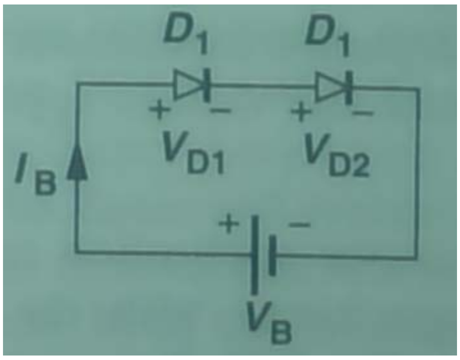
Digital Electronics Spring 2015 Midterm Exam 05/08/2015

Name: ID#

1. Two diodes with reverse saturation currents of I_{S1} and I_{S2} placed series. Calculate I_B , V_{D1} , and V_{D2} in terms of V_B , I_{S1} , and I_{S2} .



By KVL, $V_B = V_{D_1} + V_{D_2} = V_T \ln\left(\frac{I_B}{I_{S_1}}\right) + V_T \ln\left(\frac{I_B}{I_{S_2}}\right)$

$\Rightarrow V_B = V_T \ln\left(\frac{I_B^2}{I_{S_1} I_{S_2}}\right)$

$\therefore I_B = \sqrt{I_{S_1} I_{S_2} \cdot \exp V_B/V_T} = \sqrt{I_{S_1} I_{S_2}} \cdot \exp\left(\frac{V_B}{2V_T}\right)$

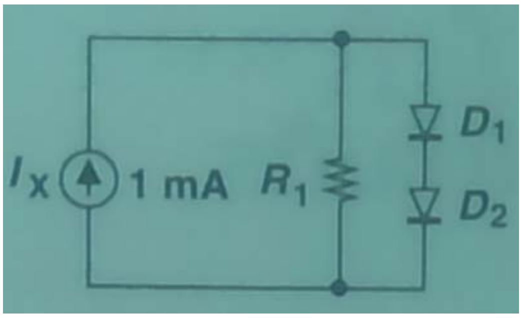
$V_{D_1} = V_T \ln\left(\frac{I_B}{I_{S_1}}\right) = V_T \ln\left(\frac{\sqrt{I_{S_1} I_{S_2}}}{I_{S_1}} \cdot \exp \frac{V_B}{2V_T}\right)$

$= V_T \ln \sqrt{\frac{I_{S_2}}{I_{S_1}}} + \frac{V_B}{2}$

$V_{D_2} = V_T \ln\left(\frac{I_B}{I_{S_2}}\right) = V_T \ln\left(\frac{\sqrt{I_{S_1} I_{S_2}}}{I_{S_2}} \cdot \exp \frac{V_B}{2V_T}\right)$

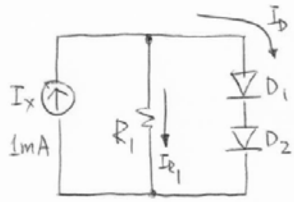
$= V_T \ln \sqrt{\frac{I_{S_1}}{I_{S_2}}} + \frac{V_B}{2}$

2. (10%) Determine the value of R_1 such that R_1 carries 0.5mA. Assume $I_S = 5\times10^{-16}$ A for each diode.



Ans:

24.



Given $I_{R_1} = 0.5\,mA$, $I_S = 5\cdot10^{-16} A$ for each diode.

Find R_1.

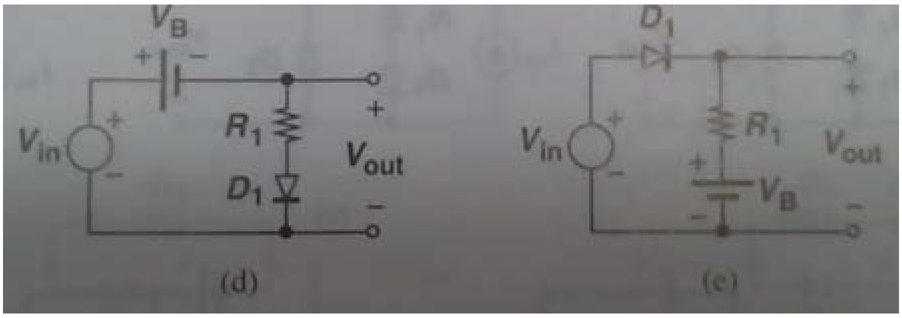
By KCL, $I_D = I_X - I_{R_1} = 0.5\,mA$

$\Rightarrow V_{D_1} = V_{D_2} = V_T \ln\left(\frac{I_D}{I_S}\right) = 0.026 \ln\left(\frac{0.5mA}{5\cdot10^{-16}A}\right)$

