Homework 4 solution:

2. Consider half-wave, full-wave and bridge rectifier circuits shown in Figure 4.23(a), 4.24(a) and 4.25(a). If the input signal to the rectifier $v_s(t)$ is a rectangle pulse train with 1ms pulse width and 3ms repetition period as shown in the following figure. Use diode CVD model (0.7V), please find the average output voltage $v_{0,\text{ave}}$ for each of these three rectifiers.

Solution:

For half-wave rectifier, the average output voltage is $v_{0,\text{ave}} = (5 - 0.7) \times \frac{1}{3} = 1.433V$

For full-wave rectifier, $v_{0,\text{ave}} = (5 - 0.7) \times \frac{1}{3} + (2 - 0.7) \times \frac{2}{3} = 2.3V$

For bridge rectifier, $v_{0,\text{ave}} = (5 - 1.4) \times \frac{1}{3} + (2 - 1.4) \times \frac{2}{3} = 1.6V$
3. A peak rectifier shown below is based on a half-wave rectifier circuit with a filter capacitor. The voltage source $v_s(t)$ is a 60Hz sinusoid with 10V $rms$ voltage. The load resistance is $R_L = 1k\Omega$, and the capacitor is $C = 200\mu F$. Use diode CVD (0.7V) model please find,
(a) peak-to-peak voltage variation of the output $v_0(t)$
(b) maximum current that flows through the diode

![Diagram of peak rectifier circuit]

Solution:
For the source of 10V $rms$ voltage, the peak voltage is $V_s = 10\sqrt{2} = 14.14V$
Because of the 0.7V voltage drop when diode is forward biased, the peak voltage of the output $v_0(t)$ is $V_p = 14.14 - 0.7 = 13.44V$
(a) peak-to-peak voltage variation of the output $v_0(t)$ is,
$$V_r = \frac{V_p}{fCR_L} = \frac{13.44}{60 \times 200 \times 10^{-6} \times 10^3} = 1.12V$$
(b) maximum current that flows through the diode is,
$$i_{max} = I_L \left(1 + 2\pi \sqrt{\frac{2V_p}{V_r}}\right) = \frac{V_p}{R_L} \left(1 + 2\pi \sqrt{\frac{2V_p}{V_r}}\right) = \frac{13.44}{10^3} \left(1 + 2\pi \sqrt{\frac{2 \times 13.44}{1.12}}\right) = 0.414A$$

4. For the following circuit the breakdown voltage of the Zener diode is $V_{zk} = 10V$. Please determine the transfer function for the limiter shown below. In other words, determine $V_0$ as a function of $V_{in}$.

![Diagram of limiter circuit]
Solution:

(1) If the Zener diode is in breakdown, the equivalent circuit is, 
\[ V_{in} - i_i \times 1k - i_D \times 1k - 10 = -6 \]
and \( i_i = 10 + i_D \)

Combine them,
\[ V_{in} - (10 + i_D) \times 1k = -6 \]

In order for the diode to be in breakdown \( i_D > 0 \) is required, that is, 
\( V_{in} > 14V \)

Under this condition, the output voltage can be found using,
\[ i_D = \frac{V_{in}}{2} - 7, \quad \text{and} \quad V_0 = -6 + 10 + i_D \times 1k \]

That is, 
\[ V_0 = 4 + \frac{V_{in}}{2} - 7 = \frac{V_{in}}{2} - 3 \]

(2) Then, if the Zener diode is forward biased, the equivalent circuit is, 
\[ V_{in} - i_i \times 1k + i_D \times 1k + 0.7 = -6 \]
and \( i_i = 10 - i_D \)

Combine them,
\[ V_{in} - (10 - i_D) \times 1k + i_D \times 1k + 0.7 = -6 \]

In order for the diode to be in forward bias \( i_D > 0 \) is required, that is, 
\( V_{in} < 3.3V \)

Under this condition, the output voltage can be found using,
\[ i_D = \frac{3.3 - V_{in}}{2}, \quad \text{and} \quad V_0 = -6 - 0.7 - i_D \times 1k \]

That is, 
\[ V_0 = -6.7 - \frac{3.3 - V_{in}}{2} = \frac{V_{in}}{2} - 8.35 \]

(3) Then, if the Zener diode is reverse biased, the equivalent circuit is, 
\( i_i = 10mA \) and \( V_0 = V_{in} - 10V \)

In order for the diode to be in reverse bias \(-10 < V_D < 0\) is required, that is, 
\(-10 < -6 - (V_{in} - 10V) < 0\)

Or, \( 3.3 < V_{in} < 14 \)

So that the overall transfer function is,
5. The circuit shown below is a diode limiter. Determine and draw the transfer characteristics ($V_0$ versus $V_i$). Be sure and label all relevant values (slope, intercept points, maximum values, etc.).

Solution:
(1) If zener diode is in breakdown (the regular diode is reverse biased),
$$V_0 = \frac{V_{in} - 8.35V}{2} \text{ for } V_{in} < 3.3V$$
(2) If the regular diode is in forward bias (the zener diode is reverse biased),
$$V_0 = \frac{V_{in} - 10V}{2} \text{ for } 3.3V < V_{in} < 14V$$
(3) If zener diode is in forward bias (the regular diode is reverse biased),
$$V_0 = \frac{V_{in} - 3V}{2} \text{ for } V_{in} > 14V$$

$$V_0 = \begin{cases} \frac{V_{in} - 8.35V}{2} & \text{for } V_{in} < 3.3V \\ \frac{V_{in} - 10V}{2} & \text{for } 3.3V < V_{in} < 14V \\ \frac{V_{in} - 3V}{2} & \text{for } V_{in} > 14V \end{cases}$$