Homework No. 2 – Diodes
Electronics I

Homework Quiz: See website for quiz date.

Reading Assignment: Chapters 1 through 4 in “Microelectronic Circuits,” by Adel S. Sedra and Kenneth C. Smith.


**Ex: 4.1**
Refer to Fig 4.3(a). for $V_I \geq 0$, the diode conducts and presents a zero voltage drop. Thus $V_O = V_I$. For $V_I < 0$, the diode is cut-off, zero current flows through R and $V_O = 0$. The results is the transfer characteristic in Fig E4.1

2. Exercises 4.2 (page 169) – Ideal diode problem.

**Ex: 4.2**
see Figure 4.3a and 4.3b
During the positive half of the sinusoid, the diode is forward biased, so it conducts resulting in $V_O = 0$ During the negative half of the input signal $v_I$, the diode is reverse biased. The diode does not conduct resulting in no current flowing in the circuit. So $v_O = 0$ and $v_D = v_I - v_O = v_I$.
This results in the waveform shown in Figure E4.2


**Ex: 4.3**

\[
\hat{I}_D = \frac{\hat{V}_I}{R} = \frac{10 \text{ V}}{1 \text{ k}\Omega} = 10 \text{ mA}
\]

de component of $v_O = \frac{1}{\pi}v_O$

\[
= \frac{1}{\pi}v_I = \frac{10}{\pi}
\]

$= 3.18 \text{ V}$
4. Exercises 4.6 (page 177) – Shockley diode equation problem.

**Ex: 4.6**

**Equation 4.5**

\[ V_2 - V_1 = 2.3 \, V_T \log \left( \frac{I_2}{I_1} \right) \]

At room temperature \( V_T = 25 \, mV \)

\[ V_2 - V_1 = 2.3 \times 25 \times 10^{-3} \times \log \left( \frac{10}{0.1} \right) \]

\[ = 115 \, mV \]

5. Exercises 4.7 (page 177) – Shockley diode equation problem.

**Ex: 4.7**

\[ i = I_s e^{\frac{V}{V_T}} \]

\[ 1 \times 10^{-3} = I_s e^{0.7/0.025} \]

\[ \Rightarrow I_s = 6.9 \times 10^{-16} \, A \]

Now \( i = 0.1 \, mA \)

\[ V = V_T \ln \left( \frac{i}{I_s} \right) = 25 \times 10^{-3} \times \ln \left( \frac{0.1 \times 10^{-3}}{6.9 \times 10^{-16}} \right) \]

\[ = 0.64 \, V \]

For \( i = 10 \, mA \)

\[ V = 25 \times 10^{-3} \left( \frac{10 \times 10^{-3}}{6.9 \times 10^{-16}} \right) \]

\[ \approx 0.76 \, V \]


**Ex: 4.8**

\[ \Delta T = 125 - 25 = 100^\circ C \]

\[ I_s = 10^{-14} \times 1.15^{\Delta T} \]

\[ = 1.17 \times 10^{-8} \, A \]


b. Use constant voltage drop model

\[ V_D = 0.7 \, V \quad \text{constant voltage drop} \]

\[ I_D = \frac{5 - 0.7}{10 \, k} = 0.43 \, mA \]

Ex: 4.19

![Diagram of voltage waveforms]

a. The diode starts conduction at

\[ v_S = V_D = 0.7 \text{ V} \]

\[ v_S = V_S \sin \omega t, \text{ here } V_S = 12 \sqrt{2} \]

At \( \omega t = \theta \)

\[ v_S = V_S \sin \theta = V_D = 0.7 \text{ V} \]

\[ 12 \sqrt{2} \sin \theta = 0.7 \]

\[ \theta = \sin^{-1} \left( \frac{0.7}{12 \sqrt{2}} \right) \approx 2.4^\circ \]

Conduction starts at \( \theta \) and stops at \( 180 - \theta \).

\[ \therefore \text{ Total conduction angle } = 180 - 2\theta \]

\[ = 175.2^\circ \]

b. \( v_{O, avg} = \frac{1}{2\pi} \int_{\theta}^{(\pi - \theta)} (V_S \sin \phi - V_D) d\phi \)

\[ = \frac{1}{2\pi} [V_S \cos \phi - V_D]_{\phi = 0}^{\phi = \pi - \theta} \]

\[ = \frac{1}{2\pi} [V_S \cos \theta - V_S \cos(\pi - \theta) - V_D(\pi - 2\theta)] \]

But \( \cos \theta \approx 1 \), \( \cos(\pi - \theta) \approx -1 \) and \( \pi - 2\theta \approx \pi \)

\[ v_{O, avg} = \frac{2V_S}{2\pi} - \frac{V_D}{2} \]

\[ = \frac{V_S}{\pi} - \frac{V_D}{2} \]

For \( V_S = 12 \sqrt{2} \) and \( V_D = 0.7 \text{ V} \)

\[ v_{O, avg} = \frac{12 \sqrt{2}}{\pi} - \frac{0.7}{2} = 5.05 \text{ V} \]

c. The peak diode current occurs at the peak diode voltage

\[ i_D = \frac{V_S - V_D}{R} = \frac{12 \sqrt{2} - 0.7}{100} \]

\[ = 163 \text{ mA} \]

\[ P_{IV} = +V_S = 12 \sqrt{2} \]

\[ \geq 17 \text{ V} \]
9. Plot the Shockley equation from $-1 < v < 0.9$. Use the following values: $I_0 = 1\text{nA}; m = 1.4$. Be certain your units work out and label axes appropriately. The voltage should be on the $x$-axis. Do not hand-draw this plot!
10. Using the Shockley equation plotted above, develop piecewise-linear diode models that include $r_d$ and $V_0$. Using the graph above, when the diode is on

\[
\begin{align*}
    r_d &= \frac{\Delta v}{\Delta i} \\
    \Delta v &= 0.034 \text{ (measuring distances)} \\
    \Delta i &= 50 \\
    r_d &= 7 \times 10^{-4} \Omega \text{ and} \\
    V_0 &= 0.84.
\end{align*}
\]
11. Plot the $v-i$ curves for the diode described by the Shockley equation and the piecewise-linear model on the same axes. Comment on the accuracy of the piecewise-linear model.

