA. If the load R_L is attached as shown, find the voltage gain $A_v = v_{out}/v_{in}$. You may neglect the Early effect.

Question 4 (13 pts)

Consider the following circuit. All FETs are operating in saturation. You must decide for each FET whether or not to include Channel Length Modulation and the Body Effect in your analysis.



a) [2 pts] Draw the small signal equivalent circuit.

b) [2 pts] Find an expression for Vx/Vin.

c) [3 pts] Find an expression for Vout/Vx.

d) [1 pts] Find an expression for Vout/Vin.

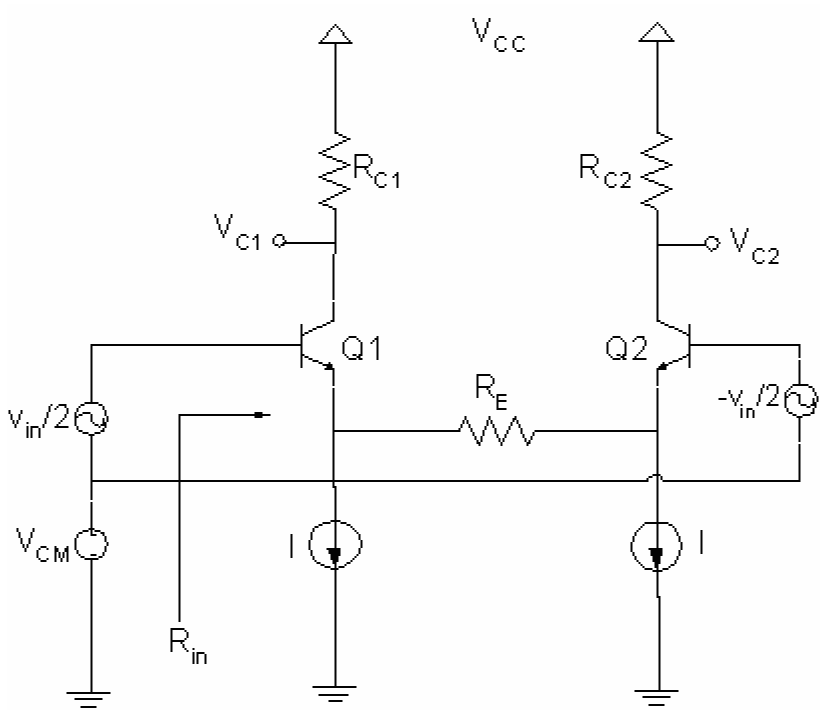
e) [2 pts] Find an expression for Rout1.

f) [3 pts] Find an expression for Rout2.

Question 5 [10 pts]:

Consider the following circuit. Assume $V_{BE} = 0.7$ V for Q1 and Q2.

$V_{CC} = 3.3$ V
$V_{CM} = 1.8$ V
$ß = 99$ for all BJTs
$V_A = 20$ V for all BJTs
$I = 1$mA



a) [3 pts] Calculate the value of RC1 and RC2 that simultaneously places Q1 and Q2 saturation/active boundary.

For parts (b) to (d), assume RC1 = RC2 = 500Ω.

b) [2 pts] Draw the small signal equivalent circuit.

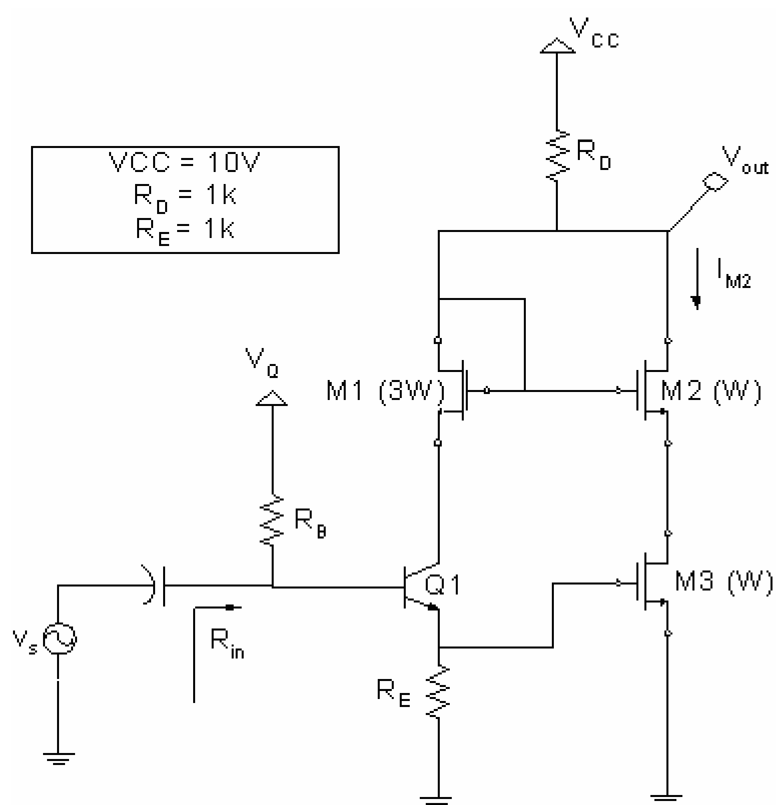
c) [2 pts] Calculate the differential voltage gain, $v_{out}/v_{in} = (v_{c1} - v_{c2})/v_{in}$.

d) [3 pts] Calculate the differential input resistance, R_{IN}.