$\approx 0.718\ V$

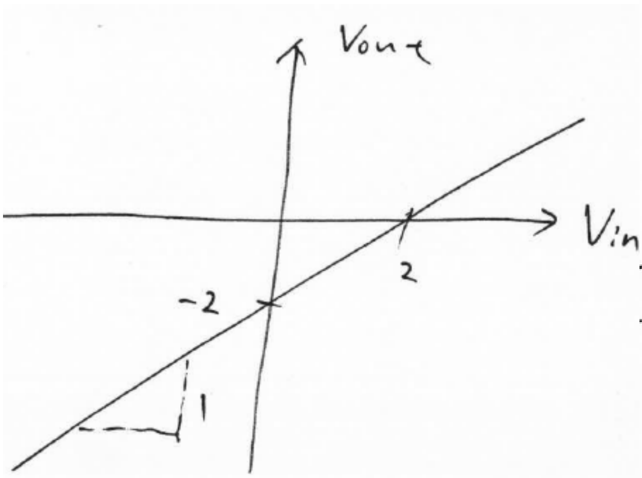
$\therefore R_1 = \frac{V_{R_1}}{I_{R_1}} = \frac{2V_{D_1}}{I_{R_1}} = \frac{2(0.718V)}{0.5mA} \approx 2.87\,k\Omega$

3. (10%) Plot the input/output characteristics of the circuit shown below using an ideal model for the diode. (Assume V_B =2V).

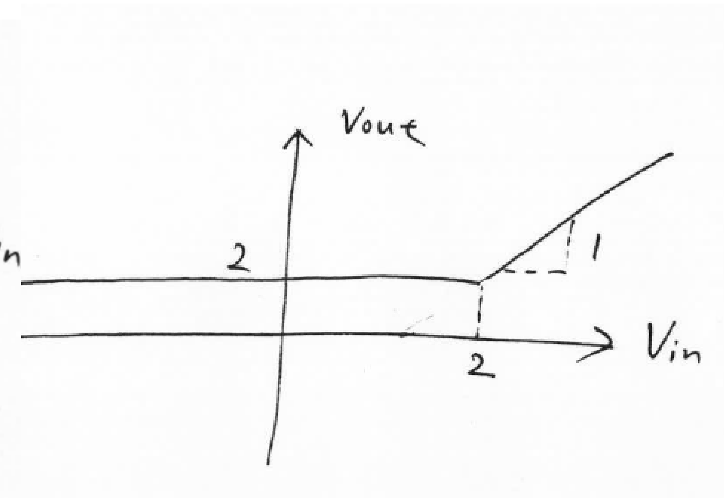


Ans:

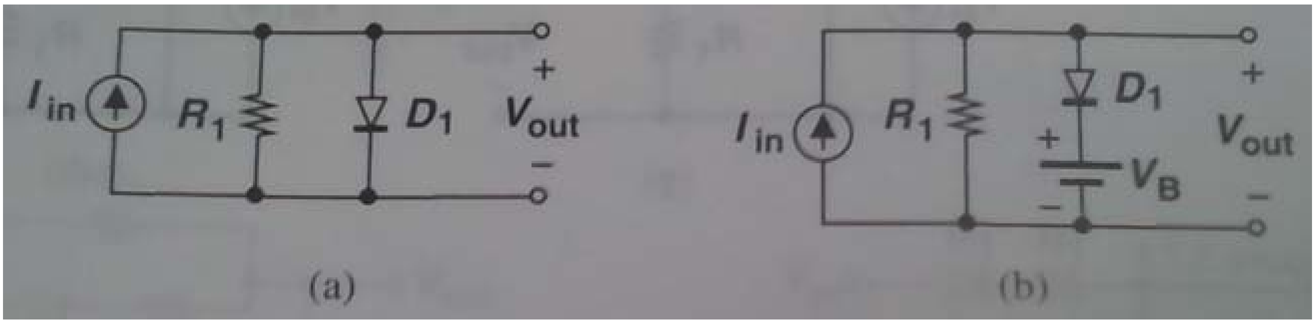
(d)



(e)

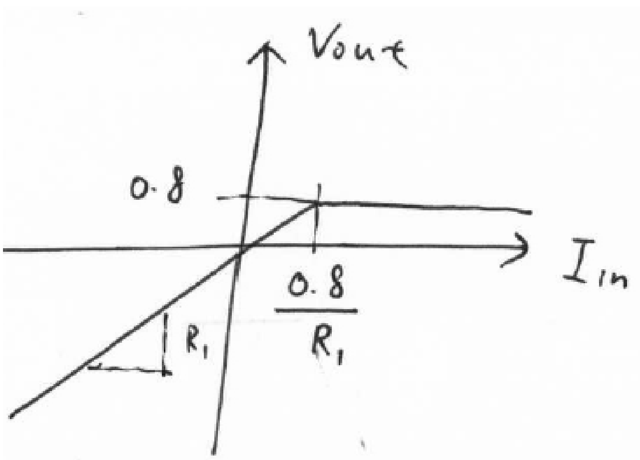


4. (10%) Assume constant voltage diode model, plot V_{out} as a function of I_{in} for the circuits shown below. (Assume V_B =2V).

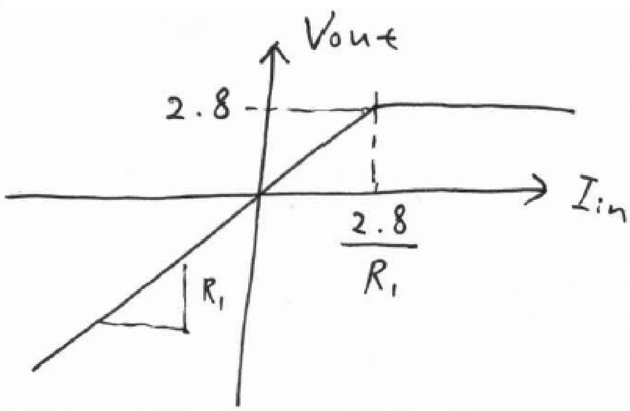


Ans:

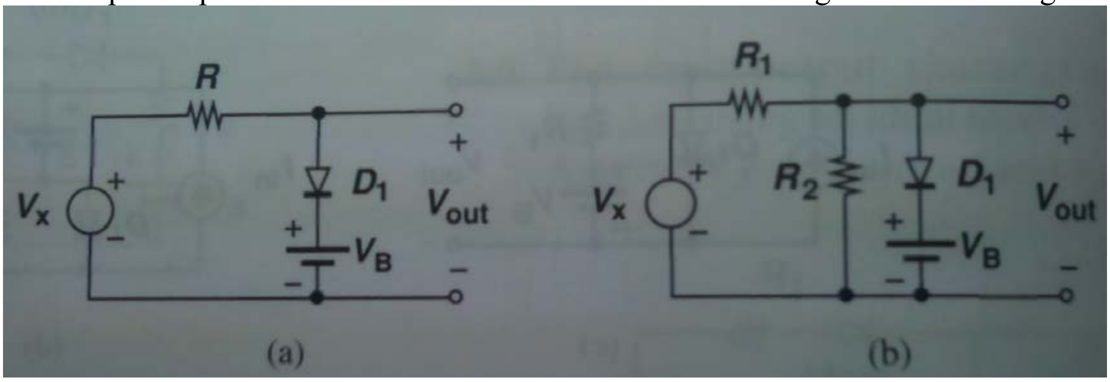
(a)



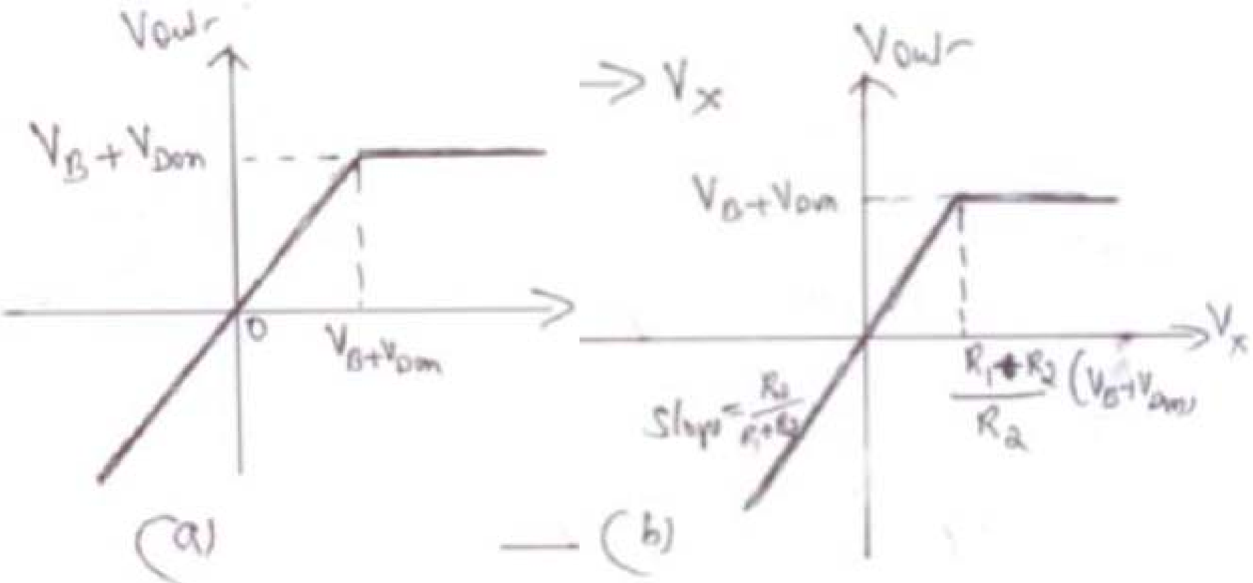
(b)



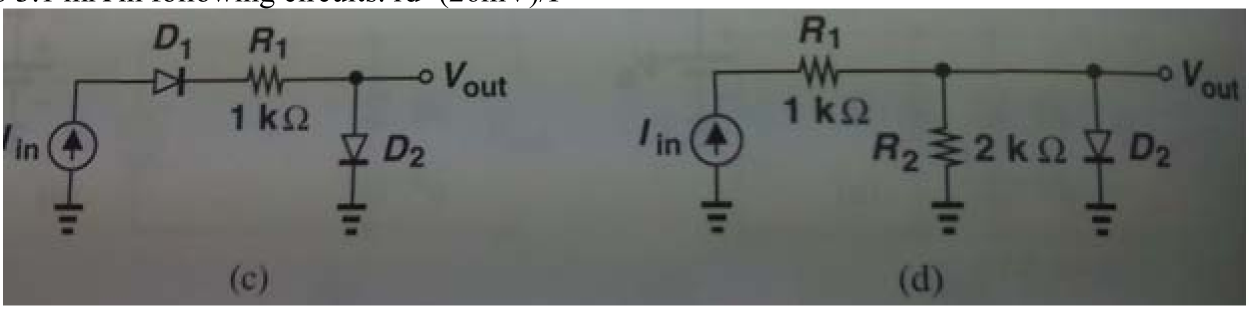
5. (10%) Plot the input/output characteristics of the circuit below. Assuming a constant voltage diode model.



Ans:



6. (10%) Beginning with $V_{D,on} \cong 800\text{mV}$ for each diode, calculate the change in V_{out} if I_{in} changes from 3 mA to 3.1 mA in following circuits. rd=(26mV)/I



Ans:

c) $V_{out} = i \times r_{d2}$

$= 0.1\,mA \times 8.67$ (from (b))

$= 0.867\,mV$

d) $V_{out} = i \times (R_2 \,//\, r_{d2})$

$\approx i \times r_{d2}$ ($\because R_2 >> r_{d2}$)

$= 0.867\,mV$

$\mu_n C_{ox} = 200\ \mu A/V^2$, $\mu_p C_{ox} = 100\ \mu A/V^2$, NMOS $V_{TH} = 0.4$ V, PMOS $V_{TH} = -0.4$ V,

7. (10%) Calculate the value of drain current in the circuit shown below, with W=5μm, L =0.5μm, and $\lambda = 0$.

