

Simon Fraser University

Mechatronic Systems Engineering

Final Exam for ENSC 226: Electronic Circuits

Instructor: Behraad Bahreyni

13 April 2011

Time: 150 minutes

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Student number: _____

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Question	Mark
1	/ 40
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Physical model of a diode: $I_D = I_s \left(e^{\frac{V_D}{V_T}} - 1 \right)$

For BJTs:

	Active	Saturation	Cut-off
	BE forward biased BC reverse biased	BE forward biased BC forward biased	BE reverse biased BC reverse biased
npn	$I_C = \beta I_B = \alpha I_E, V_{BE} \approx 0.7V$	$I_B > \frac{I_C}{\beta}, V_{CE} \approx 0.2V$	$I_B \approx I_C \approx I_E \approx 0$
pnp	$I_C = \beta I_B = \alpha I_E, V_{EB} \approx 0.7V$	$I_B > \frac{I_C}{\beta}, V_{EC} \approx 0.2V$	$I_B \approx I_C \approx I_E \approx 0$

$$I_C(\text{active}) = I_s e^{\frac{|V_{BE}|}{V_T}} \left(1 + \frac{|V_{CE}|}{V_A} \right)$$

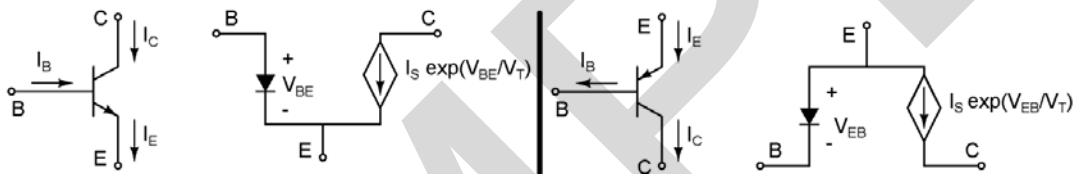
$$\alpha = \frac{\beta}{\beta + 1}$$

$$V_T = 25mV$$

$$g_m = \frac{1}{r_m} = \frac{I_C}{V_T}$$

$$r_{\pi} = \beta r_m = \frac{\beta}{g_m}$$

$$r_o = \frac{V_A}{I_C}$$



For MOSFETs:

	Saturation	Triode	Cut-off
NFET ($V_{TH} > 0$)	$V_{GS} > V_{TH} \ \& \ V_{GD} < V_{TH}$	$V_{GS} > V_{TH} \ \& \ V_{GD} > V_{TH}$	$V_{GS} < V_{TH} \ \& \ V_{GD} < V_{TH}$
PFET ($V_{TH} < 0$)	$V_{GS} < V_{TH} \ \& \ V_{GD} > V_{TH}$	$V_{GS} < V_{TH} \ \& \ V_{GD} < V_{TH}$	$V_{GS} > V_{TH} \ \& \ V_{GD} > V_{TH}$

$$I_D(\text{saturation}) = \frac{K'}{2} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS})$$

$$K' \equiv \mu_n C_{ox} \frac{W}{L} \text{ for NFETS}$$

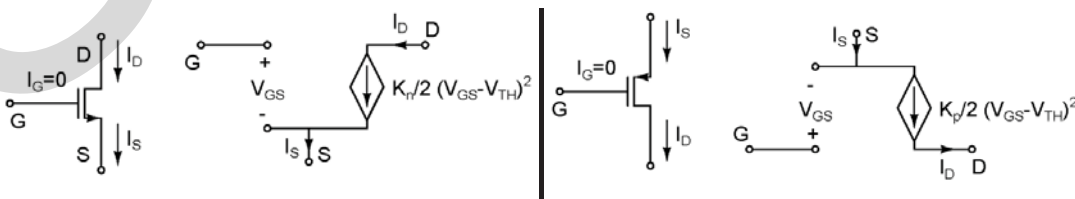
$$K' \equiv \mu_p C_{ox} \frac{W}{L} \text{ for PFETS}$$

$$I_D(\text{triode}) = \frac{K'}{2} [2(V_{GS} - V_{TH})V_{DS} - V_{DS}^2]$$

$$r_{DS}(\text{triode}) \approx \frac{1}{K'(V_{GS} - V_{TH})}$$

$$g_m = K'(V_{GS} - V_{TH}) = \sqrt{2K'I_D} = \frac{2I_D}{V_{GS} - V_{TH}}$$

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



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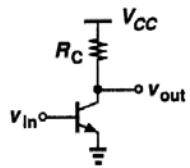
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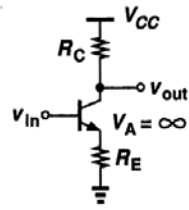
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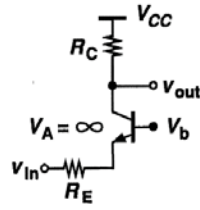
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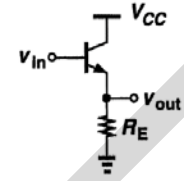
$$A_v = -g_m(R_C \parallel r_o)$$



