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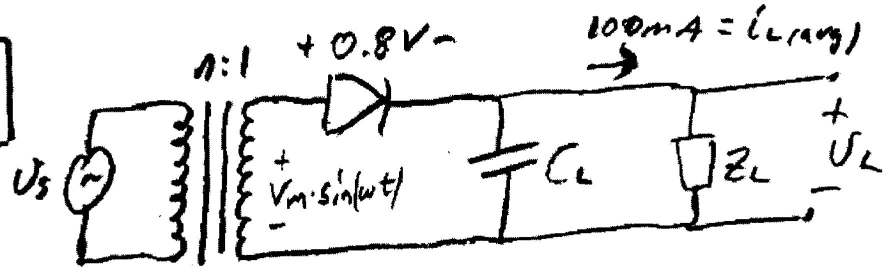
Homework 4 Solutions

Fall 2018

Prob. 1



1.) $V_{L(avg)} = 9V \pm 1V$ ripple (2 V peak-peak) → $\boxed{V_{L(min)} = 8V}$

$\boxed{V_{L(max)} = 10V}$

2.) KVL:

$V_{L(peak)} = -0.8V + V_m = 10V$ → $\boxed{V_m = 10.8V}$

3.) $V_{s(peak)} = V_{s(RMS)} \cdot \sqrt{2} = 110V \cdot \sqrt{2} = 155.563V$

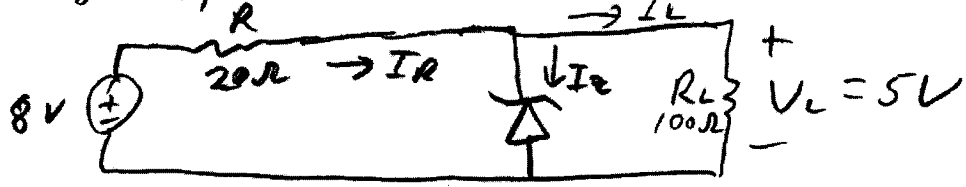
$$n = \frac{V_{s(peak)}}{V_m} = \frac{155.563V}{10.8V} = \boxed{14.4 = n}$$

4.) Using equation 3.4 in the book:

$$C = \frac{i_{L(avg)} \cdot T}{V_r} = \frac{(100mA)\cdot\left(\frac{1}{60Hz}\right)}{2V}$$

Problem 2

DC equivalent circuit for Q-point analysis:



$$I_R = \frac{8V - 5V}{20\Omega} = 150mA$$

$$I_L = \frac{5V}{100\Omega} = 50mA$$

KCL: $I_R = I_L + I_Z \rightarrow I_Z = 150mA - 50mA = 100mA$

$$\boxed{I_{Z\,Q\text{-point}} = 100mA}$$

Equivalent circuit for AC analysis:

$$v_L = V_{ripple} \cdot \left(\frac{R_L \| r_d}{R_L \| r_d + R} \right)$$

$$v_L = V_{ripple} \cdot \frac{\left(\frac{1}{R_L} + \frac{1}{r_d}\right)^{-1}}{\left(\frac{1}{R_L} + \frac{1}{r_d}\right)^{-1} + R}$$

$$10 \times 10^{-3} V = 1V \cdot \frac{\left(\frac{1}{100} + \frac{1}{r_d}\right)^{-1}}{\left(\frac{1}{100} + \frac{1}{r_d}\right) + 20}$$

solve for rd

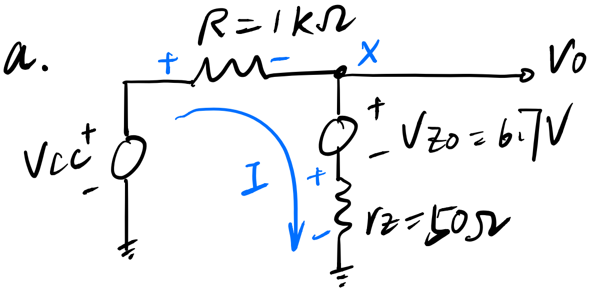
max. allowed resistance:

$$\boxed{r_d = 0.2024\ \Omega}$$

③

Problem (3)

a.



KVL: $(R+r_Z)\cdot I = V_{CC} - V_{Z0}$

$$I = \frac{15-6.7}{1000+50} = 7.905\,mA$$

$$V_o = V_{Z0} + r_Z \cdot I$$
$$= 6.7 + 50 \times 7.905\,mA$$

$$\boxed{V_o = 7.095\,V}$$

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b. $V_{ripple} = \pm 1V$

$$\frac{\Delta V_o}{V_{ripple}} = \frac{r_Z}{R+r_Z} = \frac{50}{1050}$$

$$\Delta V_o = \frac{50}{1050} \times (\pm 1V) = \pm 47.619\,mV$$

$$\boxed{\Delta V_o = \pm 47.619\,mV}$$

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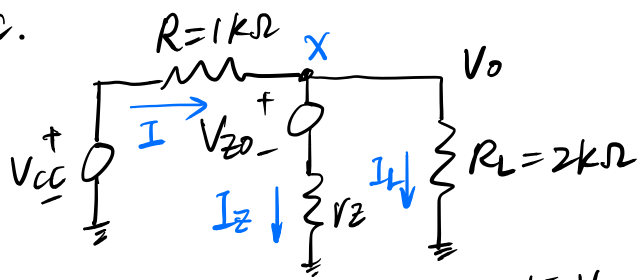
c.



KCL at node X:

$I = I_{ZK} + I_L$

$$\begin{cases} I = \dfrac{V_{CC}-V_o}{R} \\ I_Z = \dfrac{V_o - V_{Z0}}{r_Z} \\ I_L = \dfrac{V_o}{R_L} \end{cases}$$

$$\frac{15-V_o}{1000} = \frac{V_o - 6.7}{50} + \frac{V_o}{2000}$$

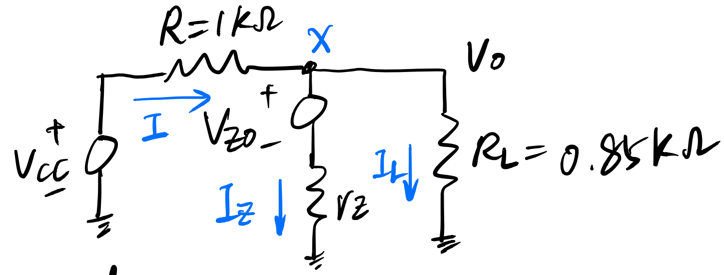
$$\boxed{V_o = 6.93\,V}$$

change in V_o (compared to "No load" case in part a)

$$\boxed{\Delta V_o = 6.93V - 7.095V = -0.165V}$$

(checks:) $I_Z = \dfrac{V_o - V_{Z0}}{r_Z} = \dfrac{6.93V - 6.7V}{50\Omega} = 4.6\,mA > I_{ZK} = 0.5\,mA$ → The zener is in breakdown region.

(4) d.



KCL at node X:

$I = I_{ZK} + I_L$

$$\begin{cases} I = \frac{V_{CC} - V_O}{R} \\ I_Z = \frac{V_O - V_{Z0}}{r_Z} \\ I_L = \frac{V_O}{R_L} \end{cases}$$

$$\frac{15 - V_O}{1000} = \frac{V_O - 6.7}{50} + \frac{V_O}{850}$$

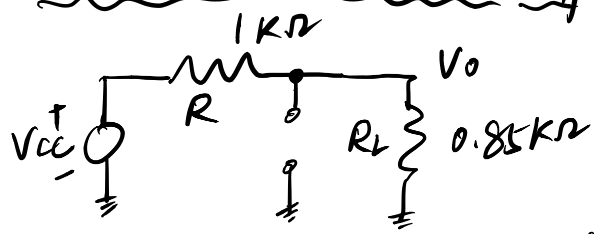
$V_O = 6.719\,V$

checks

$$I_Z = \frac{V_O - V_{Z0}}{r_Z} = 0.38\ mA < I_{ZK} = 0.5\,mA$$

"doesn't satisfy the breakdown region condition"

