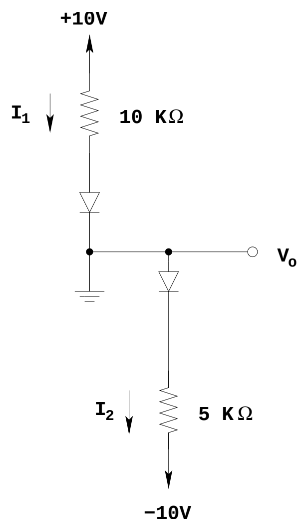
# EE 321 - Exam 2

## October 14, 2002

Name: ______________________________________________

Closed book. One page of notes and a calculator are allowed. Show all work. Partial credit will be given. No credit will be given if an answer appears with no supporting work.

1. In the circuit below assume the diodes are ideal. Find the labeled voltages and currents for the following circuit:




$V_O$ is connected directly to ground, so $V_O = 0$ V.

Diode 1 is forward biased, so the voltage at the top of D1 is 0. There is 10 V across the 10 kΩ resistor, so $I_1 = 1\ mA$.

Diode 2 is forward biased, so the voltage at the bottom of D2 is 0. There is 10 V across the 5 kΩ resistor, so $I_2 = 2\ mA$.

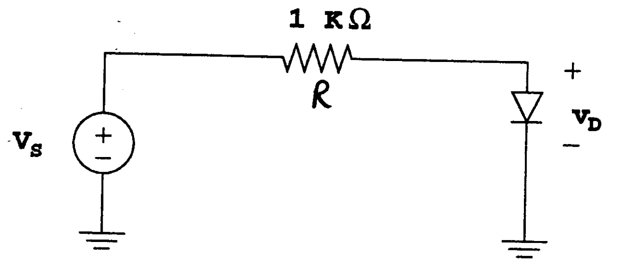
At the node with $V_O$ there is 1 mA coming into the node from $I_1$, and there is 2 mA leaving the node from $I_2$. Since the total current must be zero, there must be another 1 mA coming into the node — this is coming from the ground connection.

We have $v_{D_1} = 0$ V and $i_{D_1} = 1$ mA, so this is okay.

We have $v_{D_2} = 0$ V and $i_{D_2} = 2$ mA, so this is okay.

- To show that D1 is not reverse-biased, assume that it is. Then $I_1$ is 0, so there is no voltage drop across $R_1$. The voltage at the top of $D_1$ is +10 V.
  We have $I_{D_1} = 0$ V and $V_{D_1} = +10$ V. A diode cannot have positive voltage across it, so $D_1$ cannot be reverse biased.
- The same argument can be used to show $D_2$ is not reverse biased.

2. The figure below shows $v_D$ measured for two different source voltages $V_S$.




| $V_S$ | $V_D$ | |
|---|---|---|
| 2 V | 0.526 V | 1.474 |
| 10 V | 0.595 V | 9.405 |

(a) Find the diode parameters $n$ and $I_S$.

(b) Find the diode voltage $v_D$ when $V_S = 5$ V.

(a) $i_D = \frac{V_S - v_D}{R}$ $\quad i_{D1} = \frac{2-0.526}{1k} = 1.474\,mA$ $\quad i_{D2} = \frac{10-0.595}{1k} = 9.405\,mA$

$i_{D1} = I_S e^{\frac{v_{D1}}{nV_T}}$ $\quad i_{D2} = I_S e^{\frac{v_{D2}}{nV_T}}$ $\quad$ Divide: $\frac{i_{D2}}{i_{D1}} = e^{\frac{v_{D2}-v_{D1}}{nV_T}}$

$\frac{v_{D2}-v_{D1}}{nV_T} = \ln\left(\frac{i_{D2}}{i_{D1}}\right)$ $\quad n = \frac{v_{D2}-v_{D1}}{V_T \ln\left(\frac{i_{D2}}{i_{D1}}\right)} = \frac{0.595-0.526}{25mV \ln\left(\frac{9.405}{1.474}\right)} = 1.49$

$I_S = i_{D1} e^{-\frac{v_{D1}}{nV_T}} = 1.474\,mA\, e^{-\frac{0.526}{(1.49)(25mV)}} = 1.09\times10^{-9}A = 1.09\,nA$