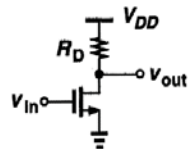
$$A_v = -\frac{R_C}{\frac{1}{g_m} + R_E}$$



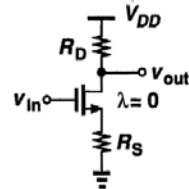
$$A_v = \frac{R_C}{\frac{1}{g_m} + R_E}$$



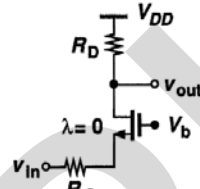
$$A_v = \frac{R_E \parallel r_o}{\frac{1}{g_m} + R_E \parallel r_o}$$



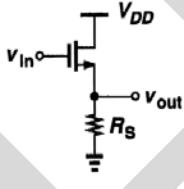
$$A_v = -g_m(R_D \parallel r_o)$$



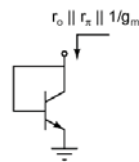
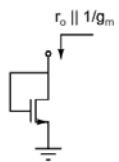
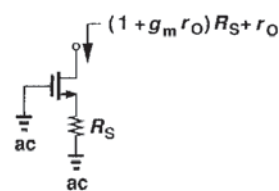
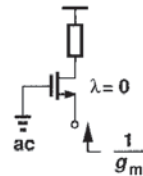
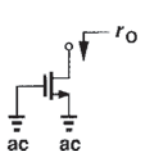
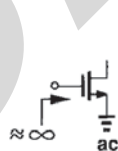
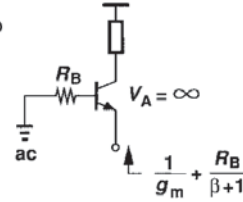
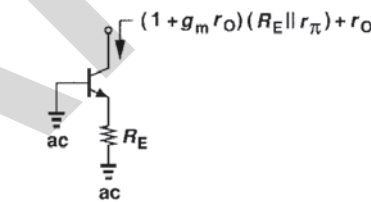
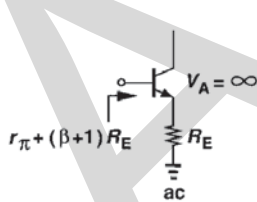
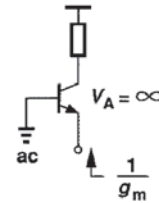
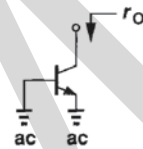
$$A_v = -\frac{R_D}{\frac{1}{g_m} + R_S}$$



$$A_v = \frac{R_D}{\frac{1}{g_m} + R_S}$$



$$A_v = \frac{R_S \parallel r_o}{\frac{1}{g_m} + R_S \parallel r_o}$$



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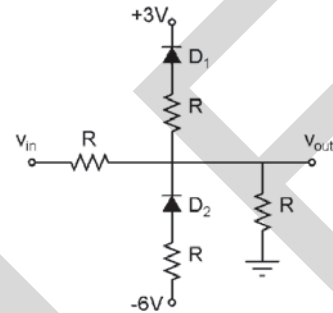
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Question 1. [40 marks]

Circle the correct answer for each of the following problems.

1.a. [5 marks] What is the range for the output voltage if $-36V < v_{in} < +36V$? Assume the diodes are ideal.

- (a) $-12V < v_{out} < +12V$ (b) $-10V < v_{out} < +9V$
 (c) $-14V < v_{out} < +13V$ (d) $-18V < v_{out} < +18V$
 (e) None of the above



1.b. [5 marks] A student wants to measure the input resistance of an amplifier using the method you learned in Lab 4. However, he only has a fixed $10k\Omega$ resistor instead of a proper variable resistor. When he puts this resistor in series with the input of the amplifier, the output signal amplitude changes from 1V to 0.80V. What is the input resistance of this amplifier?

