# Electronics I

**Midterm #1**

<table>
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<th>Problems</th>
<th>Points</th>
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<td><strong>Total</strong></td>
<td><strong>15</strong></td>
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Was the exam fair?

- yes [ ]
- no [ ]
Problem 1  

4 points

For full credit, mark your answers yes, no, or not applicable for all offered answers!

1.1 In a pn-junction diode:

- [ ] yes  [ ] no  [ ] not applicable

- [X] the terminal called the anode is connected to the region of the junction which is doped by the atoms of a five-valent element,
- [X] the terminal called the cathode is connected to the region of the junction which is doped by the atoms of a five-valent element,
- [X] the terminal called the cathode is connected to the region of the junction which is doped by the atoms of a three-valent element,
- [ ] the terminal called the anode is connected to the region of the junction which is doped by the atoms of a three-valent element.

1.2 In a pn-junction diode:

- [ ] yes  [ ] no  [ ] not applicable

- [ ] majority charge carriers on the p-side of the junction are holes,
- [ ] minority charge carriers on the p-side of the junction are free electrons,
- [X] majority charge carriers on the n-side of the junction are holes,
- [X] minority charge carriers on the n-side of the junction are free electrons,

1.3 When a pn-junction diode is biased by the voltage \( v_D = v_{AC} = -0.5\, \text{V} \), the current flow through the diode is a consequence of the cumulative effect of:

- [ ] yes  [ ] no  [ ] not applicable

- [ ] the transition of electrons through the depletion region from the n-side to the p-side of the pn-junction,
- [X] the transition of holes through the depletion region from the n-side to the p-side of the pn-junction,
- [X] the transition of electrons through the depletion region from the p-side to the n-side of the pn-junction,
- [X] the transition of holes through the depletion region from the p-side to the n-side of the pn-junction.

1.4 Breakdown (Zener) diodes are specialized devices constructed for operation in:

- [ ] yes  [ ] no  [ ] not applicable

- [X] bridge-rectifier circuits,
- [X] their breakdown region,
- [X] circuits where diodes are exposed to high reverse bias voltages,
- [X] circuits which require diodes with a low value of the forward bias dynamic resistance.
Problem 2  5 points

Given is the electric circuit model shown in Figure 2.1.

Figure 2.1 A nonlinear circuit model containing a pn-junction diode. (a) The circuit model. (b) Diode’s piece-wise linear model.

Circuit elements in the circuit of Figure 2.1 are described by the following properties:

(a) diode is accurately represented by its constant voltage drop model shown in Figure 2.1(b);
(b) temperature dependence of the diode’s reverse leakage current $I_L$ is described by: $I_L$ doubles for every $10^9$K increase in diode’s temperature.

For the electric circuit model of Figure 2.1, demonstrate an ability to:

1. indicate the positive reference directions of the diode’s current flow and voltage drop;
2. determine the value of the temperature $T_1$ at which the condition $v_D(T_1) = -V_Z$ will be satisfied in the circuit modeled of Figure 2.1(a); in other words, determine the temperature $T_1$ at which the voltage drop across the diode will be equal to the diode’s breakdown voltage.

Solution

Hint #1 For full credit, give answers to all questions, prepare all required circuit diagrams, write all equations for which the space is left, and show all symbolic and numerical expressions whose evaluation produces shown numerical results.

An explicit demonstration of understanding the following solution steps is expected.

0.5 2.1 Show in the electrical model of Figure 2.1(a) the positive reference directions for diode’s voltage $v_D$ and current $i_D$.

2.2 Calculate the diode’s voltage at the known temperature $T_0$, $v_D(T_0)$,

The known value of the voltage drop $V_R$ at the temperature $T_0 = 293^9$K, and the KVL law provide the equation,

\[
v_D(T_0) = V_R(T_0) - V_{DD} = 8 - 30 = -22V \tag{2-1}
\]
2.3 Describe the operating region of the diode at temperature $T_0=293^\circ K$ by checking the conditions on all three lines below,

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>Not applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
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<tr>
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<td>X</td>
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<td>X</td>
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</table>

- The diode is forward biased,
- The diode is reverse biased,
- The diode is in its breakdown region.

2.4 Calculate the magnitude of the diode’s reverse leakage current $I_L$ at the known temperature $T_0$, $I_{L0} = I_L(T_0) = -i_D(T_0)$.

