EE 115A Analog Electronic Circuits

Winter 2013

Test 1

Closed Book

Name: Solution

Student ID No.: Solution

1) ________ / 10

2) ________ / 12

3) ________ / 10

4) ________ / 8

TOTAL ________ / 40

10 pts 1) Provide a short answer to each of the following.

2 pts a) Why/How is the depletion region formed in a PN junction when there is nothing connected to the terminals?

Electrons tend to diffuse from N-type to P-type while holes tend to diffuse from P-type to N-type. Diffusion leaves immobile atoms which forms depletion region. (1pt) Depletion region creates electrical field which opposes diffusion so that net current is zero at equilibrium. (1pt)

2 pts b) Name 4 Operations that are possible with analog electronics but are not possible if you were constrained to the tools and circuit elements used in EE10 and EE110?

(1) AC–DC converter (Voltage doubler, tripler ......)

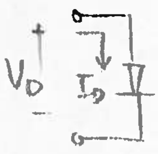
(2) Rectifier (Full wave, half wave ...)

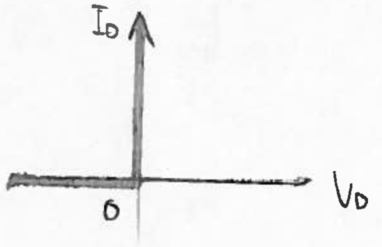
(3) Switch (Frequency translation, create digital logic ...)

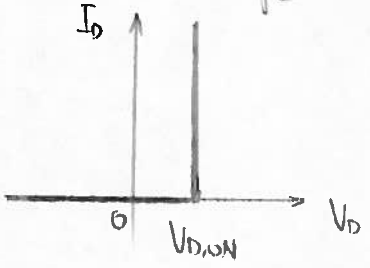
(4) Data Converters (Analog to digital, digital to analog)

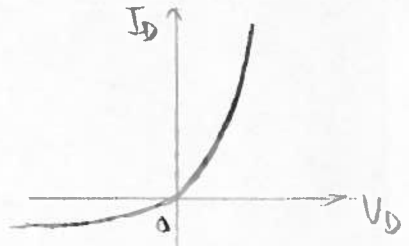
2 pts c) Name the three different diode models/equations. Why do we have three different diode models?

(1) Ideal diode (2) Constant Voltage model (3) Exponential mode









$$\begin{cases} I_D = I_S\left(e^{\frac{V_D}{V_T}} - 1\right) \\ V_T = \frac{kT}{q} \end{cases}$$

(c)&(d) graded together, 4 pts in total

2 pts d) When should we use each of the three different diode models?

Ideal diode model provides a quick understanding of circuit behavior

Constant voltage model is a much better approximation to real model.

Exponential model is the most accurate, but takes much more effort to solve. It is only use when great accuracy is demanded

2 pts e) Name 4 of the factors that determine the amount of current flowing in a PN-junction

(1) Doping density

(2) cross section area of PN-junction

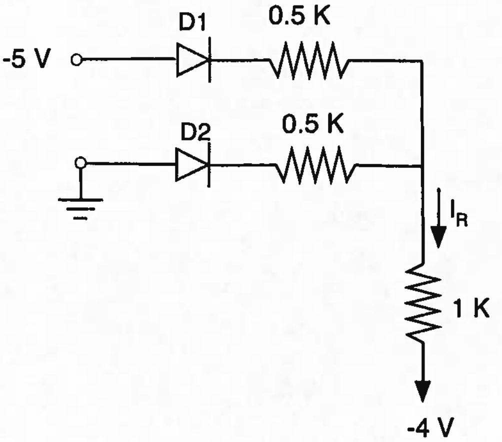
(3) Voltage applied to PN-junction

(4) temprature, determines V_T

2) Find the value of the current flowing in the 1K resistance.

