McGill University

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

Examiner: Dr. David V. Plant; ____________________
Associate Examiner: Dr. Ramesh Abhari (signature on file)
Date: Tuesday, December 21, 2004
Time: 2:00 – 5:00
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 6 problems; you must answer all 6 problems.

3) The examination is worth 70 total points

4) The examination consists of 10 pages, including this page and the equations pages; please ensure you have a COMPLETE examination paper.

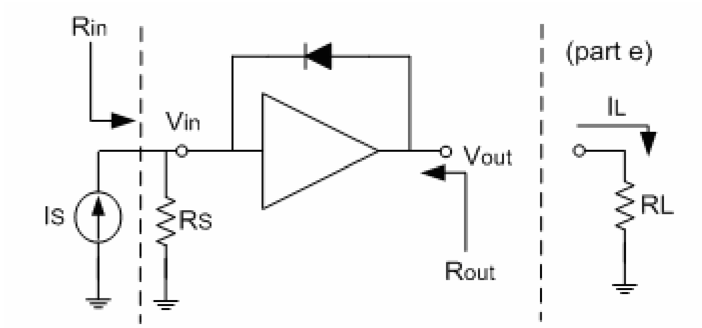
5) Only the Faculty Standard Calculator is permitted.

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.):

A transresistance amplifier with input resistance 100Ω, output resistance 150Ω, and open-circuit transresistance 400V/A is rectified by adding a feedback diode as shown below. A current source with a source resistance 1.2kΩ is applied at the input. You may assume the 0.7V-drop model for the diode.



For parts a), b), c) and d) there is no load attached (Vout is an open-circuit).

a) [2 pts.] Redraw the circuit and replace the amplifier with its equivalent circuit. (Note: Leave the diode as it is, do not replace it with its small signal model).

b) [2 pts.] Give the **voltage** gain Vout/Vin when the setup is in the linear region of operation (i.e. before clipping occurs at Vout).

c) [2 pts.] At what value of I_s does clipping occur at Vout?

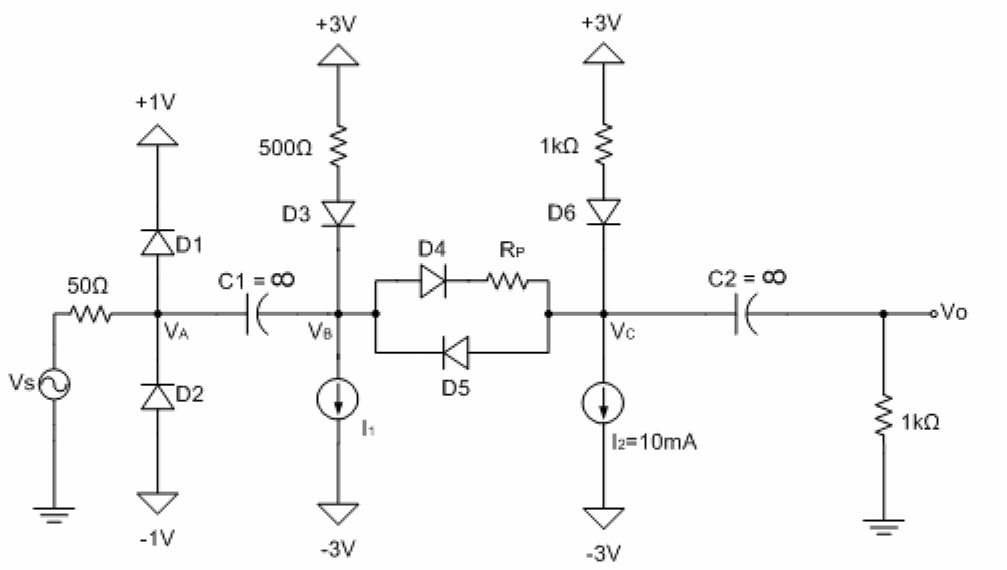
d) [1 pt.] Determine the output resistance, Rout, during linear operation. (Note: you may assume I_S is open-circuited from the input to find Rout).