(b) $v_D$ will be between 0.526 and 0.595. Start with $v_D = 0.55$ V

$i_D = \frac{V_S - v_D}{R} = \frac{5-0.55}{1k} = 4.45\,mA$

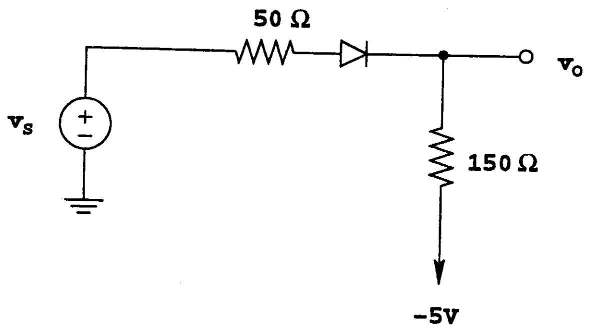
$v_D = nV_T \ln\frac{i_D}{I_S} = (1.49)(25mV)\ln\frac{4.45\,mA}{1.09\,nA} = 0.567\,V$

$i_D = \frac{V_S - v_D}{R} = 4.43\,mA$

$v_D = nV_T \ln\frac{i_D}{I_S} = (1.49)(25mV)\ln\frac{4.43\,mA}{1.09\,nA} = 0.567\,V$

Same as before, so $v_D = 0.567$ V

3. In the figure below assume $n = 2$ for the diode. When $v_S = 0$, it is found that $v_D = 0.6\ V$.

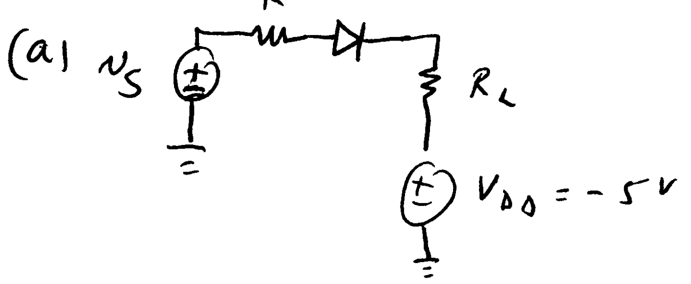



(a) Find the current through the diode $I_D$ when $v_S = 0$.

(b) Find the small-signal resistance of the diode $r_d$.

(c) Find the output voltage when $v_S = 1\sin(\omega t)$.

(a)

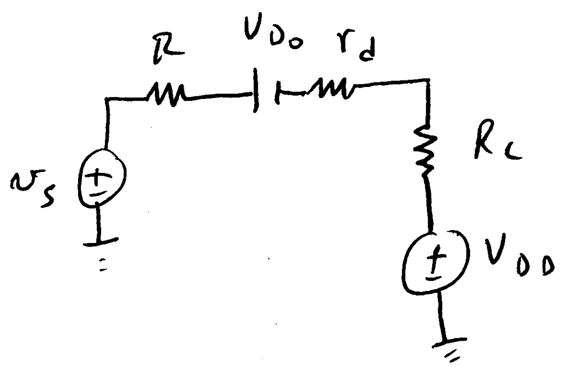



KVL: $-v_S + iR + v_D + iR_L + V_{DD} = 0$

$$i = \frac{v_S - v_D - V_{DD}}{R + R_L} = \frac{0 - 0.6V - (-5V)}{50\Omega + 150\Omega} = 22mA$$

(b) $$r_d = \frac{nV_T}{I_D} = \frac{2(25mV)}{22mA} = 2.27\Omega$$

(c) $V_{D0} = v_D - I_D r_d = 0.6 - (22mA)(2.27\Omega) = 0.55V$




KVL: $-v_S + iR + V_{D0} + i_D r_d + i_D R_L + V_{DD} = 0$

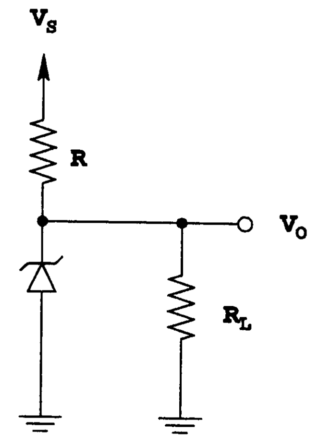
$$i_D = \frac{v_S - V_{D0} - V_{DD}}{R + r_d + R_L}$$

$$v_o = i_D R_L - V_{DD} = \frac{v_S R_L}{R + r_d + R_L} + \frac{(-V_{D0} - V_{DD})R_L}{R + r_d + R_L} - V_{DD}$$

$= 0.742\, v_S - 1.7V$

$= 0.742 \sin(\omega t) - 1.7V$

4. The figure below shows a zener regulator circuit. The zener diode has a zener voltage of $V_Z = 10$ V when the current through it is 20 mA. It has a zener resistance $r_Z = 20\ \Omega$.




(a) Find the value of $R$ such that the output voltage is 10 V when $V_S = 20\ V$ and the load current is zero (i.e., $R_L = \infty$).

(b) Find the output voltage when $V_S = 21\ V$ and the load current is zero.

(c) Find the output voltage when $V_S = 20\ V$ and $R_L = 1\ k\Omega$.

(d) What is the line regulation (percent change in output voltage for a change in $V_S$)?

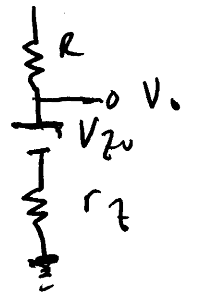
(e) What is the load regulation (percent change in output voltage for a change in $I_L$)?

(a) ~~When $V_0 = 10V$ and $V_S = 20V$, then is~~

To have $V_o = 10V$, $I_Z$ must be 20 mA. With $I_L = 0$, $I_R = I_Z$, so $I_R = 20$ mA

$$I_R = \frac{V_S - V_0}{R} \Rightarrow R = \frac{V_S - V_0}{I_R} = 500\ \Omega$$

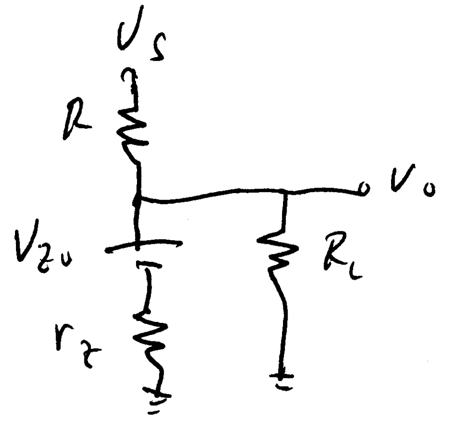
(b) $V_{Z0} = V_Z - I_{Z_T} r_Z = 9.6$ V




Using superposition

$$V_0 = V_{Z0}\left(\frac{R}{R+r_Z}\right) + V_S\left(\frac{r_Z}{R+r_Z}\right) = 10.0385V$$

(c)




Using superposition

$$V_o = V_{Z0} \frac{R \| R_L}{R \| R_L + r_Z} + V_S \frac{r_Z \| R_L}{r_Z \| R_L + R} = 9.81V$$

(d) A 1V change in $V_S$ gave a 0.0385 V change in $V_o$, so

$$\frac{\Delta V_o}{\Delta V_S} = 38.5 \text{ mV/V} = 3.85\%$$

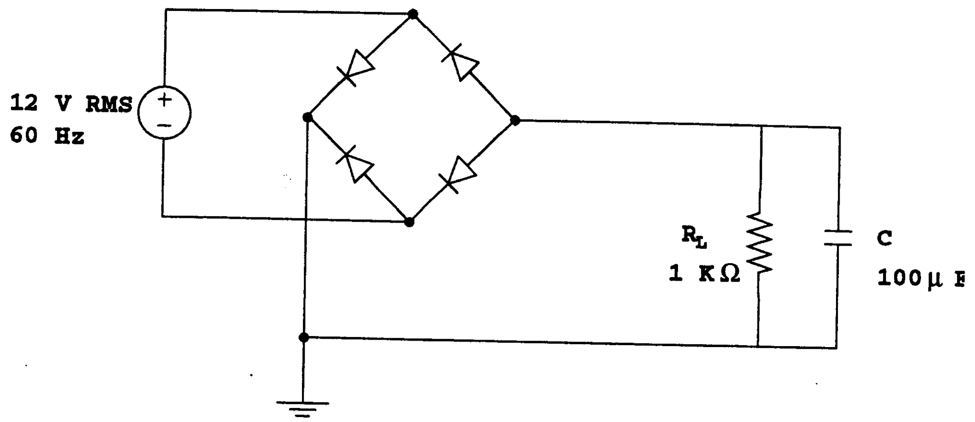
Also, $\frac{\Delta V_o}{\Delta V_S} = \frac{r_Z}{R + r_Z} = 0.0385 = 3.85\%$

(e) $R_L = 1k\Omega$, $V_o = 9.81V \Rightarrow I_L = 9.81 mA$

$$\frac{\Delta V_o}{\Delta I_L} = \frac{9.81V - 10V}{9.81mA} = -19.4 \text{ mV/mA}$$

Also, $\frac{\Delta V_o}{\Delta V_L} = -(r_Z \| R) = -19.23\,\Omega = -19.23 \text{ mV/mA}$

5. Consider the rectifier circuit in the figure below. Use the constant-voltage-drop diode model with $V_D = 0.7$ V.




(a) Sketch the output voltage waveform. Label the minimum and maximum voltages on the waveform.

(b) Find the voltage ripple $V_r$.

(c) Find the peak diode current $i_{D_{max}}$.

(a) See attached for plot. Note: The output voltage is negative

$V_s = \sqrt{2}\, V_{RMS} = \sqrt{2}\,(12\text{V}) = 16.97\text{V}$

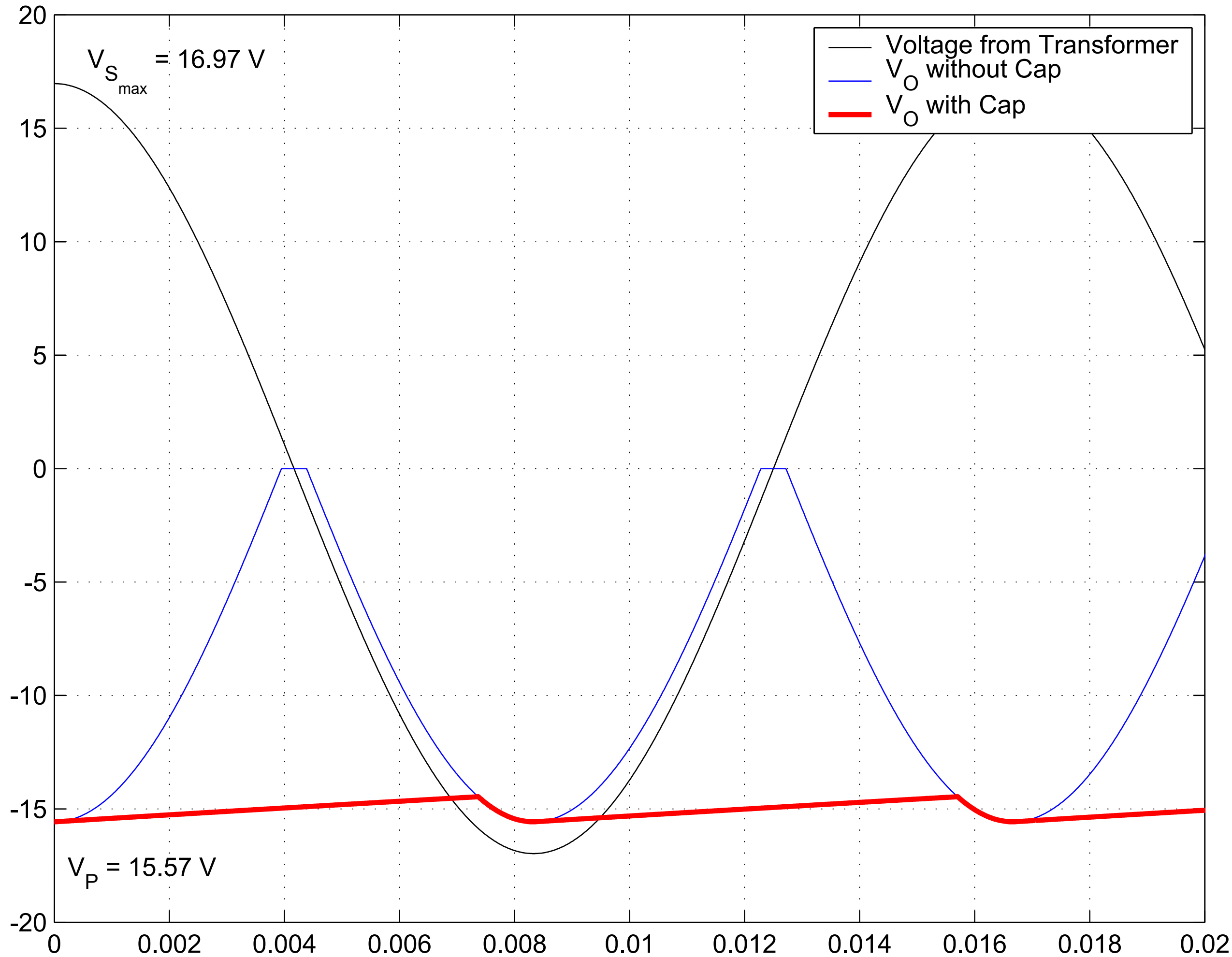
$V_p = V_s - 2V_D = 16.97\text{V} - 2 \cdot 0.7 = 15.57\text{V}$

(b) $V_r = \dfrac{V_p}{2fRC} = 1.41\ \text{V}$

(c) $i_{D_{max}} = I_L \left(1 + 2\pi \sqrt{V_p / 2V_r}\right)$

$I_L = \dfrac{V_o}{R_L}$ $\quad V_o = \dfrac{V_p - V_r/2}{\ }$

$i_{D_{max}} = \left(\dfrac{V_p - V_r/2}{R_L}\right)\left(1 + 2\pi \sqrt{V_p / 2V_r}\right) = 234\text{mA}$



Voltage from Transformer
$V_O$ without Cap
$V_O$ with Cap
$V_{S_{max}}$ = 16.97 V
$V_P$ = 15.57 V
20
15
10
5
0
-5
-10
-15
-20
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02