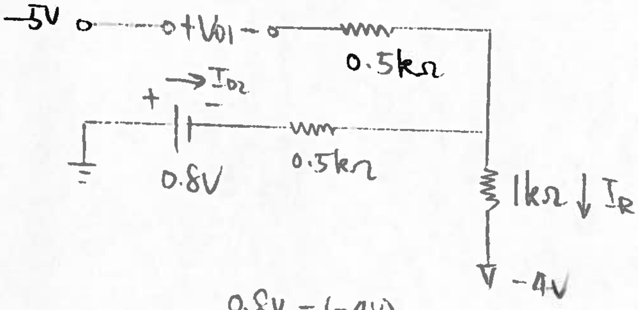
(a) Use the constant voltage drop model for the diodes, with $V_{D\text{-}on} = 0.8V$

12 pts (b) Use the real-diode equation with $I_s = 1.7 \times 10^{-17}$ A. Feel free to make "engineering" assumptions to solve the problem. Be sure to state all your assumptions.



(a) Assume D_1 OFF, D_2 ON

Equivalent circuit is shown below



$$I_{D2} = \frac{0.8V - (-4V)}{0.5k\Omega + 1k\Omega} = 2.13mA > 0$$

$$V_{D1} = -5V - (-4V + 2.13mA \times 1k\Omega) = -3.13V < 0.8V$$

$\Rightarrow$ Assumption is correct D_1 OFF, D_2 ON

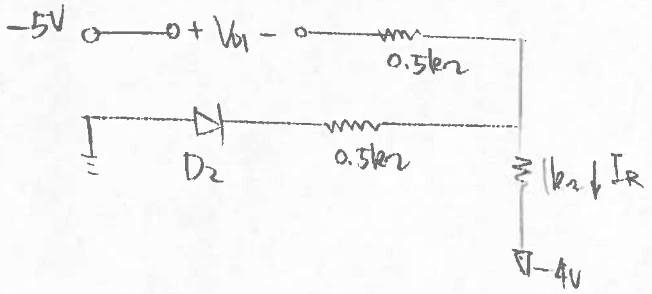
Thus, $\boxed{I_R = I_{D2} = 2.13mA}$

(b) From (a), we know that V_{D1} is very negative, so

$$I_{D1} = I_s(e^{\frac{V_{D1}}{V_T}} - 1) \approx -I_s \approx 0 \quad \text{with } V_{D1} << 0 \text{ and } I_{s1} = 1.7 \times 10^{-17} A$$

With $I_{D1} \approx 0$, D_1 can be regarded as open circuit. This assumption only creates ignorable error with $I_{D2} >> I_s$.

Equivalent circuit is shown below



$$I_s(e^{\frac{V_{D2}}{V_T}} - 1) = \frac{0 - V_D - (-4V)}{1.5k\Omega}$$

$V_T = 26mV$ @ 300K, room temprature

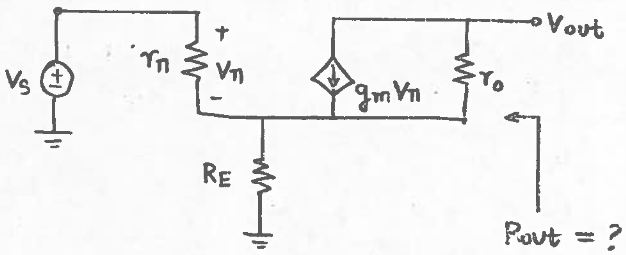
$$\Rightarrow I_R = I_s(e^{\frac{V_{D2}}{V_T}} - 1) = 2.105mA$$

$$\Rightarrow V_{D1} = -5V - (-4V + 2.105mA \times 1k\Omega) = -3.1V$$

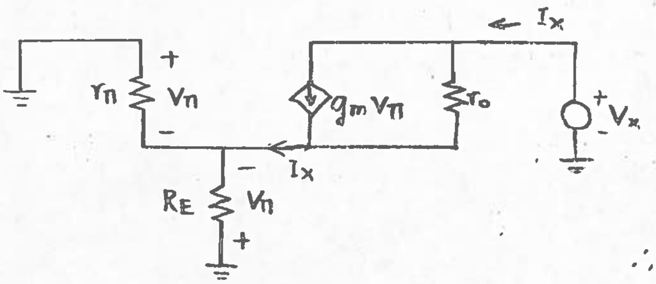
It further verifies that our assumption that $I_{D1} \approx -I_{s1} = -1.7 \times 10^{-17} A << I_{D2}$

