EECE 2412 : HW 3 Solutions

Fall 2018

Prob. 1

As stated on page 133 in the textbook, the diode voltage decreases approximately 2 mV/K with a temperature change

↳ = 2 mV/°C

$T_0 = 25°C$ $\quad$ $T_1 = ?$

$V_0 = 0.65\,V$ $\quad$ $V_1 = 0.45\,V$

$$V_1 - V_0 = -2\,\frac{mV}{°C}\cdot(T_1 - T_0)$$

$$\hookrightarrow T_1 = \frac{V_1 - V_0}{-2\,\frac{mV}{°C}} + T_0$$

$$T_1 = \frac{0.45V - 0.65V}{-0.002\,\frac{V}{°C}} + 25°C$$

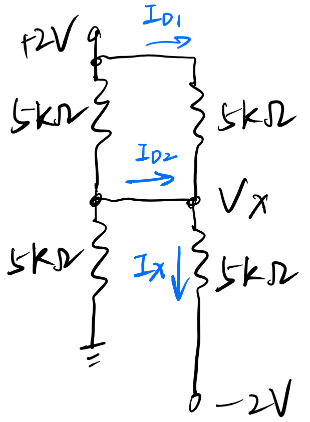
$$\boxed{T_1 = 125°C}$$

(2)

Problem (2)

FB: forward-biased
RB: reverse-biased

(a) equivalent circuit (both D_1 and D_2 are on)



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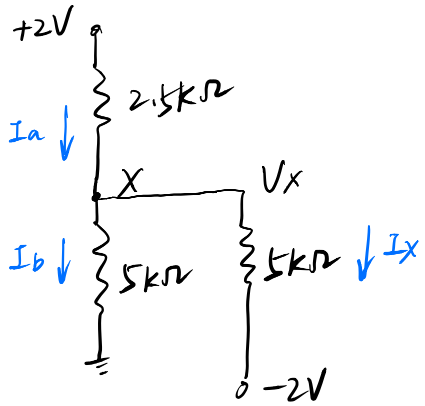


KCL at node X:

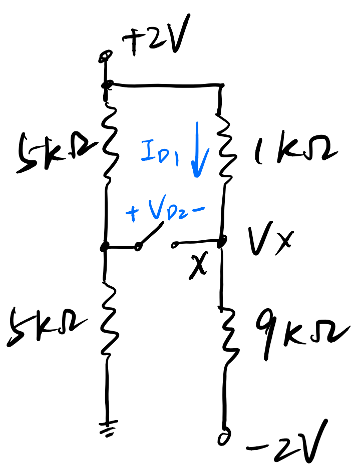
$$I_a = \frac{2-V_x}{2.5k\Omega} = I_b + I_x = \frac{V_x}{5k\Omega} + \frac{V_x+2}{5k\Omega}$$

$V_x = 0.5V$
$I_x = 500\ \mu A$

Checks: Diode 1: $I_{D_1} = \frac{2-V_x}{5k\Omega} = 300\mu A > 0$, diode 1 is on. (FB)

Diode 2: $I_{D_2} = \frac{2-V_x}{5k\Omega} - \frac{V_x}{5k\Omega} = 200\mu A > 0$, diode 2 is on. (FB)

(b) equivalent circuit (D_1 on, D_2 off)



$$I_x = \frac{V_x-(-2)}{9k\Omega}$$

$$V_x = \frac{2-(-2)}{1k\Omega+9k\Omega} \times 9k\Omega - (-2V)$$

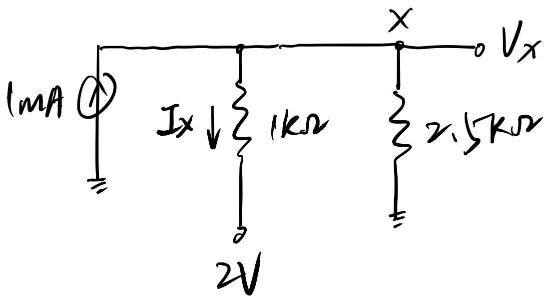
$V_x = 1.6V$
$I_x = 400\ \mu A$

checks: Diode 1: $I_{D_1} = \frac{2-V_x}{1k\Omega} = 400\mu A > 0$, diode 1 is on (FB)

Diode 2: $V_{D_2} = 2 \times \frac{1}{2} - V_x = -0.6V < 0$, diode 2 is off (RB)

(3)

(c) equivalent circuit (assume D_1 is on):



KCL at node X:

$$1mA = I_x + \frac{V_x}{2.5k\Omega}$$

$$= \frac{V_x - 2}{1k\Omega} + \frac{V_x}{2.5k\Omega}$$

$$V_x = 2.143V$$

$$I_x = \frac{V_x - 2}{1k\Omega}$$

$$V_x = 2.143\,V$$
$$I_x = 142.8\,\mu A$$

Checks: Diode 1: $I_{D_1} = \frac{V_x - 2}{1k\Omega} = 143\,\mu A > 0$

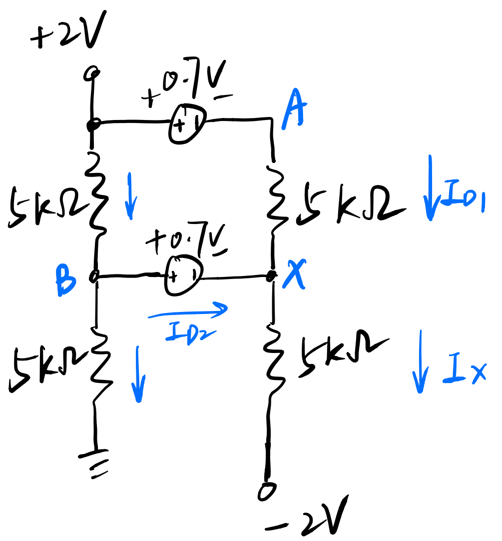
diode 1 is on (FB)

(IX)

Problem (3)

FB: forward-biased
RB: reverse-biased

(a) equivalent circuit (both D_1 and D_2 are on)



$V_A = 2 - 0.7 = 1.3V$

$V_X = V_B - 0.7$

KCL at node B:

$$\frac{2 - V_B}{5k\Omega} = \frac{V_B}{5k\Omega} + I_{D2}, \quad (V_B = V_X + 0.7) \qquad ①$$

KCL at node X:

$$I_{D2} + \frac{V_A - V_X}{5k\Omega} = I_X, \quad \left(I_X = \frac{V_X + 2}{5k\Omega}\right) \qquad ②$$

① $I_{D2} = \frac{2 \overbrace{- V_X - 0.7}^{-V_B}}{5k\Omega} - \frac{V_X + 0.7}{5k\Omega}$

② $I_{D2} = \frac{V_X + 2}{5k\Omega} - \frac{V_A - V_X}{5k\Omega}$

$\xrightarrow{① = ②}$ $\left(I_X = \frac{V_X + 2}{5k\Omega}\right)$

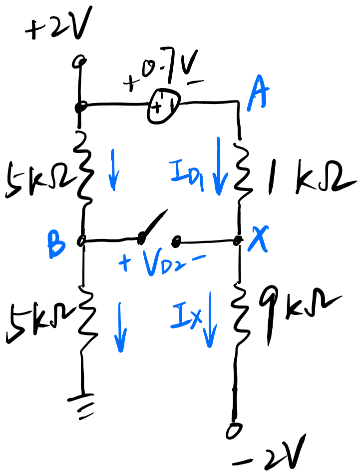
$V_X = -25\,mV$

$I_X = 395\,\mu A$

Checks: Diode 1: $I_{D1} = \frac{V_A - V_X}{5k\Omega} = 265\,\mu A > 0$, diode 1 is on (FB)

Diode 2: $I_{D2} = \frac{2 - V_B}{5k\Omega} - \frac{V_B}{5k\Omega} = 130\,\mu A > 0$, diode 2 is on (FB)

⑤ (b) equivalent circuit (D_1 on, D_2 off)