For part (e), the diode has been disconnected.

e) [2 pts.] A load, R_L = 50Ω has been added at the output as shown in the diagram. Determine the current gain, Ai, of the setup. (Hint: $Ai=I_L/I_S$).

Question #2 (13 pts):

In the following circuit, all diodes are identical. Use the constant voltage drop model.



a) [2 pts.] Assume V_S is a <u>DC source</u> and sketch the voltage transfer curve of V_A vs. V_S for V_S values from -3V DC to +3V DC. **Mark all relevant points on the plot clearly**.

For parts b), c) and d), assume Vs = v_s, a small-signal voltage source with 0V DC. Use $I_1 = 0.68mA$ and $R_P = 100\Omega$.

b) [4 pts.] Find the DC current passing through each diode in the circuit, (I_{D1} through I_{D6}) and also the DC voltage of V_B and V_C. **<u>Clearly specify your assumptions and justify them</u>**.

c) [2 pts.] Draw the small-signal equivalent circuit. Do **<u>NOT</u>** calculate the diode small-signal resistances;

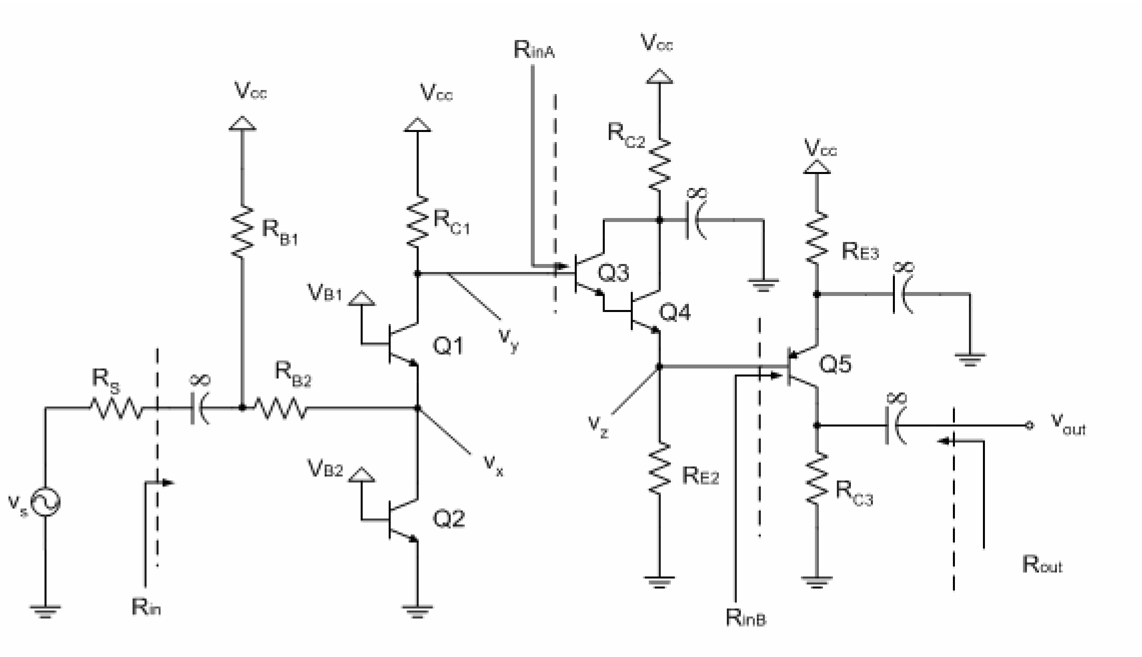
d) [2 pts.] Derive the expression of v_O/v_S. Do **<u>NOT</u>** attempt to simplify.

For part e), assume $R_P = 0$.

e) [3 pts.] For what range of values of I_1 are both D4 and D5 OFF?

Question #3 (13 pts)

In this circuit, all transistors are active and have the same β value. You must decide where to include or neglect the Early Effect in your analysis. You may refer to indicated resistances as parts of your answer (for example, you may refer to R_{inB} in your expression for R_{inA})



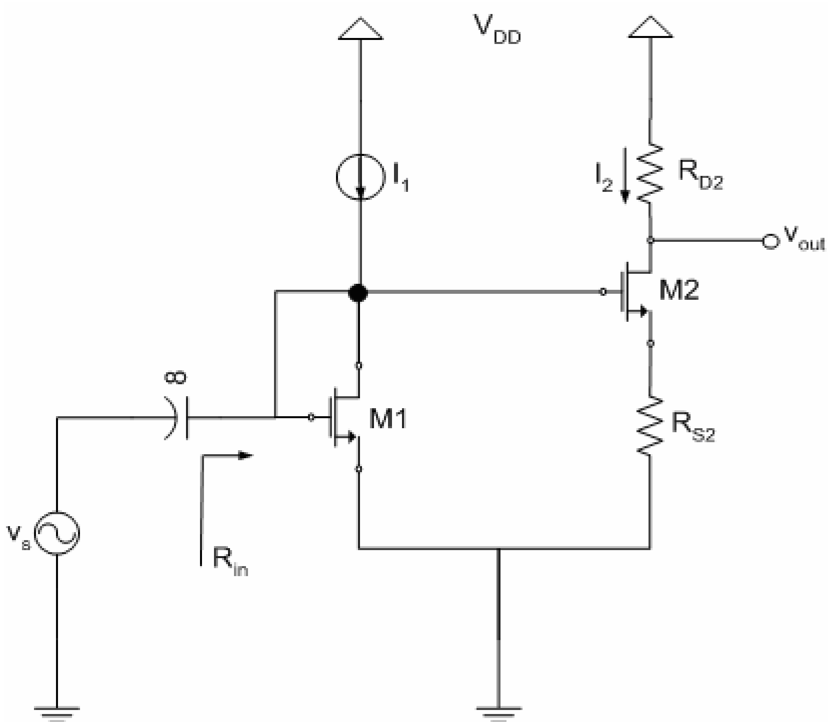
a) [5 pts.] Draw a small-signal model for this circuit.

b) [4 pts.] Find expressions for R_{in}, R_{inA}, R_{inB} and R_{out} in terms of the resistances and small-signal parameters of the transistors.

c) [4 pts.] Find expressions for the voltage gains v_x/v_s, v_y/v_x, v_z/v_y and v_{out}/v_z in terms of the resistances and small-signal parameters of the transistors.

Question #4 (10 pts)

Consider the circuit below. For **all** parts of this question, you must decide when to include CLM and the Body Effect for these FETs.



The following is known:

- λ=0.02V^{-1} and $|Vt_o|$ = 1V
- γ = 0.75$V^{1/2}$ and φ = 1.2V
- V_{G1} = 3V, V_{S2} = 1V
- The power supply V_{DD} = 5V and total current from this supply is I_1+I_2 = 4mA.
- The FETs have the same k_n'W/L value.

a) [1 pt] What is the threshold voltage Vt for each FET?

b) [2 pts] Assuming M2 is in saturation mode, calculate the value of k_n'W/L for these FETs.

c) [2 pts] Find the value of R_{S2} and a condition on R_{D2} that places M2 in saturation mode.

