6.002 Circuits and Electronics Quiz #1

October 13, 2004

GENERAL INSTRUCTIONS:

1. Please verify that there are 17 pages in your exam.

2. Please do all of your work in the spaces provided in this examination booklet. In particular, try to do your work for each question within the boundaries of the question, or on the back side of the page preceding the question. Extra pages are also available at the end of the booklet. Place the answer to each question within the appropriate answer box.

3. You may use one double-sided page of notes and a calculator while taking this exam.

TOTAL SCORE: ___________________
Problem 1  (20 Points)

Find the Thévenin equivalent of Network A and the Norton equivalent of Network B (Fig. 1), and graph their i-v relations as viewed from their ports. (Hint: you can use superposition for Network B.) For purposes of plotting, you may assume that $V$ and $I$ are both positive. Please label key intercepts on the graphs.

![Network A](image1)

![Network B](image2)

Figure 1
\[ V_{TH} = \]
\[ I_{N} = \]
\[ R_{TH} = \]
\[ R_{N} = \]
Problem 2  (10 Points)

Figure 2 shows a circuit implementing a logic function with the convention that a high voltage level denotes a Boolean 1 and a low voltage level denotes a Boolean 0. Write a logic expression relating the output $Z$ to the inputs $A$, $B$, $C$, and $D$.

$$Z =$$
Problem 3  (20 Points)

(3A) The engineers at Yikes, Inc. have developed the cool new 4-terminal device shown below in Fig. 3. The marketing team has named the device the BOBAFET in hopes of securing some Hollywood licensing deals. Draw \( v_{DS} \) vs. \( i_D \) for the BOBAFET for \( v_{GB} = 0.5 \) V and \( v_{GB} = 2 \) V. Make sure to fully label your plots.

Figure 3
(3B) Yikes engineers build the circuit shown below in Fig. 4, and claim that the circuit behaves like a logic gate. Given that the inputs $X_1$ and $X_2$ take on only two values, 5 V representing a logical 1 and 0 V representing a logical 0, write a truth table for the circuit and determine the logic function $f(X_1, X_2)$ implemented by the gate if the output is taken between the terminal labeled OUT and ground.

![Figure 4](image)

<table>
<thead>
<tr>
<th>$X_1$</th>
<th>$X_2$</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td></td>
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<tr>
<td>1</td>
<td>0</td>
<td></td>
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<tr>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

$$f(X_1, X_2) =$$
(3C) Yikes’ sales team discovers that Lintel Corp. uses large numbers of gates in its products, and offers to sell the BOBAFET-based gate in (b) to Lintel. