ECE 255 Spring 2019

Homework 3

Due 5:00 PM Monday, Jan 28 in MSEE 180 Dropbox

1. Consider a silicon diode that follows an “ideal diode” equation \( I = I_0 (\exp(V/V_T) - 1), \) with \( I_0 = 1e^{-14} \text{ A}. \) Consider forward-biased operation at room temperature \((V_T = 0.026\text{V})\). (Note that this is the region that we typically approximate as \(V_D \sim 0.7\) in circuit analysis).
   
   a. Determine the current range over which the diode voltage is between 0.65 and 0.75 V. Your solution should include a plot of the current-voltage relationship on a semilog scale (log I versus linear V).
   
   b. Determine the ratio between the largest and smallest current calculated in part a).

2. Consider the resistor/diode circuit shown below. The I-V plot shows: i) the diode current-voltage relationship (using the \(V_D \sim 0.7\) V approximation) and ii) load lines 1 and 2, representing different values of \(V_{CC}\) and \(R_L\).
   
   a. For load line 1, find the values of \(V_{CC}\) and \(R_L\).
   
   b. For load line 1, find \(I_D\) by reading it off the graph (to the nearest 0.1 mA)
   
   c. For load line 1, find \(I_D\) by expressing the load line equation in the form \(y = ax + b\) and using the \(V_D \sim 0.7\) V approximation.
   
   d. Repeats parts a) and b) for load line 2.
3. Consider the circuit shown below. The diodes are all identical, and are general purpose diodes with reverse breakdown voltage $V_Z > 10V$. In forward bias, each diode can be modeled using a “constant voltage drop” approximation ($V_D = 0.7V$).
   a. Consider the case in which $R_4 = 5\ k\Omega$ and $D_1$ is off. What is the value of the output voltage ($V_{OUT}$)?
   b. Consider the same circuit as in part a), except for the value of $R_4$. What is the minimum value of $R_4$ required in order for $D_1$ to become forward biased (i.e. for $V_{D1}$ to be 0.7V or greater, in the polarity corresponding to forward bias)?

4. Consider the clipper circuit shown below, employing two Zener diodes. In forward bias, each diode can be modeled as a standard diode using a constant voltage drop model with $V_D = 0.7V$. The Zener voltages for the two diodes are $V_{Z1} = 4.5V$ and $V_{Z2} = 5.5V$. You can assume that the series resistance in the Zener region is negligible.
   a. Consider the case in which $v_1$ is a DC bias voltage varying from -12V to +12V. Find and plot/sketch the output voltage ($v_o$) versus input voltage ($v_1$). You should state the minimum and maximum output voltages.
   b. Next, consider the case in which $v_1$ is a sinusoidal voltage $v_1 = 12V \sin (\omega t)$. Plot/sketch the input and output ($v_o$) waveforms versus time for two periods of the input sinusoid.

5. (Derived from S&S Problem 4.70). A half-wave rectifier circuit (see Fig. 4.23) with a 1 k$\Omega$ load operates from a 120-V (rms) 60 Hz household supply through a 12-to-1 step-down transformer. In forward bias, the silicon diode can be modeled using a 0.7-V drop for any current.
   a) What is the peak voltage of the rectified output?
   b) For what fraction of the cycle does the diode conduct?
   c) What is the average output voltage?
   d) What is the average current in the load?
   e) Suppose that we place a capacitor ($C_1$) in parallel with the resistor. What value of $C_1$ is required in order to realize an RC time constant equal to twice the time
interval over which the diode is “off” (determined from your analysis in parts a)-d)). For “R”, you should use 1 kΩ.

6. Consider a Zener diode in a regulator circuit, as discussed in S&S Example 4.7. The Zener diode has $V_{Z0} = 10\, \text{V}$ and $r_Z = 25\, \Omega$. $R_1 = 400\, \Omega$. To be consistent with Ex. 4.7, an $R_{LOAD}$ is shown, but $R_{LOAD} = \infty$ throughout this problem. The source represents the output of a diode regulator circuit, with $V_{th} = (16 \pm_1)\, \text{V}$.

a) First consider the case in which $R_{th} = 0$. Find the min and max values of $V_O$ (corresponding to $V_{th,min} = 15\, \text{V}$ and $V_{th,max} = 17\, \text{V}$, respectively).

b) Next, consider the case in which $R_{th}$ is not zero. What is the maximum value of $R_{th}$ for which the Zener diode is operating with a current of at least 2 mA over the full range of $V_{th}$? You may assume that the corresponding knee voltage is $\sim V_{Z0}$.

c) The regulating action of the Zener diode can be illustrated using appropriate load lines. Plot/sketch the Zener diode current-voltage relationship in the reverse-bias region – since the diode is “upside down” in the circuit, you can plot this in the first quadrant (i.e. current and voltage are both positive quantities). Plot/sketch load lines corresponding to i) the $V_{th,min}$ and $V_{th,max}$ points from part a) and ii) the $V_{th,min}$ point from part b).

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**Zener I-V Shown reflected into first quadrant, for Prob. 6c.**