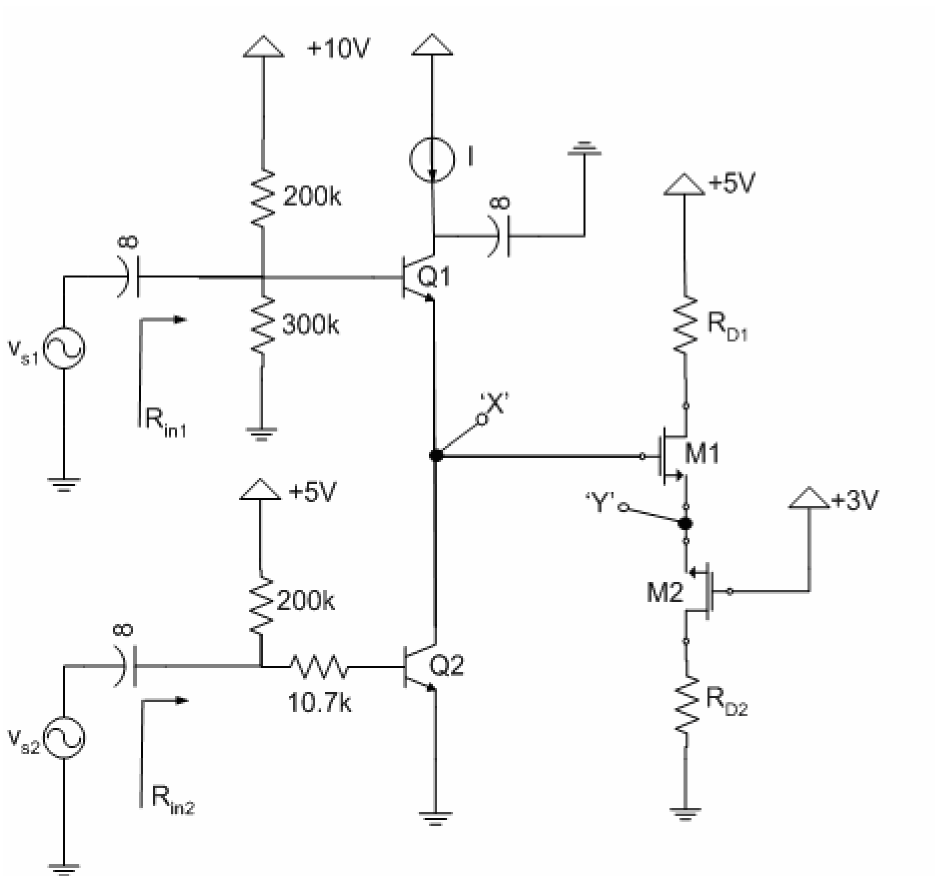
d) [2 pts] Draw the small-signal model for this circuit (do not evaluate small-signal parameters).

e) [2 pts] Find an expression for the gain v_o/v_s (do not calculate).

f) [1 pt] Find an expression for the input resistance, R_{in}.

Question #5 (13 pts)

Consider the multistage BiCMOS circuit shown here. For this circuit, you must decide whether or not to include (where appropriate) the Early Effect and CLM. You <u>must</u> include the Body Effect.



a) [2 pts] Assuming the BJT's have β=99, $|V_{BE}|$ = 0.7V and I = 2mA, determine V_X, the DC voltage at node X.

For the remainder of the question, you may assume that the FETs have equal g_m and g_{mb} values ($g_{mM1} = g_{mM2} = g_{mM}$ and $g_{mbM1} = g_{mbM2} = g_{mbM}$).

b) [3 pts] Draw the small-signal model for this circuit (do **<u>NOT</u>** calculate small-signal parameters)

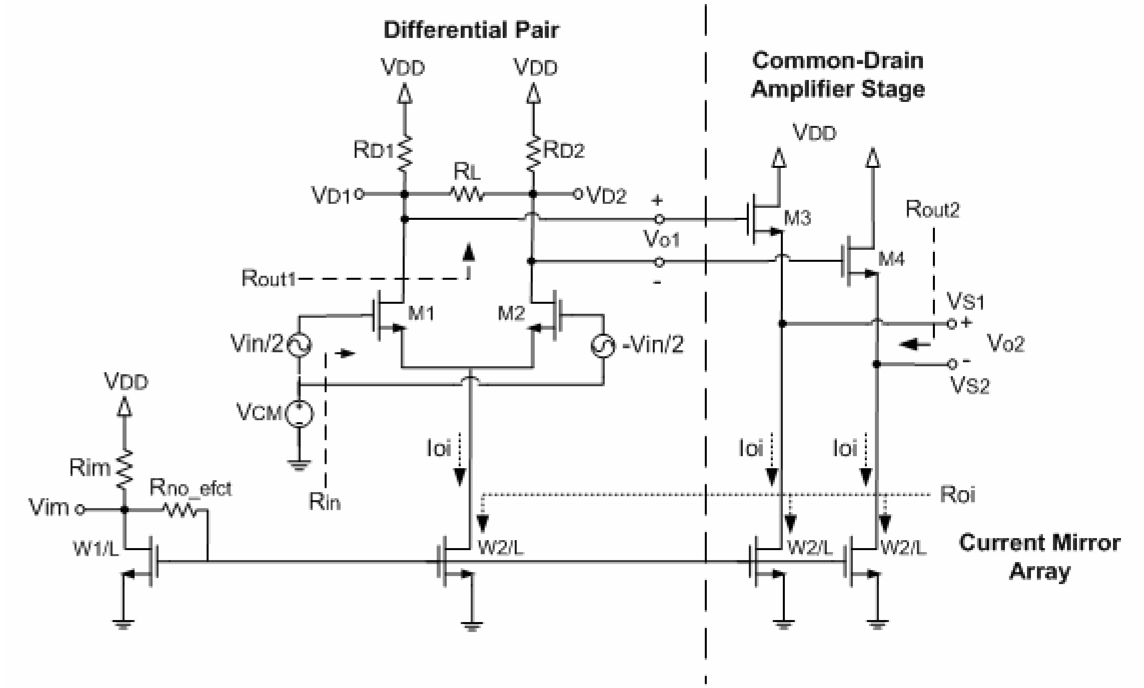
c) [3 pts] Assuming v_{s2} = 0V, find an expression for v_x/v_{s1} and R_{in1}.

d) [3 pts] Assuming v_{s1} = 0V, find an expression for v_x/v_{s2} and R_{in2}.

e) [2 pts] Find an expression for v_y/v_x.

Question #6 (12 pts)

A FET differential-pair and two common-drain amplifiers are biased using current-mirrors as shown below. The diff-pair output, $V_{o1} = V_{D1}-V_{D2}$, is amplified by the common-drain amplifier stage to produce a final differential output, $V_{o2} = V_{S1}-V_{S2}$. All FETs in the diff-pair and common-drain stages are identical, but the ones in the current mirrors have different widths W1 and W2 as shown.



Neglect the Body effect. You must include CLM output resistances for the current mirror but neglect CLM elsewhere. Assume V_{DD}=1.8V and $R_{D1} = R_{D2}$.

a) [3 pts.] Analysis of the current mirrors reveals V_{im}=1.2V, R_{im}=12kΩ, W1=1.2μm, and W2=3μm. $\lambda=0.02V^{-1}$ and L is identical for all devices. *Estimate* the output currents, I_{oi}, and output resistances, R_{oi}, at the outputs of the current mirror stages. (Note: all 3 stages have the same I_{oi} and R_{oi}).

b) [1 pt.] What is the differential small-signal input resistance, Rin, of the FET diff-pair?

Note: For the remaining parts, you may use given circuit parameters (i.e. R_{D1}) and FET small-signal parameters. DO NOT use any numeric values.

c) [4 pts.] Find expressions for the differential output resistances, R_{out1} and R_{out2}. (Hint: You may assume the V_{o1} terminals are grounded for R_{out2}).

d) [4 pts.] Give expressions for the differential gains, $V_{o1}/V_{in} = (V_{D1}-V_{D2})/V_{in}$ and $V_{o2}/V_{o1} = (V_{S1}-V_{S2})/V_{o1}$.

FORMULA SHEETS

Diodes:

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

BJTs:

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

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

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

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

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

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

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

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

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

FETs:

NMOS:

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

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: $V_{GS} > V_t$ $\quad$ $I_D = 0$

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

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

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

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

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

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

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