Assume the diode is "off":



$$V_O = V_{CC} \cdot \frac{R_L}{R + R_L} = 6.892\,V$$

change in Vo (compared to "No load" case in part a)

$$\Delta V_O = 6.892\,V - 7.095\,V = -0.203\,V$$

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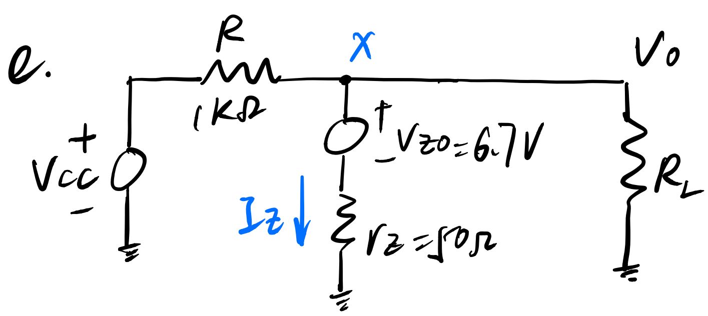
e.



$14V < V_{CC} < 16\,V$

$I > 0.5\,mA$

$V_O > V_{Z0} + r_Z \cdot I_Z = 6.725\,V$

KCL at node X:

$$(V_{CC} - V_O)\frac{1}{R} = I_Z + V_O \cdot \frac{1}{R_L}$$

$$R_L = \frac{V_O}{\frac{V_{CC} - V_O}{R} - I_Z}$$

(5)

$$V_{CC} = 14V, \quad R_L > \frac{6.725}{\frac{14-6.725}{1000} - 0.5\times10^{-3}} = 992.62\Omega$$

$$V_{CC} = 16V, \quad R_L > \frac{6.725}{\frac{16-6.725}{1000} - 0.5\times10^{-3}} = 766.38\Omega$$

$R_{L(min)} = 992.62\Omega$ ensures $I_Z > 0.5mA = I_{ZK}$ within the complete range of V_{cc}.

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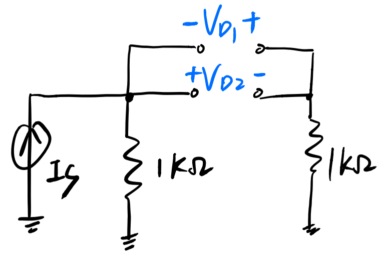
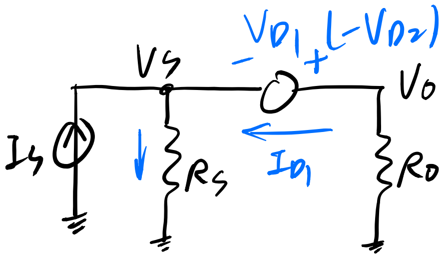
Problem (4)

① when $-0.7mA < I_S < 0.7mA$, both diodes are off, no currents flowing through R_O, $V_O = 0$



(checks) $|V_{D1}| = |V_{D2}| = |V_O - V_S| = |I_S \cdot 1k\Omega| < 0.7V$, both diodes are off

② when $I_S < -0.7mA$, D_1 is on, D_2 is off.



$$V_S = V_O - 0.7$$

$$I_S = \frac{V_S}{R_S} + \frac{V_O}{R_O} = \frac{2V_O - 0.7}{1k\Omega}$$

$$2V_O - 0.7 = I_S \times 1k\Omega$$

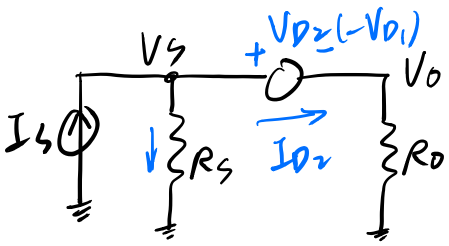
with $I_S = -2mA$,

$$V_O = \frac{-1.3V}{2} = -0.65V$$

(checks) $V_{D2} = V_S - V_O = -0.7V < 0.7V$, D_2 is off

$I_{D1} = \frac{V_S}{R_S} - I_S > -0.7mA + 0.7mA = 0$, D_1 is on.

③ when $I_S > 0.7mA$, D_1 is off, D_2 is on.



$$V_S = V_O + 0.7$$

$$I_S = \frac{V_S}{R_S} + \frac{V_O}{R_O} = \frac{2V_O + 0.7}{1k\Omega}$$

$$2V_O + 0.7 = I_S \times 1k\Omega$$

with $I_S = 2mA$,

$$V_O = \frac{1.3}{2} = 0.65V$$

(checks) $V_{D1} = V_O - V_S = -0.7V < 0$, D_1 is off

$I_{D2} = I_S - \frac{V_S}{R_S} > 0.7mA - 0.7mA = 0$, D_2 is on

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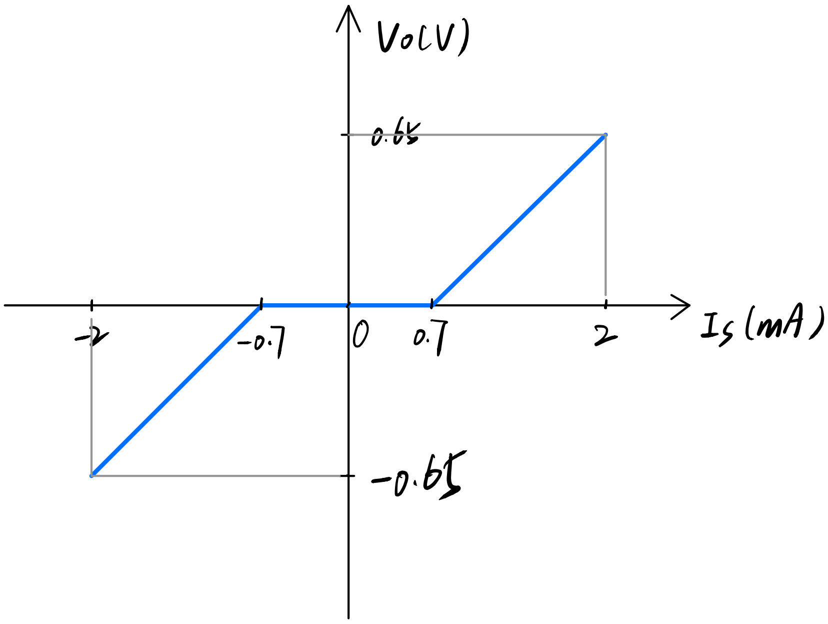
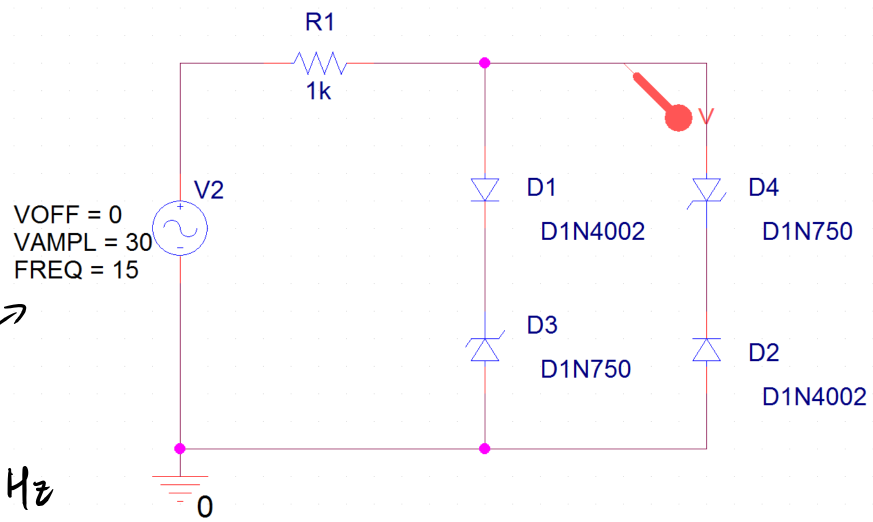


