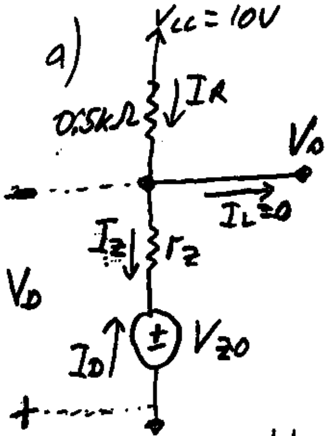
EECE2412 HW 4 Solution

1

Prob. 1

a)



assuming the diode is in the breakdown region

$$I_Z = \frac{V_{cc} - V_{Z0}}{0.5k\Omega + r_Z} = \frac{10V - 6.7V}{0.5k\Omega + 20\Omega} = 6.35mA$$

$I_Z > I_{ZK} = 0.2mA$ → The Zener is in breakdown.

$$V_o = I_Z \cdot r_Z + V_{Z0} = (6.35mA)\cdot(20\Omega) + 6.7V$$

$$\boxed{V_o = 6.827V}$$

b) Repeating the calculation in part a) with $V_{cc} = 11V$ and $V_{cc} = 9V$:

$V_{o(max)} = 6.865V$

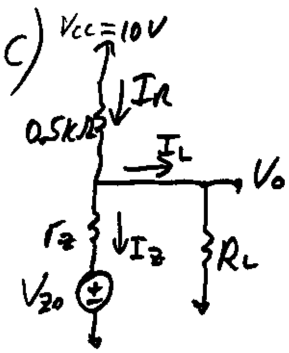
$V_{o(min)} = 6.788V$

$\Delta V_{o(max)} = V_{o(max)} - V_o \approx 38.5mV$

$\Delta V_{o(min)} = V_{o(min)} - V_o \approx 38.5mV$

$\boxed{\Delta V_{cc} \text{ of } \pm 1V \text{ results in } \Delta V_o \text{ of } \pm 38.5mV}$

c)



$$I_R = \frac{10V - V_o}{0.5k\Omega}, \quad I_L = \frac{V_o}{R_L}, \quad I_Z = \frac{V_o - V_{Z0}}{r_Z}$$

$$I_R = I_L + I_Z$$

$$\hookrightarrow \frac{10V - V_o}{0.5k\Omega} = \frac{V_o}{2k\Omega} + \frac{V_o - 6.7V}{20\Omega}$$

(solving for V_o) → $\boxed{V_o = 6.762V}$

$$\Delta V_o = 6.762V - 6.827V = \boxed{-65mV = \Delta V_o}$$

check: $I_Z = \frac{6.762V - 6.7V}{20\Omega} = 3.1mA > I_{ZK}$ → The Zener is in breakdown.

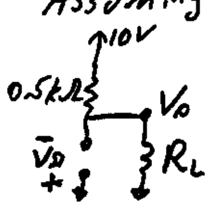
d) Repeating the analysis in c) with $R_L = 0.5k\Omega$ results in:

$V_o = 6.574V$

Diode assumption check: $I_Z = \frac{6.574V - 6.7V}{20\Omega} = -6.3mA < I_{ZK}$

→ does not satisfy the breakdown region condition

Assuming that the diode is reverse-biased ("off"):



$$V_o = 10V \cdot \left(\frac{R_L}{R_L + 0.5k\Omega}\right) = 10V\left(\frac{0.5k\Omega}{0.5k\Omega + 0.5k\Omega}\right) = \boxed{5V = V_o}$$

$\Delta V_o = 5V - 6.827V$

$\boxed{\Delta V_o = -1.827V}$

check: reverse bias requires that $-V_{Z0} = -6.7V < V_D < V_{D0} \approx 0.7V$

↪ satisfied because $V_D = -V_o = -5V$

... Prob. 1 cont.:

e) Using the same diagram as in part c):