$V_A = 2 - 0.7 = 1.3V$ $\quad V_B = 2 \times \frac{1}{2} = 1V$

$V_X = (V_A + 2) \cdot \frac{9k\Omega}{1 + 9k\Omega} - 2 = 0.97V$

$I_X = \frac{V_X + 2}{9k\Omega} = 330\mu A$

$V_X = 0.97V$

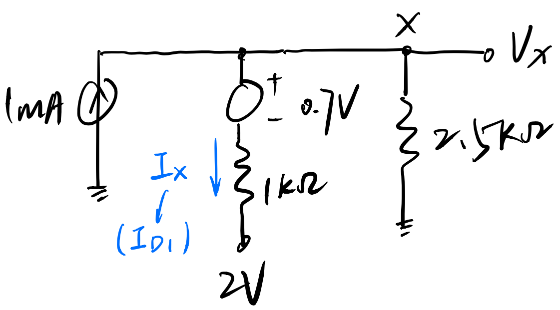
$I_X = 330\mu A$

Checks: Diode 1: $I_{D1} = \frac{V_A - V_X}{1k\Omega} = 330\mu A > 0$, diode 1 is on (FB)

Diode 2: $V_{D2} = V_B - V_X = 2 \times \frac{1}{2} - 0.97 = 0.03V < 0.7V$

diode 2 is off (RB)

(c) equivalent circuit (assume D_1 is on):



KCL at node X:

$1mA = \frac{V_X}{2.5k\Omega} + I_X$

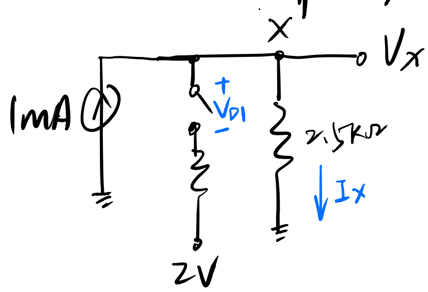
$\left(I_X = \frac{V_X - 0.7 - 2}{1k\Omega} \right)$

$V_X = 2.64\ V$

checks $I_{D1} = I_X = \frac{V_X - 0.7 - 2}{1k\Omega} = -30\mu A < 0$

when diode is on (FB), I_{D1} should always > 0, therefore assumption "diode 1 is on" is WRONG (Note: different from problem 2C)

Diode 1 is off (RB)



$V_X = 1mA \times 2.5k\Omega = 2.5V$

$I_X = 1mA$

$V_X = 2.5V$

checks

$V_{D1} = V_X - 2 = 0.5V < 0.7V$

diode 1 is off (RB)

(6)

Prob. 4

$I_s = ?$
$I_D = 2.5\,mA$
$V_D = 0.736\,V$
$n = 1$
$T = 50°C = 323\,K$

$$V_T = \frac{k \cdot T}{q} = \frac{(1.38 \times 10^{-23}\,\frac{J}{K}) \cdot (323\,K)}{1.60 \times 10^{-19}\,C}$$

$$V_T = 27.859\,mV$$

$$I_D = I_s \cdot \left[e^{\left(\frac{V_D}{n \cdot V_T}\right)} - 1 \right]$$

$$\hookrightarrow I_s = \frac{I_D}{e^{\frac{V_D}{n \cdot V_T}} - 1}$$

$$I_s = \frac{2.5 \times 10^{-3}\,A}{e^{\left(\frac{0.736\,V}{1 \cdot 27.859 \times 10^{-3}\,V}\right)} - 1}$$

$$\boxed{I_s = 8.401 \times 10^{-15}\,A = 8.401\,fA}$$

7

Problem 5

$V_D = V_{Z0} + r_Z \cdot I_Z$

$9.1V = V_{Z0} + 5\Omega \cdot (28 \times 10^{-3} A)$

$\hookrightarrow$ $\boxed{V_{Z0} = 8.96V}$

with $I_Z = 10mA$:

$V_O = 8.96V + 5\Omega \cdot 10 \times 10^{-3} A = \boxed{9.01V = V_{D(10mA)}}$

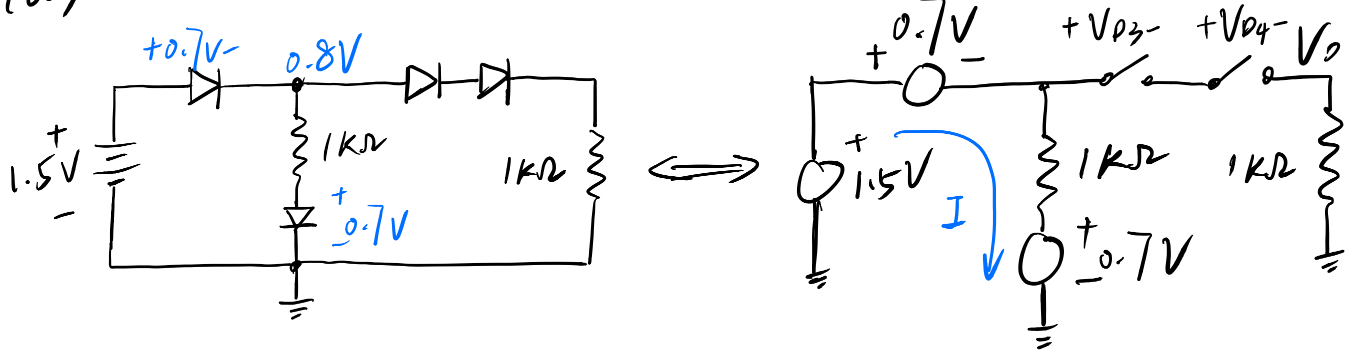
with $I_Z = 100mA$:

$V_O = 8.96V + 5\Omega \cdot 100 \times 10^{-3} A = \boxed{9.46V = V_{D(100mA)}}$

⑧

Problem (6)

(a)



Output node is open circuit (no current). $\boxed{V_o = 0V}$

$$I = \frac{1.5 - 0.7 \times 2}{1k\Omega} = 0.1mA = 100\mu A$$

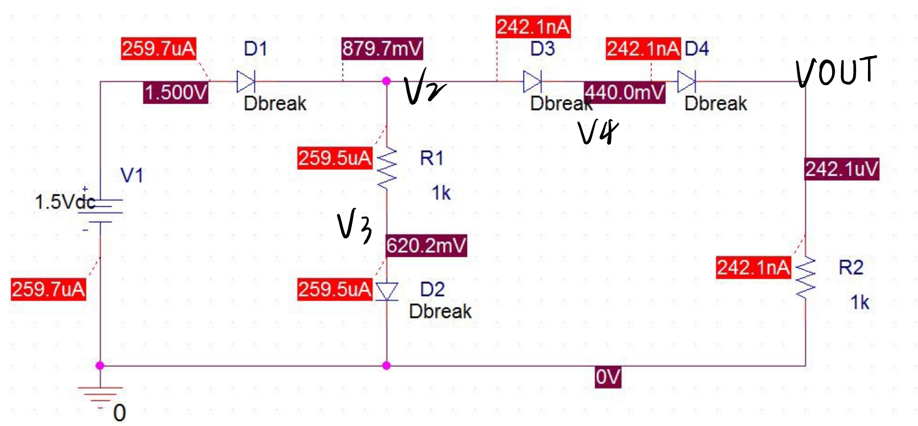
checks $I_{D_1} = I_{D_2} = I = 100\mu A > 0$

D1 and D2 are forward biased (FB)

$V_{D_3} + V_{D_4} = 0.8V < 1.4V$

D3 and D4 are reverse biased (RB)

(b) verification with $V_i = 1.5V$



✓ The on/off states of the diodes agree with the analytical results

✓ Note that the currents through diodes are different than the hand calculation results due to the simplification of the CVD model with 0.7V forward-bias drop voltage which is lower with the simulation model.

(9) (c) Transfer characteristics (voltage drop across diode is 620.3mV)