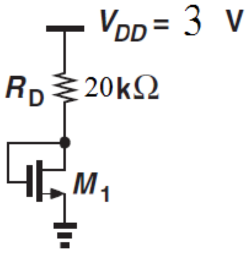


Fig 6.37

Ans:

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$$

$$V_{GS} = V_{DD} - I_D R_D$$
$$= 3 - I_D 20k$$

$$I_D = \frac{1}{2} \times 200 \times 10^{-6} \times \frac{5 \times 10^{-6}}{0.5 \times 10^{-6}} \times (3 - I_D 20k - 0.4)^2$$

$$(I_D 20k)^2 - 105 I_D + 2.6^2 = 0.$$

$$I_D = 113.17\mu A$$

$$\text{Overdrive voltage } V_{ov} = \sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}} = 0.336 \text{ V}$$

$$V_{GS} = V_{TH} + V_{ov}$$
$$= 0.736 \text{ V}.$$

8. (10%) What is the current when $V_{GS} = 2V_{TH}$? Find the region in which the device operates.

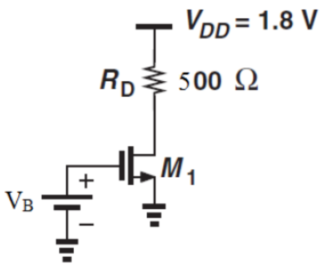


Fig 6.42

ANS:

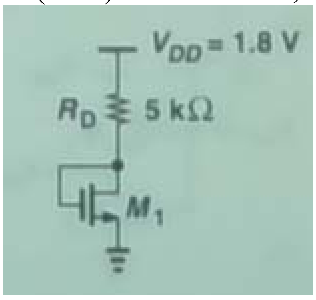
Assume that the device is in the saturation region. Then,

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2$$
$$= \frac{1}{2} \times 200 \times 10^{-6} \times \frac{10}{0.14}(2V_{TH} - V_{TH})^2$$
$$= \frac{1}{2} \times 200 \times 10^{-6} \times \frac{10}{0.14}(V_{TH})^2$$
$$= \frac{1}{2} \times 200 \times 10^{-6} \times \frac{10}{0.14}(0.4)^2$$
$$= 1.142 \text{ mA}$$

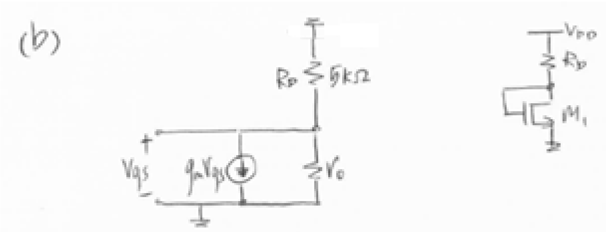
$$V_{DS} = V_{DD} - I_D R_D$$
$$= 1.8 - 500 \times 1.142 \times 10^{-3}$$
$$= 1.23 \text{ V}.$$

Since $V_{DS} > V_{GS} - V_{TH}$, the device operates in the saturation region.

9. (10%) If $\lambda = 0.1\ V^{-1}$, $W/L = 20/0.18$, construct the small-signal model of each of the circuits shown below



Ans:



$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS}-V_{TH}) = \frac{200\mu A}{V^2}\left(\frac{20}{0.18}\right)(0.146V)$$

$$\approx 0.00324\ 1/\Omega$$

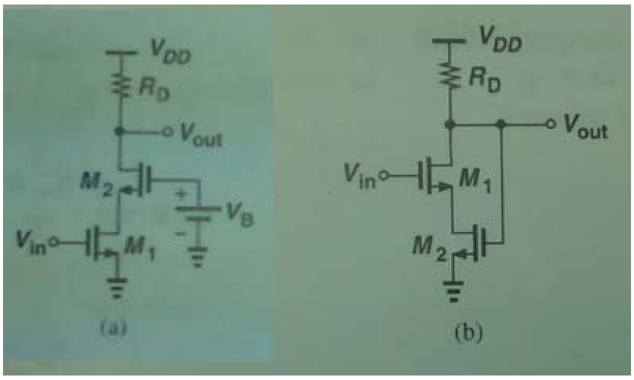
By KCL, $\frac{V_{DD}-V_{GS}}{R_D} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2(1+\lambda V_{GS})$

Solving this yields $V_{GS} \approx 0.546\ V > V_{TH}$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{\lambda\left(\frac{V_{DD}-V_{GS}}{R_D}\right)} = \frac{1}{0.1V^{-1}\left(\frac{1.8-0.546}{5k}\right)}$$

$$\approx 40.\ k\Omega$$

10.(10%) Construct the small-signal model of the circuits. Assume all transistors operate in saturation and $\lambda \neq 0$.



ANS: