EE 115A Analog Electronic Circuits

Winter 2013 Final Exam

Closed Book, sheets of notes allowed

Name: Solutions

Student ID No.: ____________

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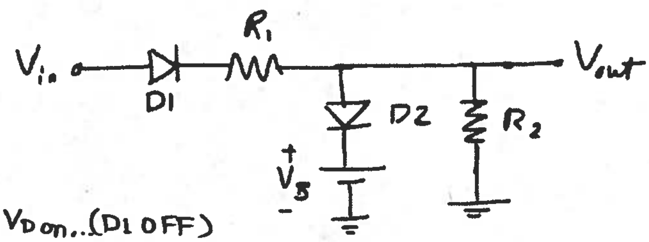
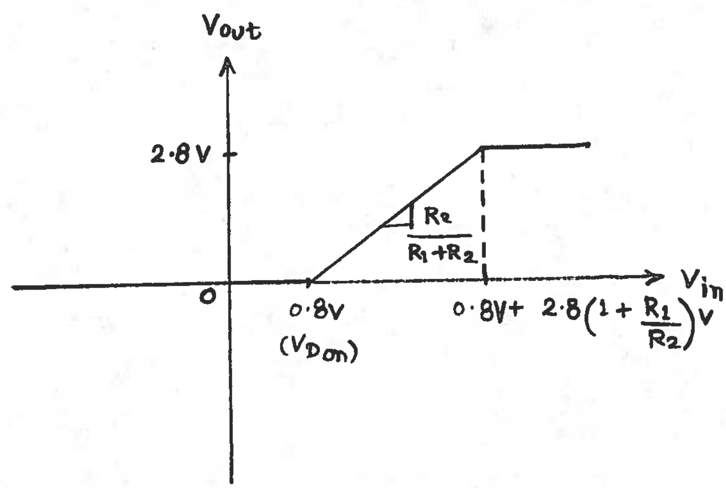
TOTAL ________ / 100

10 pts **Problem 1:**

Plot the input output characteristics assuming a constant voltage model with $V_{D\text{-}on} = 0.8V$ and $V_B = 2\ V$.



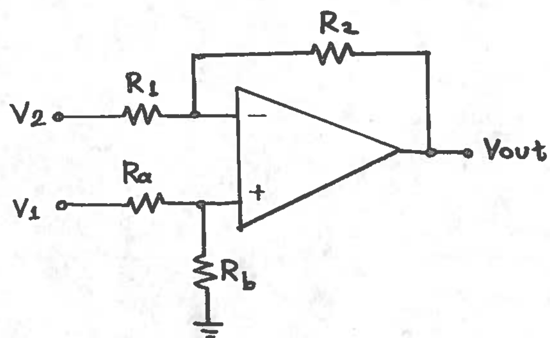
$$V_{out} = \begin{cases} 0, & V_{in} < V_{D\,on} \ldots (D1\ OFF) \\ \dfrac{R_2 (V_{in} - 0.8)}{R_1 + R_2}, & V_{D\,on} < V_{in} < 0.8 + 2.8\left(1 + \dfrac{R_1}{R_2}\right) V \ldots \left(\begin{matrix} D1\ ON \\ D2\ OFF \end{matrix}\right) \\ 2.8\ V, & V_{in} > 0.8V + 2.8\left(1 + \dfrac{R_1}{R_2}\right) V \ldots (D1, D2\ ON) \end{cases}$$



Problem 2:

10 pts **Operational Amplifiers:**

Design a circuit with two voltage inputs V_1 and V_2, using <u>one</u> ideal operational amplifier and a set of resistors, to obtain an output voltage given by the following expression:
$V_{out} = 3V_1 - 4V_2$.
You are free to choose any values for the resistors.



By superposition,

$$V_{out} = \underbrace{\left(1+\frac{R_2}{R_1}\right)\frac{R_b}{R_a+R_b}}_{3} V_1 - \underbrace{\frac{R_2}{R_1}}_{4} V_2$$

Let $R_1 = 1k\Omega \Rightarrow R_2 = 4k\Omega$

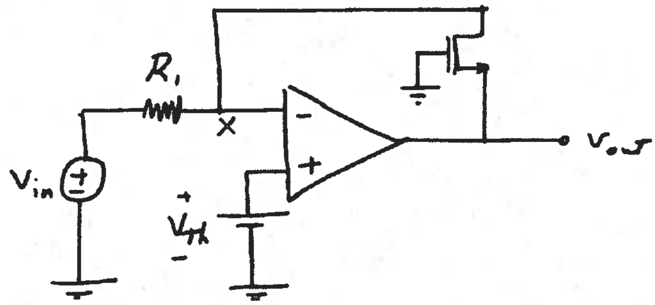
$$\therefore \frac{R_b}{R_a+R_b} = \frac{3}{5}$$

Let $R_b = 3k\Omega \Rightarrow R_a = 2k\Omega$

Ans. $R_1 = 1k\Omega$
$R_2 = 4k\Omega$
$R_a = 2k\Omega$
$R_b = 3k\Omega$

Problem 3:

10 pts The circuit shown below uses an ideal op amp. It is referred to as a true square-root amplifier. Determine V_{out} in terms of V_{in}.



Virtual short ⇒ $V_x = V_{TH}$

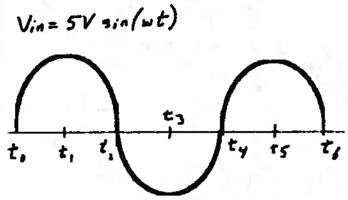
KCL at X ⇒ $\frac{V_{in} - V_{TH}}{R_1} = I_D = \mu_n C_{ox} \frac{W}{2L} (-V_{out} - V_{TH})^2$

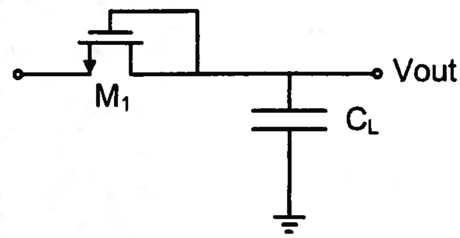
$$\Rightarrow \quad V_{out} = -V_{TH} - \sqrt{\frac{2(V_{in} - V_{TH})}{\mu_n C_{ox} \frac{W}{L} R_1}}$$

Problem 4:

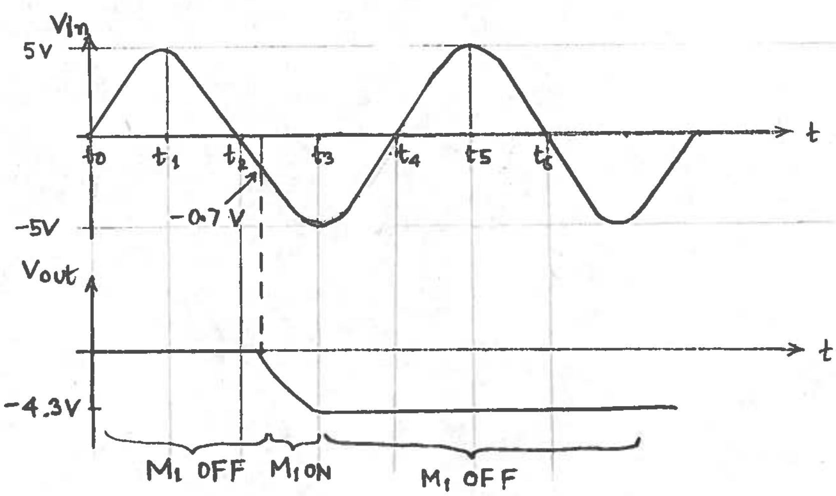
10 pts Describe the operation of the circuit at the following times and intervals

a) $t = t_0$
b) $t_0 < t < t_1$
c) $t_1 < t < t_2$
d) $t_2 < t < t_3$
e) $t_3 < t < t_4$
f) $t_4 < t$





Sketch output waveform assuming MOSFET has very large size and $V_{th}=0.7V$.
Note 1: The circuit does NOT operate under small signal conditions
Note 2: Assume capacitor is originally discharged and carries no charge.
Note 3: the NMOS is a symmetric device with respect to the Source and the Drain. The source is the terminal with lower potential as compared to the Drain.



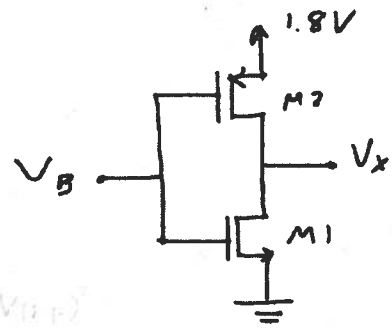
The circuit works as a peak detector / AC → DC converter.

Problem 5:

10 pts

$(W/L)_1 = 10/0.18$ $(W/L)_2 = 30/0.18$ $\lambda = 0.1\ V^{-1}$, $\mu_n C_{ox} = 200\ \mu A/V^2$, $\mu_p C_{ox} = 100\ \mu A/V^2$, $V_{thN} = 0.4V$, and $V_{thP} = -0.4V$

find V_B such that $V_x = 0.9V$.



$I_{D1} = I_{D2}$

$\mu_n C_{ox} \frac{W_1}{2L_1} (V_b - V_{thN})^2 (1 + \lambda \cdot V_x)$

$= \mu_p C_{ox} \frac{W_2}{2L_2} (V_b - 1.8 - V_{thP})^2 (1 - \lambda(V_x - V_{DD}))$

$\therefore\ 200 \times 10^{-6} \times \frac{10}{2(0.18)} (V_b - 0.4)^2 (1 + 0.09)$

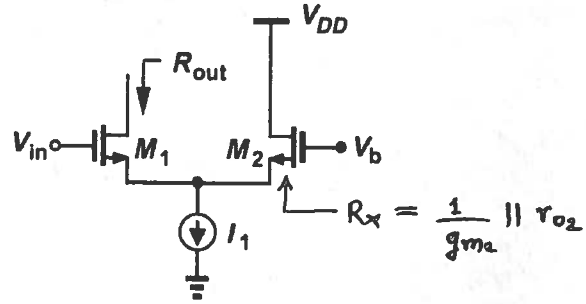
$= 100 \times 10^{-6} \times \frac{30}{2(0.18)} (V_b - 1.8 + 0.4)^2 (1 + 0.09)$

$\therefore\ V_b - 0.4 = (1.4 - V_b)\sqrt{1.5}$

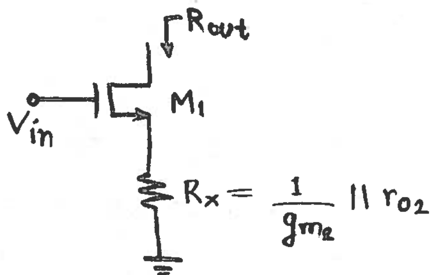
$\therefore\ \boxed{V_b = 0.95\ V}$

Problem 6:

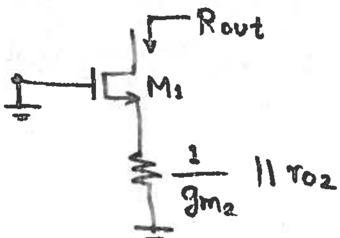
10 pts Determine the small signal output impedance for the circuit shown below. Assume $\lambda \neq 0$.



The circuit can be simplified for small-signals as follows:



To calculate Rout, set $V_{in} = 0$

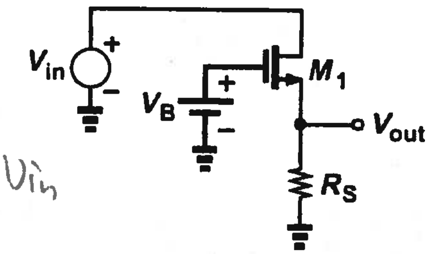


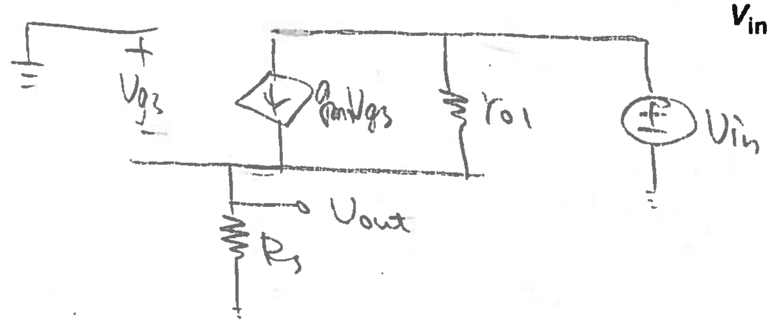
$$\therefore R_{out} = \left(\frac{1}{g_{m2}} \parallel r_{o2}\right)(1 + g_{m1} r_{o1}) + r_{o1}$$

Problem 7:

10 pts An adventurous student decides to try a new circuit topology wherein the input is applied to the drain and the output is sensed at the source. Assuming $\lambda \neq 0$, determine the voltage gain of the circuit and discuss the result.

Small signal equivalent circuit is shown below





$$g_{m1}(0 - V_{out}) + \frac{V_{in} - V_{out}}{r_{o1}} = \frac{V_{out}}{R_s}$$

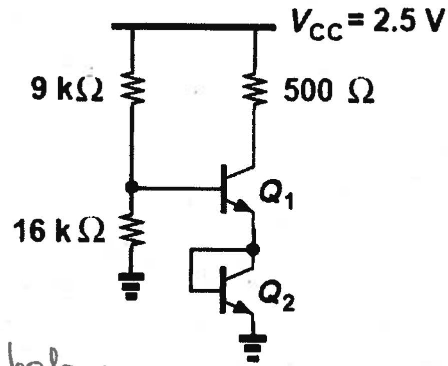
$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{1}{(1+\frac{r_{o1}}{R_s}) + g_{m1}r_{o1}}$$

Since $g_{m1}r_{o1} >> 1$ for most MOSFET, this circuit does not provide gain, thus is of little use.

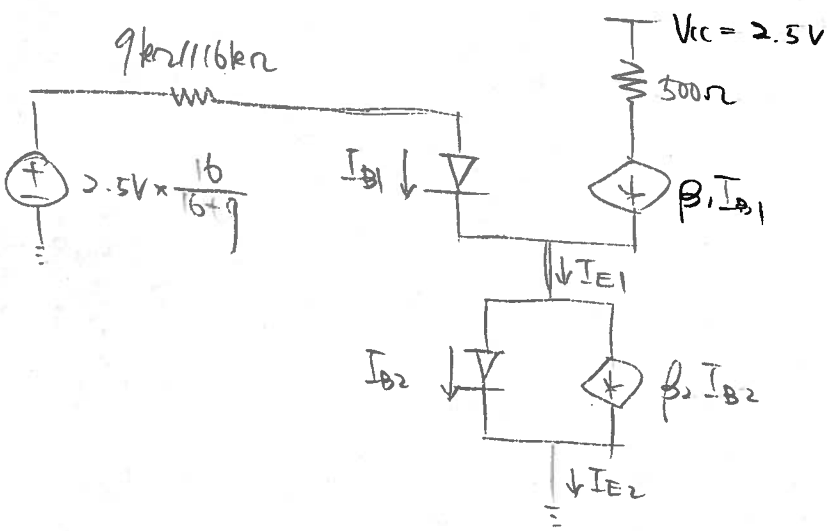
Problem 8:

15 pts

Calculate bias point of the circuit shown below, specifically we are looking for I_{B1}, I_{C1}, I_{C2}, V_{B1}, V_{C1} and V_{E1}. You may assume β=100; I_s-5x10^{-16} A and $V_A = \infty$.
Note: you may not assume that $V_{BE}=0.7V$, rather you need to make an attempt to ESTIMATE the proper values for V_{BE1} and V_{BE2}.



Equivalent circuit is shown below



As $I_{E1} = I_{E2}$ and $I_{E1} = I_s[\exp(\frac{V_{BE1}}{V_T})-1]$, $I_{E2} = I_s[\exp(\frac{V_{BE2}}{V_T})-1]$.