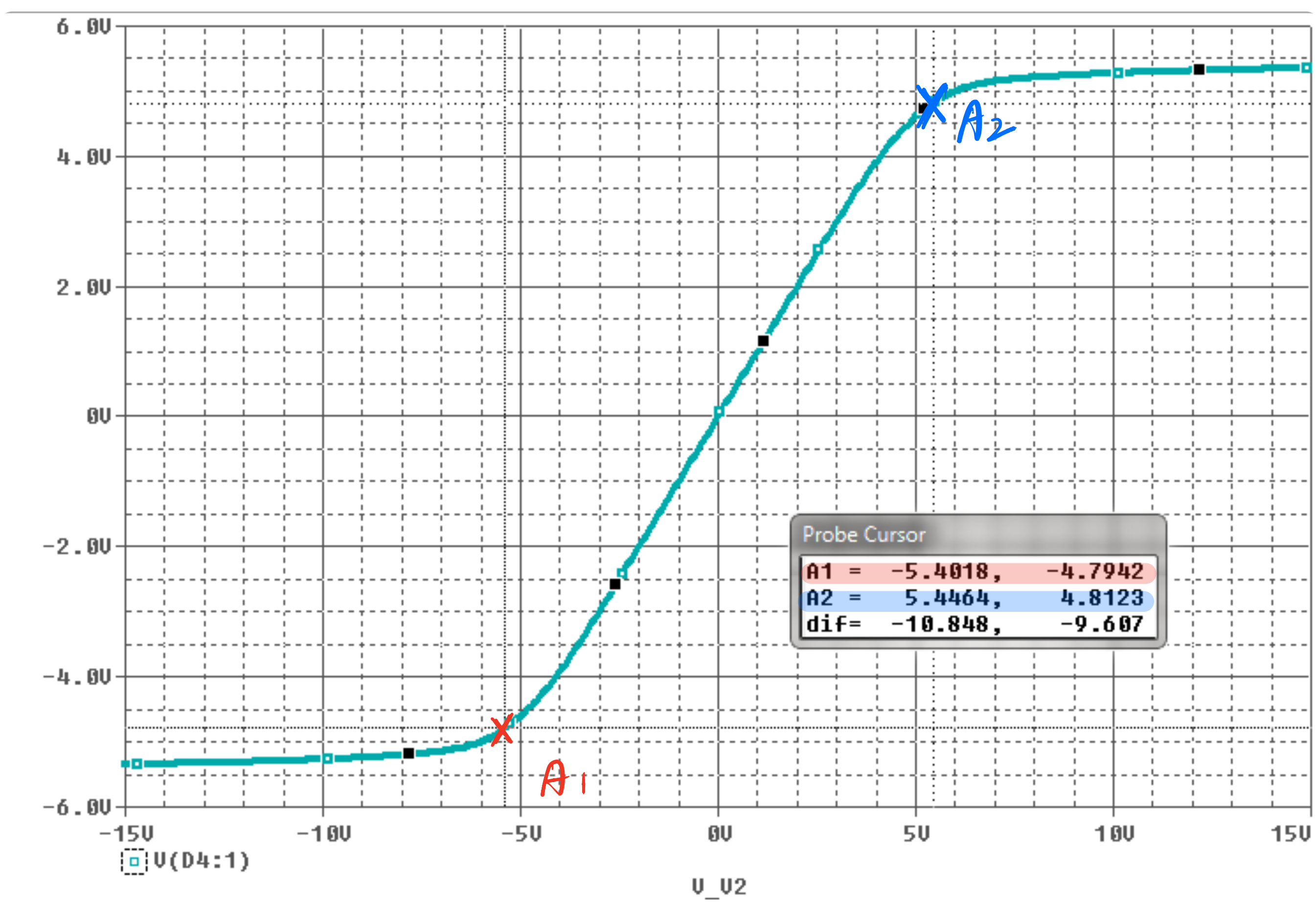
⑧ Problem (b)



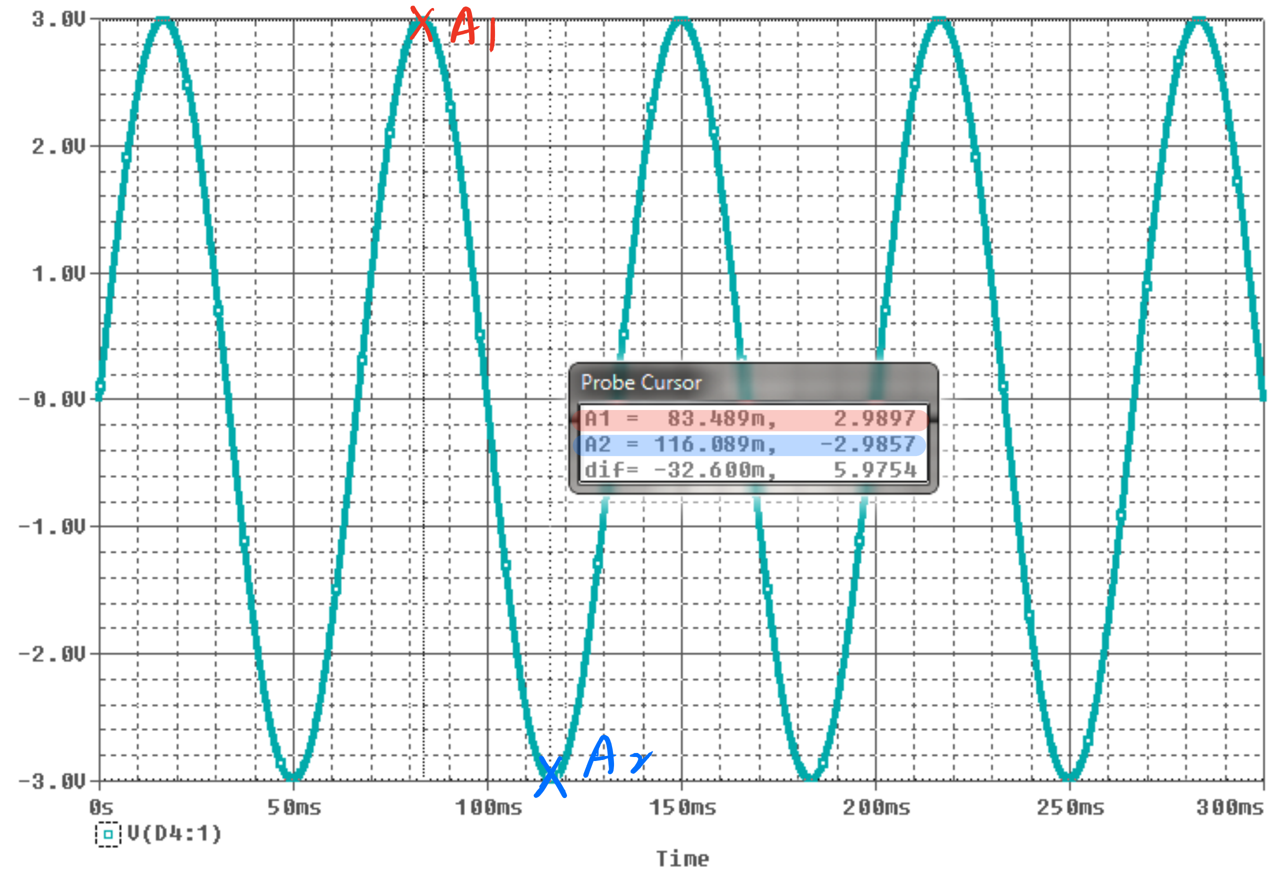
$\omega = 30\pi$

$f = \frac{\omega}{2\pi} = 15\ Hz$

DC sweeping



9 transient simulation ($v_{in} = 3\sin(30\pi t)$)



transient simulation ($v_{in} = 12\sin(30\pi t)$)