McGill

April 2007
Final Examination

Introduction to Electronics
ECSE330 - Sec.001

April 25th 2007, 2:00pm – 5:00pm

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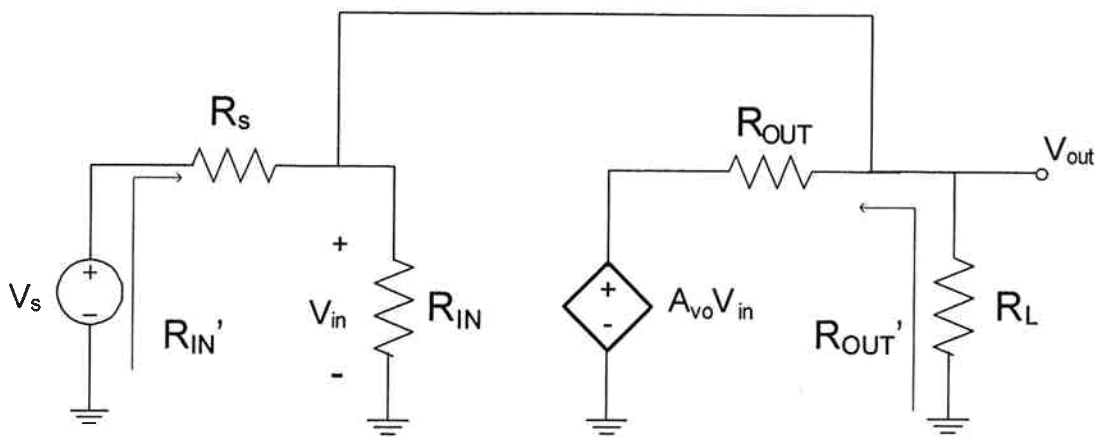
INSTRUCTIONS:

- This is a **CLOSED BOOK** examination. No notes are permitted.
- There are 2 pages of equations provided at the end of the questions.
- The examination consists of **8 problems** with the **total possible points of 50**. Partial point distribution is indicated in brackets.
- The examination consists of **11 pages**, including this page and the equation pages; make sure you have a COMPLETE exam book.
- Faculty of Engineering **STANDARD CALCULATOR** permitted ONLY.
- Show your work: Answers without justification will not receive marks. State any assumption you find necessary to complete your answer.

Question 1 (4 pts)

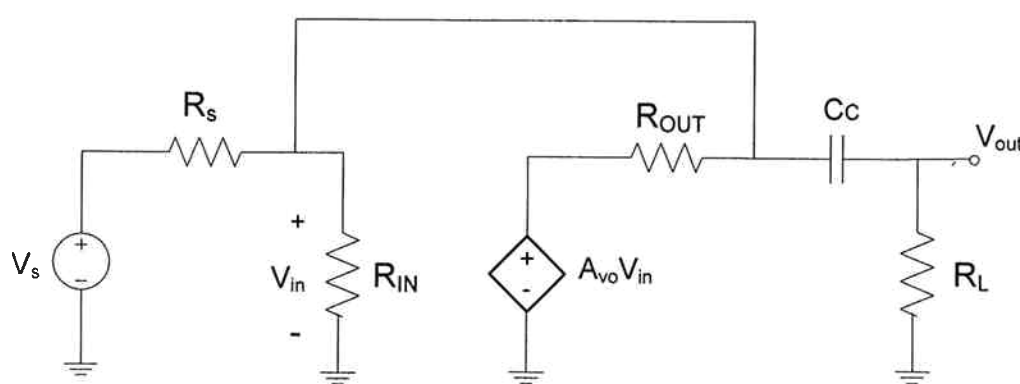
A voltage amplifier has its output connected back to its input as indicated in the figure below.



a) Derive expressions for the output resistance (R_{OUT}') and input resistance (R_{IN}') of the amplifier. (1 pt)

b) Derive the expression for the overall voltage transfer function (V_{out}/V_s) of the amplifier. (0.5 pt)

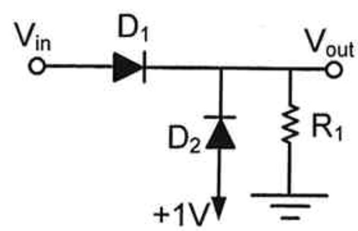
c) The circuit in part c) is now modified such that a coupling capacitor (C_C) is used to connect the output terminal (V_{out}) of the amplifier to the load resistor (R_L) as shown below. Find the cutoff frequency and derive the expression for the modified transfer function $T(s)=V_{out}/V_s$ of the amplifier. (1.5 pt)



d) Provide a Bode magnitude plot for T(s) derived in part (c) clearly showing all the relevant details. (1pt)

Question 2 (5 pts)

In the following circuit:



D_1 and D_2 are identical diodes with **n=2,** $V_T = 25$ mV and $\mathbf{R_1=1K\Omega}$.

a) Use constant voltage drop model (CVDM) for the diodes to find the voltage transfer characteristic of the above circuit (plot V_{out} vs V_{in} for $-5V<V_{in}<5V$). (2 pts)

b) Assume that $\mathbf{V_{in}=1.5^{V}+1^{mV}sin(20t)}$ and (3 pts)

I. Determine the state of each diode.
II. Find the DC current going through the diodes that are "on".
III. Find the small-signal resistance of the diodes that are "on".
IV. Find the DC and AC components of the output voltage.

Question 3 (6 pts)

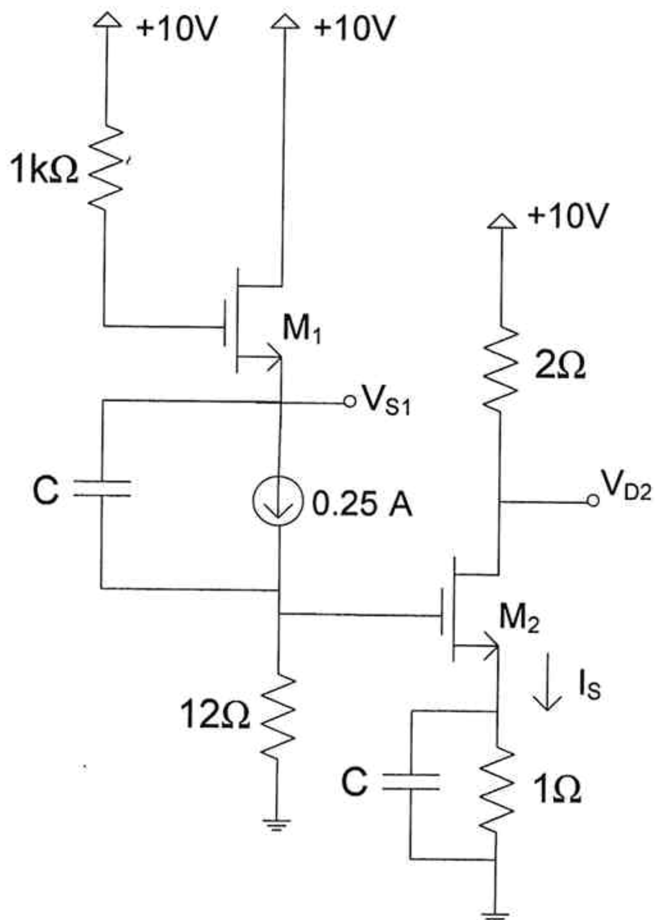
Assume V_t = **1V**, **k_n' (W/L)** = **2 A/V²**, **λ** = **0** and both transistors are operating in the saturation mode. The current source as shown in the diagram supplies **0.25 A** and all capacitors are large. Ignore CLM and body effect.

Solve the circuit below for the DC values of :

a) V_{D2} (2 pts)

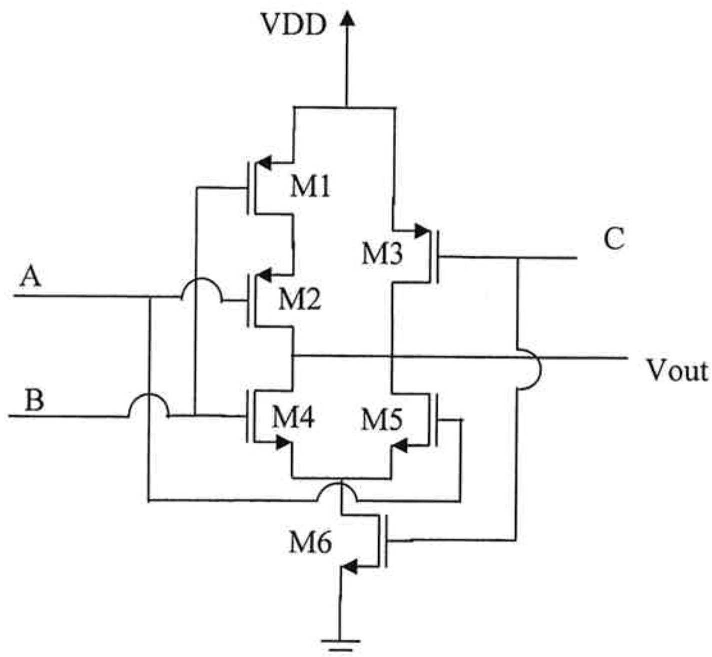
b) V_{S1} (2 pts)

c) I_S (2 pts)



Question 4 (3 points)

Consider the following digital CMOS circuit with three logic inputs labeled as A, B, and C. Note: VDD is logic 1 and GND is logic 0.



Find Vout for each of the following input combinations. Explain in each case which transistors are ON and which ones are OFF.

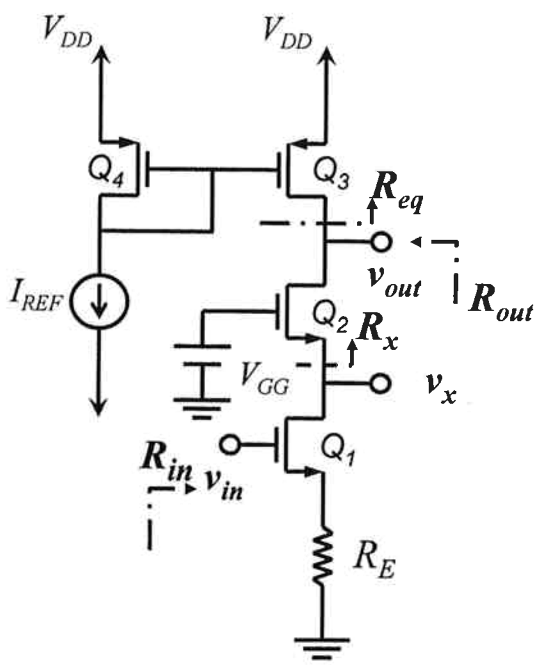
a) A=0 B=0 C=0. (1 pt)

b) A=1 B=1 C=1. (1 pt)

c) A=0 B=1 C=1. (1 pt)

Question 5 (9 Points)

Consider the following circuit. All FETs are operating in saturation.



a) Specify the type of amplifiers configured by Q1 and Q2 (1 pt)

b) Draw the small signal equivalent circuit for the section of circuit containing Q3 and Q4. Also, find an expression for **Req**. (1.5 pts)

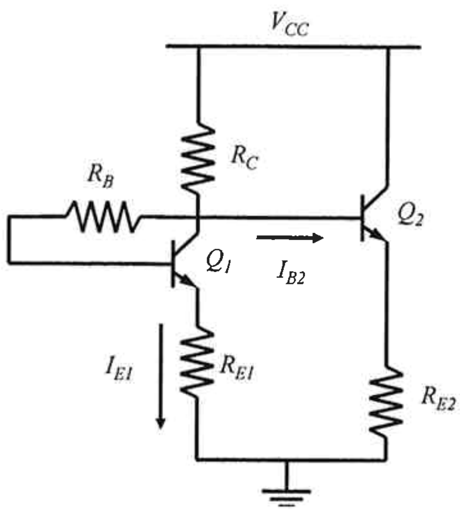
For the following parts replace the loading effect of Q3 with Req. <u>Ignore the channel length modulation but you must include the Body effect if needed</u>.

c) Draw the small signal equivalent circuit of the entire amplifier circuit. (2 pts)

d) Find expressions for **Rin, Rx** and **Rout**. (2.5 pts)

e) Find expressions for **Vout/Vx** and **Vout/Vin**. (2 pts)

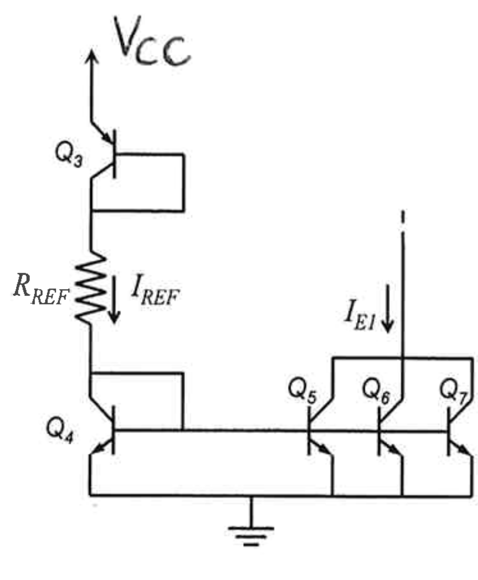
Question 6 (8 pts):
Consider the multistage BJT amplifier shown below. In this circuit, $\mathbf{V_{CC} = 2.5V}$, $\mathbf{I_{E1}=2mA}$, $\mathbf{R_B= 2\ k\Omega}$, $\mathbf{R_C= 0.6\ k\Omega}$, $\mathbf{R_{E2}= 0.2\ k\Omega}$, $\boldsymbol{\beta}\mathbf{=99}$, and V_A is infinite.



a) If $\mathbf{I_{E1}=2\ mA}$, determine the value of $\mathbf{R_{E1}}$. (4 pts)

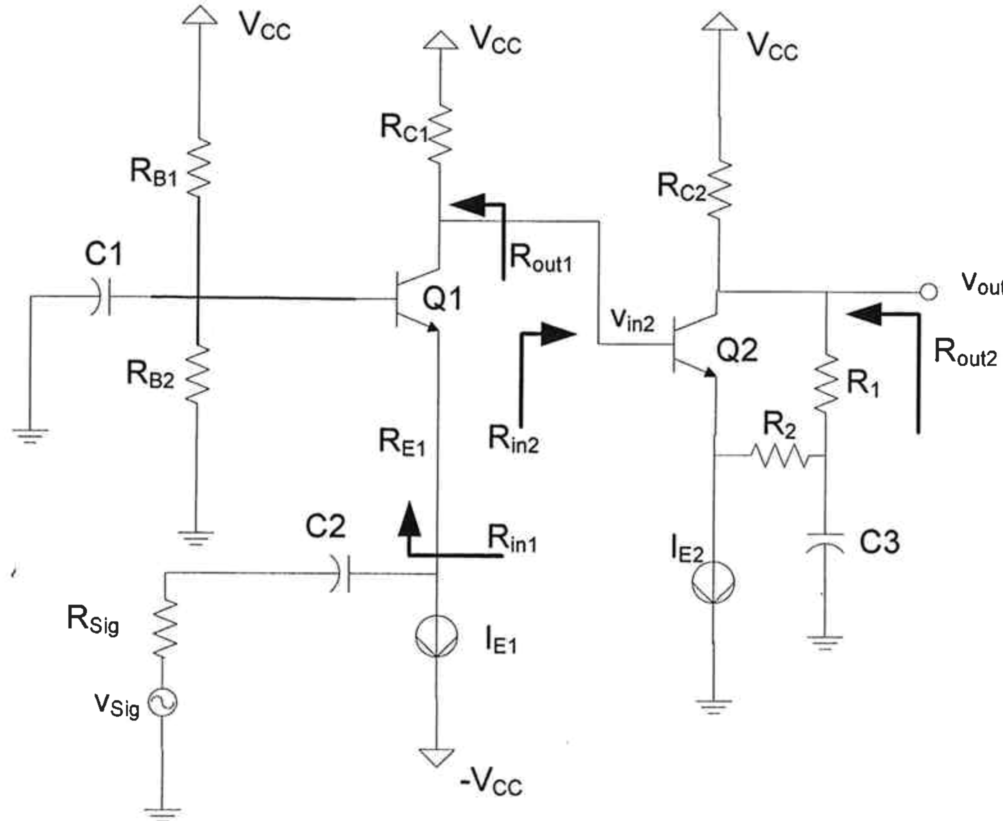
b) If I_{B2} is fixed to value you found in part (a) and $\mathbf{I_{E1}=2\ mA}$, determine the minimum value for $\mathbf{R_C}$ to keep Q_1 is the active mode. (1pt)

c) In order to generate the $\mathbf{I_{E1}=2\ mA}$, the following current steering circuit is used, if all BJTs are identical with $\boldsymbol{\beta}\mathbf{=99}$, find $\mathbf{R_{REF}}$. (3 pts)



Question 7 (10 pts):

Consider the following amplifier circuit. All capacitors are infinite valued.



a) This is a two stage amplifier. Specify the type of the amplifiers used at each stage. (1 pt)

b) Draw the small-signal model of the entire circuit and include the early effect. (2 pts)

c) Derive an expression for $\mathbf{R_{out1}}$ <u>including the early effect</u>. (2 pts)

For the following parts ignore the early effect.

d) Find expressions for Rin1, Rin2, Rout1, Rout2. (3 pts).

e) Find expressions for the voltage gains, v_{out}/v_{in2} and v_{out}/v_{Sig}. (2 pts)

Question 8 (5 pts):

Draw the high-frequency hybrid-π model of the BJT. (2 pts)

a) Derive an expression for the short circuit current gain, $\mathbf{h_{fe}=I_c/I_b}$. (2 pts)

b) Derive an expression for the unity-gain bandwidth, f_T. (1 pts)

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:

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

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

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

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

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

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

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

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

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