NAME ______________________________________ NETID ________________

MIDTERM EXAM 1 - SOLUTIONS

(Closed book)

ECE 442

March 1, 2007

7:00 p.m. – 8:30 p.m.

Instructions: Write your name, and NetID where indicated. You are allowed to use a calculator. This examination consists of 5 problems. Each problem is worth 20 points. Show all work in order to receive partial credit.

Problem 1	Problem 2	Problem 3	Problem 4	Problem 5	Total

Formula Sheet

DIODE

$$I_D = I_S(e^{V_D/V_T} - 1)\text{, where } V_T = \frac{k_B T}{q} = 26\text{ mV}$$

BIPOLAR (NPN forward active $I_B>0$, $V_{CE}>V_{CE,sat}$)

$$I_C = I_S e^{V_{BE}/V_T} \cdot \left(1 + \frac{V_{CE}}{V_A}\right) \cong I_S e^{V_{BE}/V_T} \text{ where } V_T = \frac{k_B T}{q} = 26\text{ mV}$$

$$I_C = \alpha I_E$$

$$I_C = \beta I_B \cdot \left(1 + \frac{V_{CE}}{V_A}\right) \cong \beta I_B$$

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

MOSFET (long channel model equations)

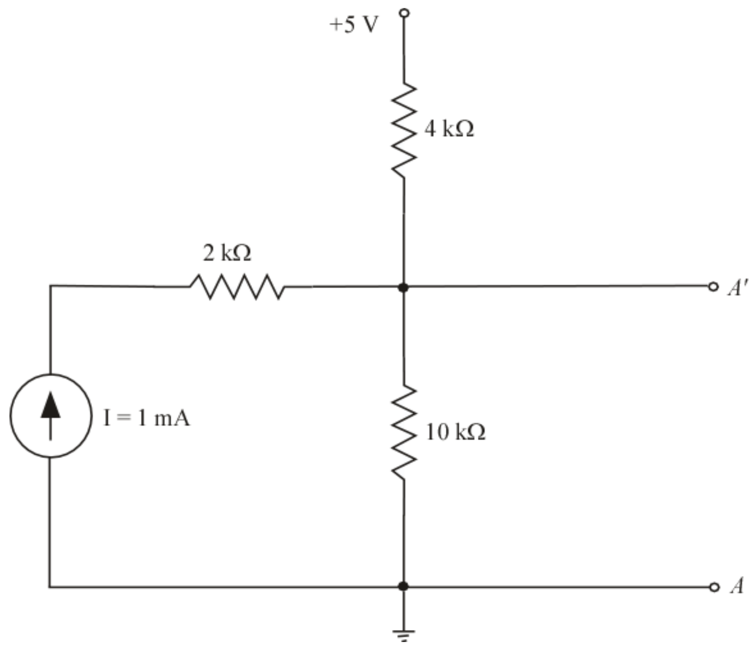
Define $V_{DSP} = V_{GS}\text{-}V_T$, where V_T is the threshold voltage

NMOS	PMOS
Triode Region (Linear) $V_{GS} > V_T$ & $V_{DS} < V_{DSP}$, $I_D = \frac{W}{L} \cdot k' \left((V_{GS} - V_T) \cdot V_{DS} - \frac{V_{DS}^2}{2} \right)$ Active Region (Saturation) $V_{GS} > V_T$ & $V_{DS} \geq V_{DSP}$, $I_D = \frac{W}{L} \cdot \frac{k'}{2} \cdot (V_{GS} - V_T)^2 \cdot [1 + \lambda \cdot V_{DS}]$ Body Effect $V_T = V_{To} + \gamma \cdot \left(\sqrt{\lvert V_{SB} \rvert + 2\phi_F} - \sqrt{2\phi_F} \right)$ $V_{GS} \leq V_T,\ I_D = 0$	Triode Region (Linear) $V_{GS} < V_T$ & $V_{DS} > V_{DSP}$, $I_D = \frac{W}{L} \cdot k' \left((V_{GS} - V_T) \cdot V_{DS} - \frac{V_{DS}^2}{2} \right)$ Active Region (Saturation) $V_{GS} < V_T$ & $V_{DS} \leq V_{DSP}$, $I_D = \frac{W}{L} \cdot \frac{k'}{2} \cdot (V_{GS} - V_T)^2 \cdot [1 - \lambda \cdot V_{DS}]$ Body Effect $V_T = V_{To} - \gamma \cdot \left(\sqrt{\lvert V_{SB} \rvert + 2\phi_F} - \sqrt{2\phi_F} \right)$ $V_{GS} \geq V_T,\ I_D = 0$

1. If the output of a filter falls with frequency at a rate of -6dB/octave, how many dB per decade does the output fall?

One decade is $1/ \log_{10}(2) = 3.3$ octave. A -6dB/octave function would fall at $-6 \times 3.3 = -20$ dB/decade.

2. Determine the Thévenin equivalent circuit for the network in the figure. Form the Thévenin equivalent across the terminals *A'-A*



$$\frac{5-V_x}{4}+1=\frac{V_x}{10}$$

$$50+40=14V_x$$

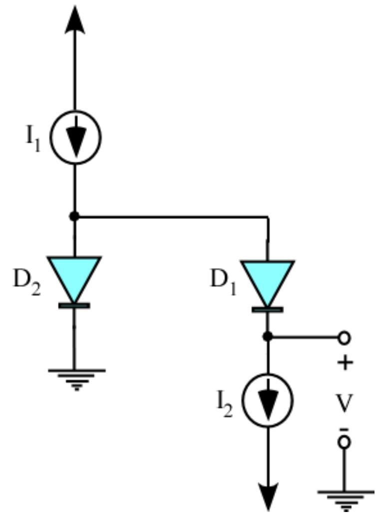
$$V_{TH}=V_x=\frac{90}{14}=6.42\,V$$

$$R_{TH}=10\ k\Omega\,||\,4\ k\Omega=2.856\ k\Omega$$

3. In the circuit shown, D_1 has a saturation current that is 10 times larger than that of D_2.

(a) If I_1 = 10 mA and I_2 = 2 mA, find the voltage V

(b) If I_1 is maintained at 10 mA, what current I_2 is needed to obtain a value for V of 52 mV?



(a) Current through D_1 is: $10 I_S e^{\frac{V_1 - V}{V_T}} = I_2$

The current through D_2 is: $I_S e^{\frac{V_1}{V_T}} = I_1 - I_2$; $\quad I_S = (I_1 - I_2) e^{-\frac{V_1}{V_T}}$;

Substitute into equation for I_2 which leads to: $10(I_1 - I_2) e^{-\frac{V}{V_T}} = I_2$

$$V = -V_T \ln\left(\frac{I_2}{10(I_1 - I_2)}\right); \qquad V = -0.026 \ln\left(\frac{2}{10(8)}\right) = 95.9\ mV$$

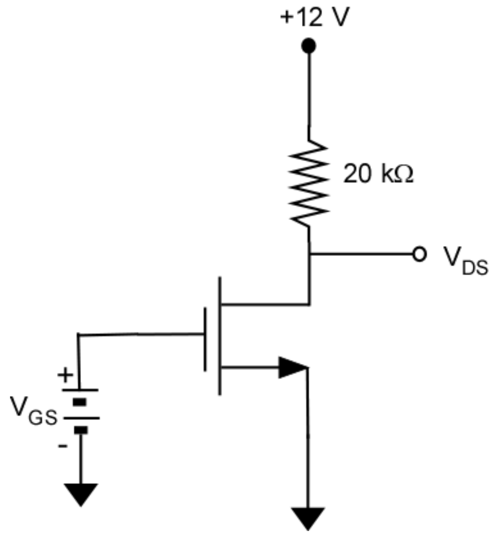
(b) For V = 52 mV, from: $10(I_1 - I_2) e^{-\frac{V}{V_T}} = I_2$, we get $I_2 = \dfrac{10 I_1 e^{-\frac{V}{V_T}}}{1 + 10 e^{-\frac{V}{V_T}}}$

$$I_2 = \frac{10 \times 10 \times e^{-2}}{1 + 10 e^{-2}} = 5.75\ mA$$

4. For the MOSFET circuit shown, $\mu W C_{ox}/2L = 80\mu A/V^2$, $V_T = 0.9$ V, $\lambda = 0$.

(a) What value must V_{GS} have to bring the device from the active region to the edge of the cutoff region?

(b) What value must V_{GS} have to bring the device from the active region to the edge of the triode region?



(a) $I_D=0$, therefore, $V_{GS} = V_T = 0.9$ V

(b) At boundary, $V_{DS} = V_{DSP}$

$$I_{DP} = \frac{1}{2}\mu C_{ox}\frac{W}{L}\left(V_{DSP}\right)^2$$

$$I_{DP} = \frac{12 - V_{DSP}}{20k\Omega}$$

$$\frac{12 - V_{DSP}}{20k\Omega} = \left(80\times10^{-6}\right)\left(V_{DSP}\right)^2 \Rightarrow 12 - V_{DSP} - 1.6\,V_{DSP}^2 = 0$$

or $V_{DSP}^2 + 0.625\,V_{DSP} - 7.5 = 0$

$$V_{DSP} = -.3125 \pm \frac{\sqrt{\left(0.625\right)^2 + 30}}{2} \qquad \textit{throw out } V_{DSP} < 0 \textit{ value}$$

$$\Rightarrow V_{DSP} = 2.44\,V$$

$$V_{GS} = V_{DSP} + V_T = 2.44 + 0.9 = 3.34\,V$$

5. Give a CMOS realization of the function

$$\overline{Y} = A\overline{B} + C \, .$$

Show the finished schematic and assume that input variables and complements are available to drive the system.