$I_{ZK} = 0.2\,mA$ at the edge of the breakdown region

$$I_{ZK} = 0.2\,mA = \frac{V_o - V_{Z0}}{r_Z} = \frac{V_o - 6.7V}{20}$$

$\rightarrow V_o = 6.704\,V$

$$I_{ZK} = 0.2\,mA = I_R - I_L$$

$$0.2\,mA = \frac{V_{CC} - V_o}{0.5\,k\Omega} - \frac{V_o}{R_{L(min.)}} = \frac{V_{CC} - 6.704}{500} - \frac{6.704}{R_{L(min.)}}$$

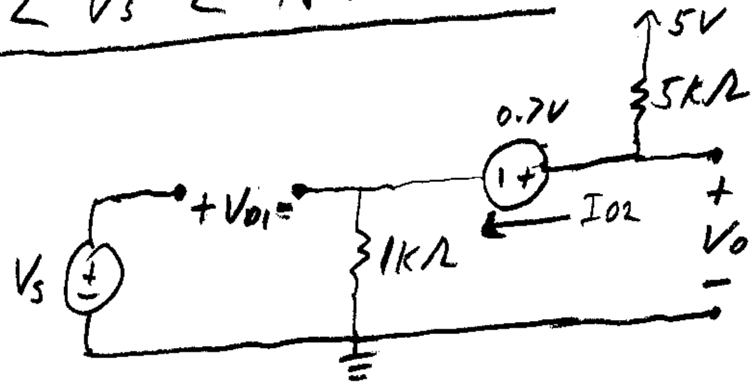
with $V_{CC} = 11V \rightarrow R_{L(min.)} = 798.9\,\Omega$

with $V_{CC} = 9V \rightarrow R_{L(min.)} = 1.526\,k\Omega$

$R_{L(min.)} = 1.526\,k\Omega$ ensures $I_Z > 0.2\,mA = I_{ZK}$ (over the complete range of V_{CC})

Prob. 2

for $0 < V_S < 1.4167\,V$: D_1 off, D_2 on



KVL:

$0 = -I_{D2} \cdot 1k\Omega - 0.7V - I_{D2} \cdot 5k\Omega + 5V$

$I_{D2} = \frac{5V - 0.7V}{6k\Omega} = 0.7167\,mA > 0 \rightarrow D_2$ is on

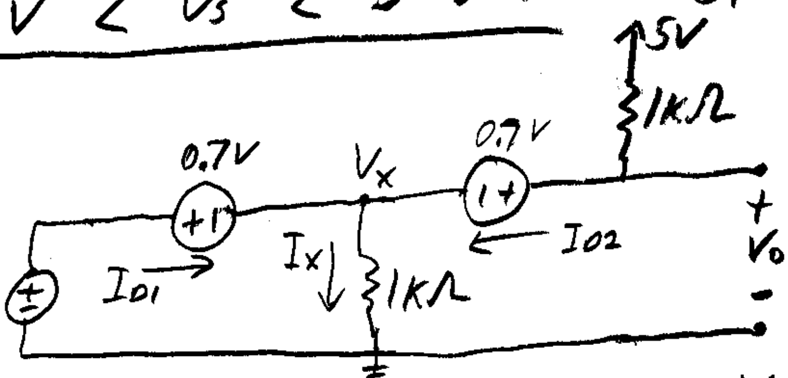
$V_o = 0.7V + I_{D2} \cdot 1k\Omega = \underline{1.4167\,V = V_o}$

D_1 turns on when $V_{D1} \geq 0.7V$:

$0 = -V_{S(max)} + V_{D1(max)} - 0.7V + V_o$

$\rightarrow V_{S(max)} = 0.7V - 0.7V + V_o = 1.4167V$

for $1.4167V < V_S < 5\,V$: D_1 on, D_2 on



$0 = -V_S + 0.7V + V_x$

$\rightarrow V_x = V_S - 0.7V$

$I_x = \frac{V_x}{1k\Omega} = \frac{V_S - 0.7V}{1k\Omega}$

$0 = -V_o + 0.7V + V_x \rightarrow V_o = 0.7V + V_S - 0.7V = \underline{V_S = V_o}$

D_2 is on when $I_{D2} > 0$:

$I_{D2} = \frac{5V - V_o}{5k\Omega} > 0 \rightarrow I_{D2} > 0$ requires $V_o = V_S < 5V$

$\rightarrow D_2$ is on in this range of V_S

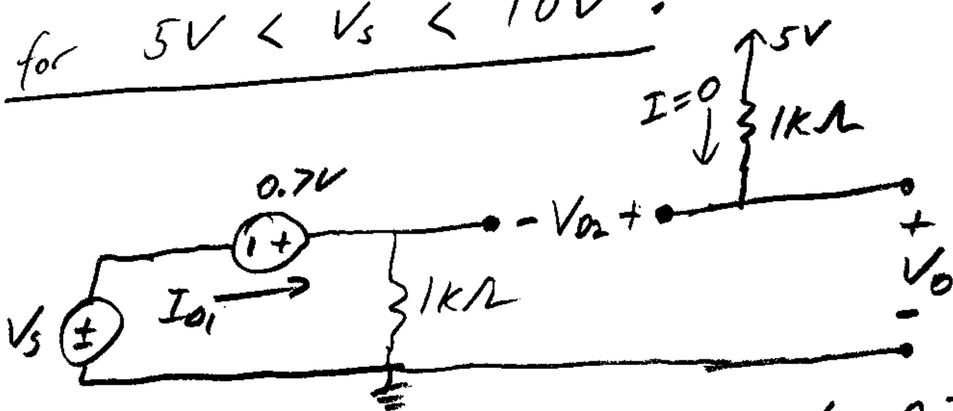
D_1 is on when $I_{D1} > 0$:

$I_{D1} = I_X - I_{D2} = \frac{V_S - 0.7V}{1k\Omega} - \frac{5V - V_o}{5k\Omega} = \frac{V_S - 0.7V}{1k\Omega} - \frac{5V - V_S}{5k\Omega}$

$\rightarrow I_{D1} > 0$ is ensured when $V_S > 1.4167V \rightarrow D_1$ is on in this range of V_S

... Prob. 2 continued:

for $5V < V_s < 10V$: D_1 on, D_2 off



$$0 = -V_s + 0.7V + I_{D1} \cdot 1k\Omega \rightarrow I_{D1} = \frac{V_s - 0.7V}{1k\Omega}$$