We know $V_{BE1} = V_{BE2}$. Thus,

$$\begin{cases} 2.5V \times \frac{16}{16+9} - I_{B1} \times (9k\Omega // 16k\Omega) - 2V_{BE1} = 0 \\ V_{BE1} = V_T \ln\left(\frac{\beta I_{B1}}{I_s}\right) \end{cases}$$

$\Rightarrow$ $V_{BE1} = V_{BE2} = 752mV$, $I_{B1} = I_{B2} = 0.0172mA$

$I_{C1} = I_{C2} = 1.72mA$, $V_{CE2} = 750mV$,

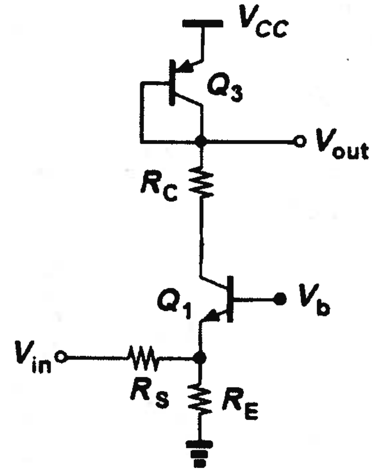
$V_{CE1} = 2.5V - I_{C1} \times 500\Omega - 750mV = 890mV > V_{BE1}$

$\Rightarrow$ Q_1, Q_2 both forward active.

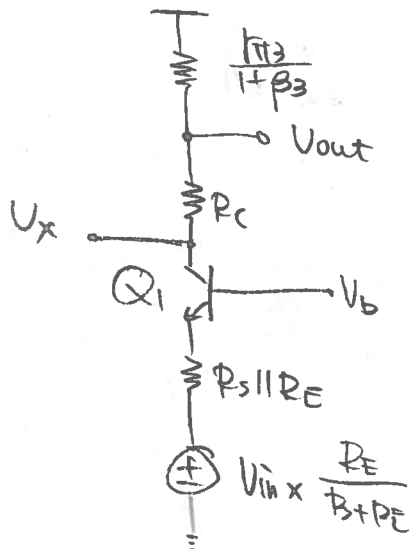
Problem 9:

15 pts

Find voltage gain of circuit below, assuming $V_A = \infty$.
Find output resistance of the same circuit, but assume $V_A \neq \infty$.

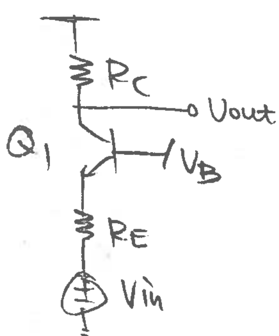


To find the gain, consider circuit below



$$\frac{V_{out}}{V_{in}} = \frac{V_x}{V_{in}} \times \frac{V_{out}}{V_x} = \frac{\beta_1 \times \frac{r_{\pi 3}}{1+\beta_3}}{(1+\beta_1)(R_S \| R_E) + r_{\pi 1}} \times \frac{\frac{r_{\pi 3}}{1+\beta_3}}{R_C + \frac{r_{\pi 3}}{1+\beta_3}}$$

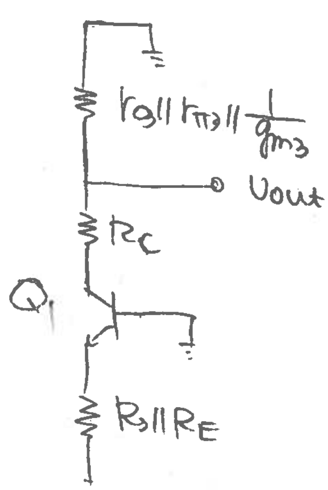
Hint:

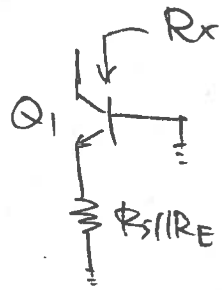


For this circuit, which is a basic common gate amplifier.

$$\frac{V_{out}}{V_{in}} = \frac{\beta R_C}{r_{\pi 1} + (1+\beta) R_E}$$

To find output resistance, circuit is show below





$$R_x = r_{o1} + (r_{\pi 1} \| R_S \| R_E) + g_{m1} r_{o1} (r_{\pi 1} \| R_S \| R_E)$$

Thus, $R_{out} = (R_C + R_x) \| \left(r_{o3} \| r_{\pi 3} \| \frac{1}{g_{m3}} \right)$

$$= \left[R_C + r_{o1} + (r_{\pi 1} \| R_S \| R_E) + g_{m1} r_{o1} (r_{\pi 1} \| R_S \| R_E) \right] \| r_{o3} \| r_{\pi 3} \| \frac{1}{g_{m3}}$$