- (a) $10k\Omega$ (b) $20k\Omega$
 (c) $30k\Omega$ (d) $40k\Omega$
 (e) None of the above

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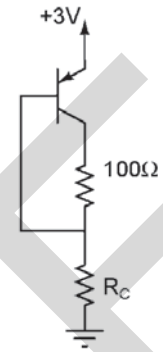
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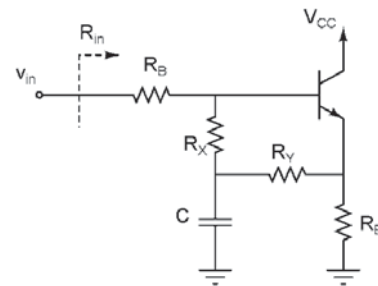
1.c. [5 marks] Assume $V_A = \infty$, $\beta = \infty$ (i.e., ignore the base current) and $R_C = 2.4k\Omega$. What should the value of I_S be such that the base-collector junction is forward biased by 100mV?

- (a) $4.83 \times 10^{-15} A$ (b) $1.27 \times 10^{-17} A$
 (c) $3.76 \times 10^{-14} A$ (d) $8.03 \times 10^{-12} A$
 (e) None of the above



1.d. [5 marks] Assume the circuit is properly biased to keep the transistor in active region and $V_A < \infty$ (i.e., take Early effect into account). Using formulas provided on page 3, find out the input resistance, R_{in} , of this circuit.

The capacitor is short-circuit for small-signal analysis.



$R_{in} =$

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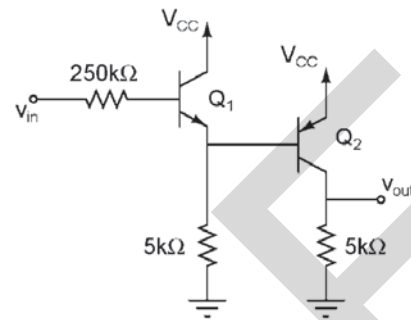
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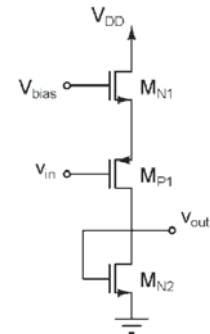
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I.e. [5 marks] Assume the circuit is properly biased to keep the transistors in active region and $\beta = 200$, $V_A = \infty$, and $I_{C1} = I_{C2} = 1\text{mA}$. Use formulas on page 3 to find the voltage gain, $A_v = \frac{v_{out}}{v_{in}}$, of this circuit.



- (a) $A_v = 132\text{ V/V}$ (b) $A_v = -132\text{ V/V}$
 (c) $A_v = 198\text{ V/V}$ (d) $A_v = -198\text{ V/V}$
 (e) None of the above

I.f. [5 marks] Assume the circuit is properly biased to keep the transistors in active region and that the transconductance of the PMOSFETs is twice as big as that of the NMOSFETs; i.e., $g_{mn1} = g_{mn2} = 0.5 g_{mp}$. Using formulas on page 3, find the voltage gain, $A_v = \frac{v_{out}}{v_{in}}$, of the circuit.



- (a) $A_v = -2/3$ (b) $A_v = +2/3$
 (c) $A_v = -1/3$ (d) $A_v = +1/3$
 (e) None of the above

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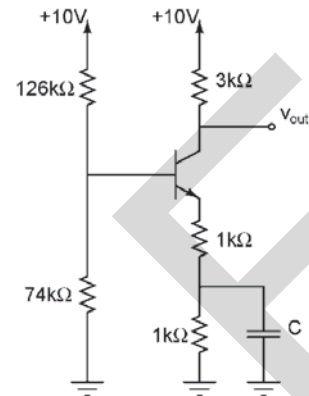
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I.g. [5 marks] Assume $V_A = \infty$, $V_{BE,on} = 0.7V$, $V_{CE,sat} = 0.2V$, and $\beta = \infty$ (i.e., ignore the base current). What is the maximum symmetric swing at the output? In other words, what is the peak-to-peak value of the largest output signal without distortion?

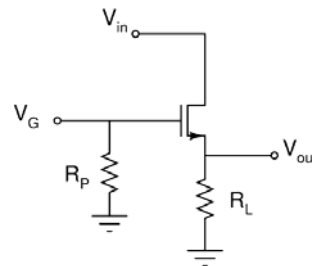
Maximum symmetric swing = _____ V

What limits the swing, cut-off or saturation? _____



I.h. [5 marks] We know that the threshold voltage of the transistor shown here is less than $2.5V$. Assume that $R_L = 100\Omega$ and $V_{in} = 100mV$. For $V_G = 3V$, $v_{out} = 80mV$ and for $V_G = 4V$, $v_{out} = 90mV$. What is the threshold voltage of this transistor?