So $\boxed{I_R = I_{R2} = 2.105mA}$

(3) Excluding R_c,



To calculate R_{out}, we suppress all independent sources



$$R_{out} = V_x / I_x$$

$$I_x = \frac{-V_\pi}{(R_E \parallel r_\pi)}$$

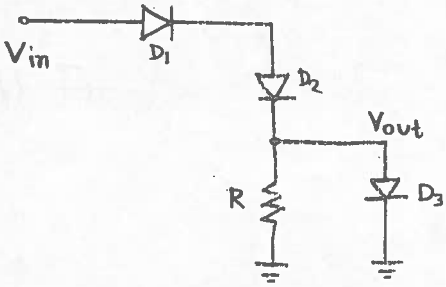
$$V_x = V_{r_o} - V_\pi$$

$$\therefore \quad V_x = (I_x - g_m V_\pi)\, r_o - V_\pi$$

$$\therefore \quad V_x = I_x \{1 + g_m (R_E \parallel r_\pi)\}\, r_o + (R_E \parallel r_\pi) I_x$$

$$\therefore \boxed{R_{out} = \frac{V_x}{I_x} = (R_E \parallel r_\pi) + r_o + g_m r_o (R_E \parallel r_\pi)}$$

(4)



Plot. V_{out} vs V_{in}.

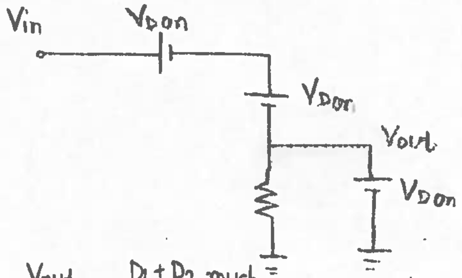
For $V_{in} < 2V_{Don}$, D_1 & D_2 off $\Rightarrow V_{out} = 0 \Rightarrow D_3$ off

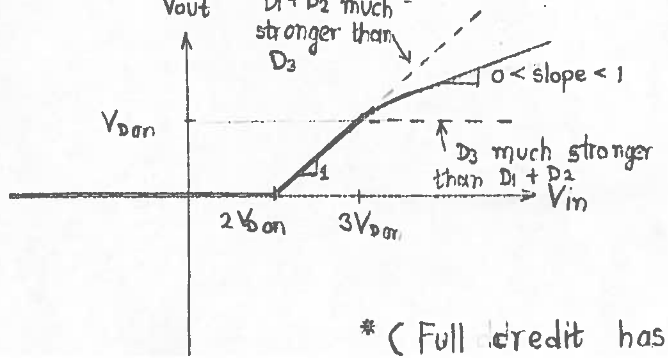
For $2V_{Don} \le V_{in} < 3V_{Don}$, D_1 & D_2 on

$\Rightarrow V_{out} = V_{in} - 2V_{Don}$

But when $V_{out} \geq V_{Don}$, D_3 turns on & now we have following situation

At $V_{out} \geq V_{Don}$ i.e. $V_{in} \geq 3V_{Don}$





$V_{out} \overset{?}{=} V_{in} - 2V_{Don} \overset{?}{=} V_{Don}$ which is not possible. Hence constant voltage model fails. So, at this point we can make following argument. If D_3 was absent, $V_{out} = V_{in} - 2V_{Don}$. If $D_1 + D_2$ were absent, $V_{out} = V_{Don}$. But since all 3 are present V_{out} will be some intermediate voltage as shown (a first order approximation) & slope of V_{out} will depend on relative strength of D_3 & $D_1 + D_2$.

* (Full credit has been given if you got either of the dotted lines)