Question 6 (13 pts)

Consider the following circuit.

- For this problem, assume that $V_{GS\text{-}M1} = V_{GS\text{-}M2}$.
- BJT Q1 is active and has β=99 and V_{BE}=0.7
- All FETs are in saturation and have V_t=1V.
- M2 and M3 have width W, and M1 has width 3W (three times wider) as shown.
- For both DC and AC, neglect the Body Effect, the Early Effect, and Channel Length Modulation (CLM). <u>**EXCEPTION**</u>: You must include CLM (DC and AC) for M3 (use $\lambda = 0.25V^{-1}$).



DC Analysis

a) [2 pts] Find expressions for <u>ALL DC CURRENTS</u> in terms of I_{M2} and ?. (If a current is 0A you do not need to write it)

b) [1 pt] Express V_{out} in terms of I_{M2}

c) [2 pts] Using results from a) and b), calculate the value of V_{out} if I_{M2} = 1mA. (Hint: You do not need a value for kW/L to do this).

AC Analysis

d) [3 pts] Draw the small-signal model for this circuit, making appropriate substitutions for the diode-connected FETs M1 and M2. What is the relationship between gm_{M1} and gm_{M2}?

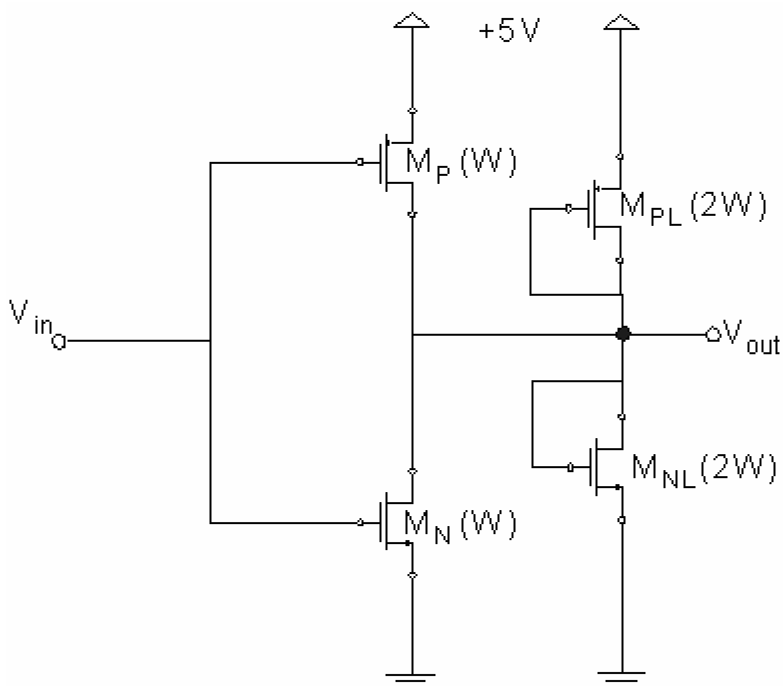
e) [2 pts] Find an expression for input resistance R_{in}.

f) [3 pts] Find an expression for the small-signal gain, v_{out}/v_s, in terms of the resistances and the small-signal parameters of the FETs and BJT.

Question 7 (10 pts)

Consider the following CMOS inverter circuit.

- FETs M_P and M_N have $k_nW/L = k_pW/L = 8mA/V^2$ and $|V_{tn}|=|V_{tp}|=1V$.
- The inverter is connected to a "load" formed by FETs M_{PL} and M_{NL} (of width 2W). These FETs are identical to the others, but are twice as wide.
- For this problem, ignore Channel Length Modulation and the Body Effect.



a) [2 pts] Calculate V_{OH} and V_{OL} for this circuit (Hint: Identify the current that flows in each case)

b) [3 pts] Sketch the voltage transfer characteristic of this device, indicating all the five regions of operation. For each region, indicate the mode of operation of each FET.

c) [2 pts] Draw the small-signal model for this device, assuming all devices are in saturation.

d) [3 pts] If this device received Vin = 2.5 V + 10sin(wt) mV, what would be the corresponding output voltage?

Diodes:

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

BJTs:

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

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

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

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

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

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

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

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

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

FETs:

<u>NMOS:</u>

Cutoff: $V_{GS} < V_t$ $I_D = 0$

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

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

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

<u>PMOS:</u>

Cutoff: $V_{GS} > V_t$ $I_D = 0$

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

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

SMALL SIGNAL

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

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

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

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

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

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