Reasonably close except near turn-on.
12. Assume you have a power supply using a bridge rectifier. The output of the supply should be 13.8 V with a maximum output current of 50 A. If we assume the voltage regulator in series with the positive output leg requires a minimum of 1.2 V, the input voltage at the regulator has a minimum value of 15 V.

(a) Draw the circuit.

(b) Determine the value of C (filter capacitor after rectifier and before regulator) that produces a maximum voltage ripple at the input to the regulator of 5 V.

(c) Determine the rms voltage of the secondary of the transformer.

\[ i \approx C \frac{\Delta v}{\Delta t} \]
\[ C \approx i \frac{\Delta t}{\Delta v} \]
\[ \Delta t = \frac{1}{120} = 0.008333 \text{ ms} \]
\[ \Delta v = 5 \text{ V} \]
\[ C = 83 \text{ mF} - \text{A large capacitor.} \]

Assuming each diode has approximately a 1 V drop, the maximum (peak) voltage coming out of the transformer is

\[ V_p = 13.8 + 1.2 + 5 + 1 + 1 = 22 \text{ V}. \]

The rms voltage is then given by

\[ V_{rms} = \frac{\sqrt{2}}{2} \times V_p = 15.5 \text{ V}. \]
13. Consider the output of a bridge rectifier. Assume the ac voltage supplying the bridge rectifier has a 17 V peak voltage and a frequency of 60 Hz. Your task is to design the rest of the power supply using a zener diode as the regulator section. The output voltage should be 12 V and the maximum output current should be 50 mA. Assume the zener diode can handle 1.2 W and further assume the minimum current flow required through the zener is approximately 1 mA.

(a) What is the maximum current that the zener can handle?
(b) Determine the value of C such that the voltage does not drop below 14 V.
(c) Determine the value of the series resistance.
(d) Determine the maximum power dissipation in the resistance.

Note, assuming the diodes are ideal.

\[
\begin{align*}
p &= v \times i \\
n &= \frac{P}{v} \\
n &= \frac{1.2}{12} = 0.1 \text{ A} = 100 \text{ mA} \\

C &\approx \frac{i \Delta t}{\Delta v} \\
C &= 0.051 \frac{0.00833}{3.0} = 142 \mu\text{F}
\end{align*}
\]

Note, the value of C should be larger because initially, more current flows out of it. In other words, the zener current is not constant. As a rule of thumb, five times the calculated value of C is usually the minimum C. Furthermore, the value of C was calculated assuming ideal diodes, i.e., no forward voltage drop. If you include a forward voltage drop of 0.7 V, or 1.4 V for the two diodes conducting at any one time, then the value of C will also be larger.

\[
\begin{align*}
R &= \frac{v}{i} \\
R &= \frac{14 - 12}{0.051} = 39.2 \Omega
\end{align*}
\]

\[
\begin{align*}
P_{\text{max}} &= \frac{V^2}{R} \\
P_{\text{max}} &= \frac{(17 - 12)^2}{39.2} \\
P_{\text{max}} &= 0.64 \text{ W}
\end{align*}
\]
14. Consider the power supply shown below. Assume the diodes are ideal and the power supply is designed to deliver a maximum current of 1 A. Further assume the following: \( V_S(t) = 18 \sin(2\pi 60t) \) V, \( C_1 = 10,000 \mu F \), \( R_1 = 3 \Omega \), and the breakdown voltage of the zener diode is \( V_Z = 13.8 \) V with a minimum breakdown current of 1 mA. Determine the following values.

(a) \( V_{\text{out}} \).
(b) \( V_{\text{ripple}} \) at full load.
(c) The maximum power dissipated in \( R_1 \).
(d) The maximum power dissipated in \( D_1 \).
15. Consider the zener voltage regulator shown below. The zener breakdown voltage is 10 V and requires a minimum current of 1 mA. The unregulated supply voltage is 12 V and $R_1$ is 2 $\Omega$.

- (a) Determine the output voltage when $R_{LOAD} = 100$ $\Omega$.
- (b) Determine the output voltage when $R_{LOAD} = 4$ $\Omega$.
- (c) Find the minimum value of $R_{LOAD}$ that will still be regulated.
- (d) Find the maximum value of $R_{LOAD}$ that will be regulated.
16. In the following circuit, plot $v_{out}$ as a function of time on the axes provided. Specify and label critical times and voltages. Assume the diodes have a turn-on voltage of 0.7 V and that $R_1 = R_2$. 

![Circuit Diagram]

![Graph]

$\text{Vin}$

$\text{Vout}$

$4.3\text{V}$

$5 \quad 10$

$-10$

$t (\text{sec})$

$10$

$0$

$-10$

$\text{Vin} (\text{V})$

$5 \quad 10$

$-10$

$t (\text{sec})$

$\text{Vout} (\text{V})$