- (a) $2.0V$ (b) $2.2V$
 (c) $2.1V$ (d) $2.3V$
 (e) None of the above



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Question 2. [15 marks]

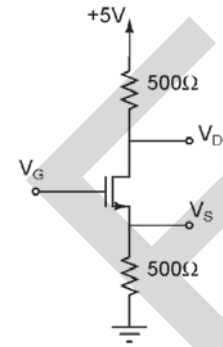
For the transistor shown in the circuit to the right, $K_n = 50 \text{ mA/V}^2$, $\lambda = 0$, and $V_{TH} = 1 \text{ V}$. We slowly change V_G from 0 to +5V.

At what gate voltages does the operating region of the transistor change from one to the other?

Cut-off: _____ $< V_G <$ _____

Saturation: _____ $< V_G <$ _____

Triode: _____ $< V_G <$ _____



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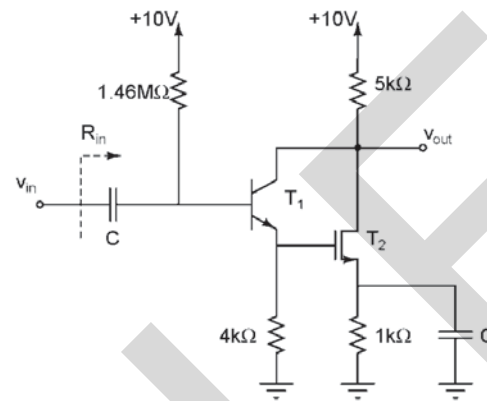
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Question 3. [20 marks]

Consider the circuit shown to the right.

For the BJT, $\beta = 100$, $V_A = \infty$, $V_{BE,on} = 0.7V$, $V_{CE,sat} = 0.2V$, and $V_A = \infty$.For the MOSFET, $K_n = 100 \text{ mA/V}^2$, $\lambda = 0$,
and $V_{TH} = 1V$.

Capacitors are assumed AC short circuits.

**3.a.** [8 marks] Calculate the operating point parameters of both transistors.

$$I_C = \text{_____ mA}$$

$$I_D = \text{_____ mA}$$

$$V_{CE} = \text{_____ V}$$

$$V_{DS} = \text{_____ V}$$

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3.b. [4 marks] Draw the small signal model of the circuit.

3.c. [8 marks] Use the small signal model to calculate the voltage gain of the circuit.

$$A_v = \frac{v_{out}}{v_{in}} = \text{_____} \text{ V/V}$$

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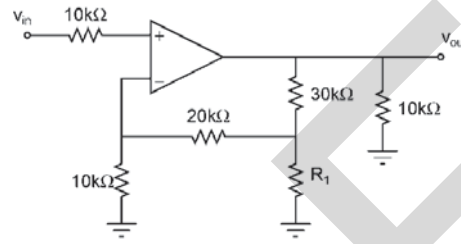
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Question 4. [15 marks]

Assume the OpAmp in circuit shown here is ideal.

3.a. [10 marks] What is the voltage gain of the circuit if $R_1 = 2k\Omega$.

$$A_v = \frac{v_{out}}{v_{in}} = \underline{\hspace{2cm}} \text{ V/V}$$



3.b. [5 marks] What is the voltage gain of the circuit if $R_1 \rightarrow \infty$.

$$A_v = \frac{v_{out}}{v_{in}} = \underline{\hspace{2cm}} \text{ V/V}$$

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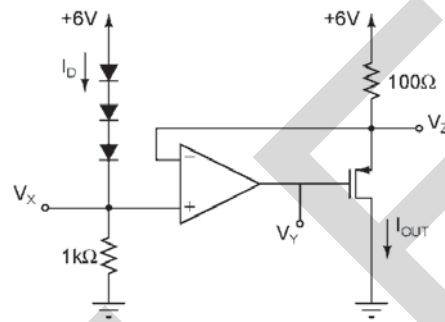
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Question 5. [10 marks]

Assume the OpAmp in circuit shown here is ideal. For the MOSFET, $K_p = 200 \text{ mA/V}^2$, $\lambda = 0$, and $V_{TH} = -2\text{V}$. The diodes are identical.

5.a. [3 marks] For each diode, $I_D = I_S e^{\frac{V_D}{nV_T}}$ where $I_S = 10^{-9}\text{A}$ and $n = 2$. What is V_X ?

$V_X = \underline{\hspace{2cm}} \text{ V}$



5.b. [4 marks] What is I_{OUT} ?

$I_{OUT} = \underline{\hspace{2cm}} \text{ mA}$

5.c. [3 marks] What is V_Y ?

$V_Y = \underline{\hspace{2cm}} \text{ V}$

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