Since the calculation in part 2.2 shows that at temperature $T_0 = 293^\circ K$, the diode operates under reverse bias and outside of the breakdown region, the Ohm’s law provides the reverse leakage current $I_{L0}$ as,

$$I_{L0} = I_L(T_0) = -i_D(T_0) = \frac{V_{Ro}}{R} = \frac{8}{2 \cdot 10^6} = 4 \cdot 10^{-6} = 4 \mu A \quad (2-2)$$

2.5 Based on positive reference directions indicated in Figure 2.1(a) and KVL, derive the expression for diode’s current $i_D$ as a function of circuit element parameters.

$$i_D = \frac{V_{DD} - v_D}{R} \quad (2-3)$$

2.6 Calculate the value of the diode’s reverse leakage current $I_{L1} = -i_D(T_1)$ at the unknown temperature $T_1$.

The current which causes the voltage drop $V_R$ in the circuit of Figure 2.1(a) is essentially the reverse leakage current of the diode $I_L$. Voltage drop across the diode at $T_1$ is specified as a part of the problem definition to be $v_D(T_1) = -V_Z$. Therefore, the reverse leakage current $I_{L1}$ at temperature $T_1$ is by equation (2-3) determined as,

$$I_{L1} = I_L(T_1) = -i_D(T_1) = \frac{V_{DD} + V_D(T_1)}{R} = \frac{V_{DD} - V_Z}{R} = \frac{30 - 28}{2 \cdot 10^6} = 1 \mu A \quad (2-4)$$
2.7 Determine the ratio of the magnitudes of diode’s reverse leakage currents at the known temperature $T_0=293^\circ K$ and the unknown temperature $T_1$.

Since both leakage current magnitudes are known now,

$$\frac{I_{L0}}{I_{L1}} = \frac{4}{1} = 4$$

(2-5)

2.8 Using the known property (b) of the diode, determine the change in temperature $\Delta T = T_0 - T_1$.

by the property (b) \[ \frac{I_{L1}}{I_{L0}} = \frac{\Delta T}{2^{10}} \]

by eqn. (2-5) \[ \frac{I_{L1}}{I_{L0}} = 2^{-2} \] \[ \Rightarrow \frac{\Delta T}{2^{10}} = 2^{-2} \]

$$\Delta T = 10 \cdot \log_2 2^{-2} = 10 \cdot (-2) = -20^\circ K$$

(2-6)

2.9 Calculate the temperature $T_1$ at which the value of the diode’s voltage $v_D$ becomes equal to $-V_Z$.

$$T_1 = T_0 + \Delta T = 293 - 20 = 273^\circ K$$

(2-7)

$I_{L1} = 1 \mu A$ \hspace{1cm} $T_1 = 273^\circ K$
Problem 3 6 points

Given is the electric circuit model shown in Figure 3.1.

![Circuit Diagram](image)

Both diodes in the circuit of Figure 3.1 are accurately modeled by the ideal diode model.

For the electric circuit model of Figure 3.1, demonstrate an ability to:

1. apply the piece-wise linear models of non linear circuit elements in the process of analysis of nonlinear circuits,
2. apply the large signal method of analysis to nonlinear electric circuits containing diodes in order to determine:
   - values of the voltages $V_1$ and $V_2$ whose positive reference directions are indicated in the circuit model of Figure 3.1.
   - values of the positive reference direction currents flowing through diodes in the circuit model of Figure 3.1.

Hint #1 For full credit, give answers to all questions, prepare all required circuit diagrams, write all equations for which the space is reserved, and show all symbolic and numerical expressions whose evaluation produces the shown numerical results.

Solution

An explicit demonstration of understanding the following solution steps is expected.

3.1 Make an educated guess as to the bias conditions of the two diodes in the circuit of Figure 3.1, and show your guess by checking the conditions on all four lines below,

<table>
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<tr>
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<tbody>
<tr>
<td>yes</td>
<td>no</td>
<td>the diode $D_1$ is forward biased,</td>
</tr>
<tr>
<td>no</td>
<td>yes</td>
<td>the diode $D_1$ is reverse biased,</td>
</tr>
<tr>
<td>no</td>
<td>yes</td>
<td>the diode $D_2$ is forward biased,</td>
</tr>
<tr>
<td>yes</td>
<td>no</td>
<td>the diode $D_2$ is reverse biased.</td>
</tr>
</tbody>
</table>

3.2 Construct the linear circuit which results when the ideal diodes in the circuit of Figure 3.1 are replaced by their models for the biasing condition guessed in Section 3.1. Draw the electrical model of the constructed linearized circuit in the space reserved for Figure 3.2.

Substituting the ideal diodes $D_1$ and $D_2$ by their equivalent circuits for the bias states guessed in Section
3.1. gives the circuit of Figure 3.2 (by the definition of an ideal diode, a forward biased diode has an internal resistance of zero Ohms, and the internal resistance of a reverse biased diode is infinite).

![Figure 3.2](image-url)

**Figure 3.2** The circuit with ideal diodes replaced by their models for the biasing conditions guessed in Section 3.1.

3.3 To check the validity of the guesses made in Section 3.1, perform an analysis of the circuit of Figure 3.2 to determine the voltage across the diodes which were guessed reverse biased, and to determine the current through the diodes which were guessed forward biased; show your work in the space reserved for equation (3-1).

**Hint #2** For a meaningful process of performing the analysis, the positive reference directions of these voltages/currents must be shown in the circuit of Figure 3.2. Failure to show these positive reference directions reduces the credit for this part to 0.1.

In the circuit of Figure 3.2, the voltages $V_1$ and $V_2$ are equal since the voltage drop across the forward biased ideal diode $D_2$ is equal to 0V.

$$V_1 = V_2 = V_N - \frac{R_1}{R_1 + R_2} \cdot V_M - \frac{R_2}{R_1 + R_2} = 5 \cdot \frac{7}{7+3} - 10 \cdot \frac{3}{7+3} = 0.5V$$

which shows that the potential at $C_1$, being equal to $V_1 = 0.5V$, is $0.5V$ above the potential of $A_1$, confirming that diode $D_1$ is reverse biased in the circuit of Figure 3.2.

To formally check the guess about the bias condition of the diode $D_2$, we ought to determine the direction of the current flowing through $D_2$ in the circuit of Figure 3.2. If the current of $D_2$ flows in the positive reference direction (anode to cathode), then $D_2$ is forward biased; otherwise, the guess was wrong. By summing the voltage rises in the positive reference direction of the current $i_{D2}$ one obtains,

$$V_M + V_N - i_{D2} R_1 - i_{D2} R_2 = 0$$

solving for $i_{D2}$, and substituting the parameter values gives

$$i_{D2} = \frac{V_M + V_N}{R_1 + R_2} = \frac{10 + 5}{(7+3) \cdot 10^3} = 1.5mA$$

The obtained positive value of the current $I_{D2}$ means that the current through $I_{D2}$ flows in the positive reference direction indicated in Figure 3.2, which confirms the guess that diode $D_2$ is forward biased in the circuit of Figure 3.2.
3.4 Compare the result of the analysis performed in Section 1.3 with the guesses made in Section 1.1, to make a conclusion as to whether the bias conditions of both diodes were guessed correctly. Indicate your conclusion by appropriate checks on both lines below.

<table>
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the bias conditions of both diodes has been guessed correctly,

the bias condition of one, or more diodes has been guessed incorrectly.

If the biasing condition of at least one diode is incorrect, repeat the steps of Sections 3.1 through 3.4 using for writing the free space on the opposite page.

3.5 When the bias conditions of all diodes have been guessed correctly, determine the values of voltages $V_1$ and $V_2$ which are indicated in the circuit of Figure 3.1; show your work in the space reserved for equation (3-3).

Since now both guesses which led to the equivalent circuit of Figure 3.2 have been found correct, the results of the analysis performed on the circuit in Figure 3.2 are valid for the circuit of Figure 3.1.

Consequently, by equations (3-1),

$$V_1 = 0.5V$$
$$V_2 = 0.5V$$

(3-3)

3.6 When the bias conditions of all diodes have been guessed correctly, determine and write into the space reserved below the values of the currents flowing through diodes $D_1$ and $D_2$ in the circuit of Figure 3.1. Show your work in the space reserved for equation (3-4).

Since the diode $D_1$ is reverse biased, it does not conduct any current, so $I_{D_1}=0A$. The current through diode $D_2$ has been determined by equation (3-2). Hence, the two current values,

$$i_{D_1} = 0A$$
$$i_{D_2} = 1.5 mA$$

(3-4)