check: $I_{D1} > 0$ for $V_s > 0.7V$ → D_1 is on for this range of V_s

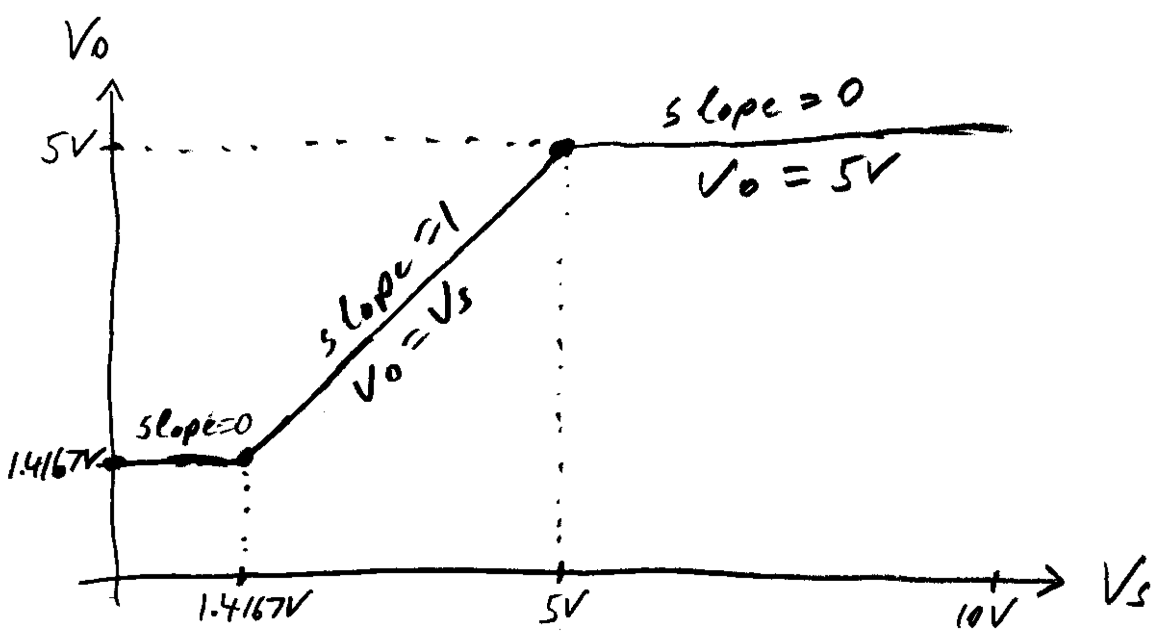
$$0 = -V_o - 5k\Omega \cdot 0 + 5V \rightarrow \underline{V_o = 5V}$$

check: $0 = -I_{D1} \cdot 1k\Omega - V_{D2} + V_o$

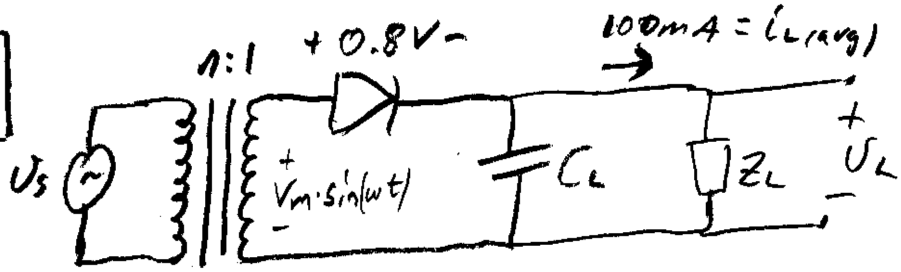
$$\rightarrow V_{D2} = V_o - I_{D1} \cdot 1k\Omega = 5V - \frac{V_s - 0.7V}{1k\Omega} \cdot 1k\Omega$$

$$V_{D2(min)} = 5V - \frac{5V - 0.7V}{1k\Omega} \cdot 1k\Omega = 0.7V$$

→ D_2 is off for $V_s > V_{s(min)} = 5V$



Prob. 3



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

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

2.) KVL:

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

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

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

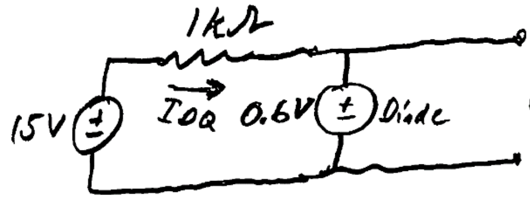
4.) Using equation 3.4 in the book:

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

$C = 833.3\,\mu F$

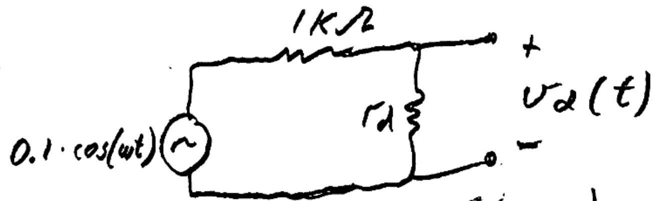
Problem 4:

a) DC equivalent circuit:



$$I_{DQ} = \frac{15V - 0.6V}{1k\Omega} = 14.4mA$$

AC equivalent circuit:



$$r_d = \frac{n \cdot V_T}{I_{DQ}} = \frac{1 \cdot 26mV}{14.4mA}$$

$$r_d = 1.806\,\Omega$$

$$v_d(t) = 0.1 \cdot \cos(\omega t) \times \left(\frac{r_d}{r_d + 1k\Omega}\right) = 0.18 \times 10^{-3} V \cdot \cos(\omega t)$$

total output voltage: $\boxed{V_D(t) = V_{DQ} + v_d(t) = 0.6V + 0.18 \times 10^{-3} V \cdot \cos(\omega t)}$

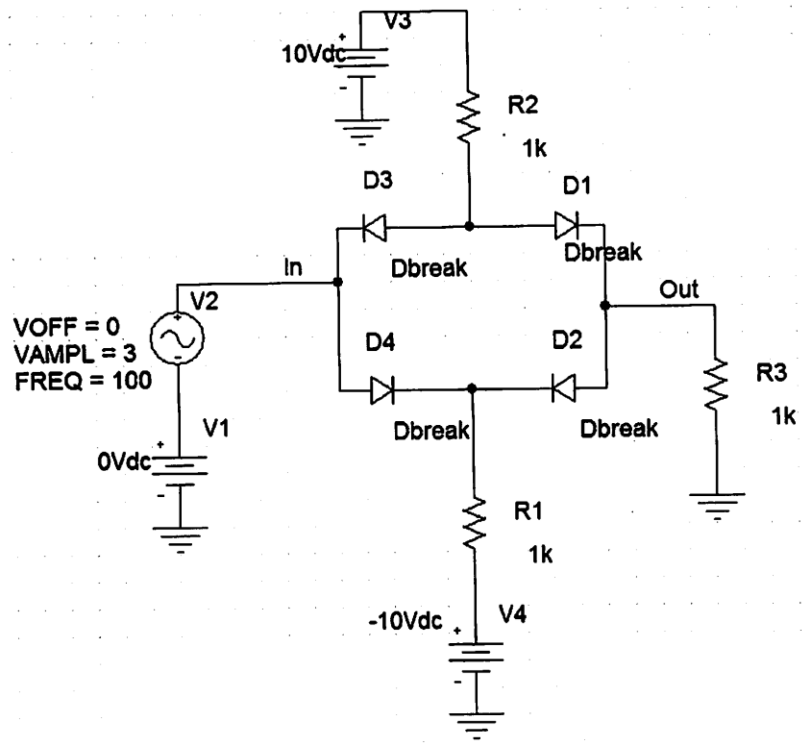
b) Source regulation $= \dfrac{\Delta V_o}{\Delta V_{ss}} \times 100\%$

In part a), the change of the source voltage is $\Delta V_{ss} = 0.1V\cos(\omega t)$, while $\Delta V_o = v_d(t) = 0.18 \times 10^{-3} V \cdot \cos(\omega t)$.

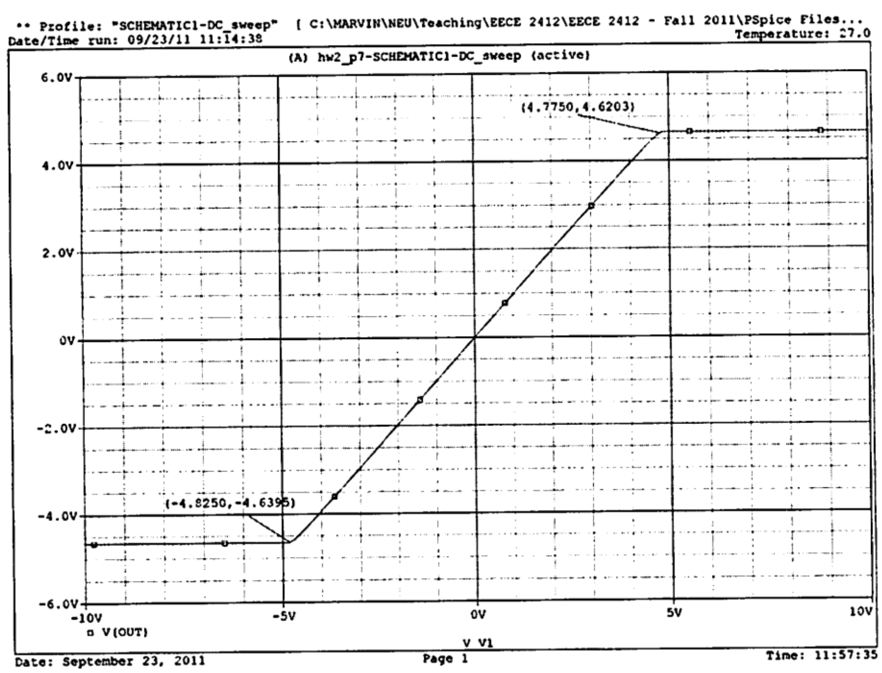
Thus, source regulation $= \dfrac{0.18 \times 10^{-3} V \cdot \cos(\omega t)}{0.1 V \cdot \cos(\omega t)} \times 100\% = \boxed{0.18\%}$

Problem 5

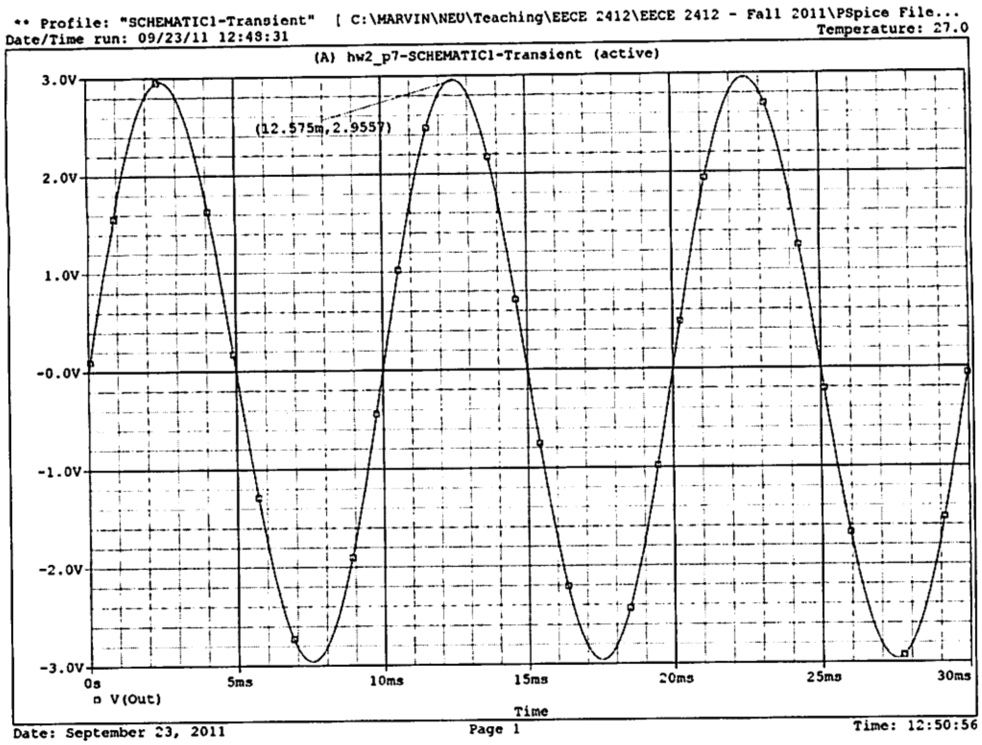
Schematic:



Transfer characteristic:



$V_o(t)$ with $V_{in}(t) = 3V \cdot sin(200\pi \cdot t)$:



$V_o(t)$ with $V_{in}(t) = 10V \cdot sin(200\pi \cdot t)$: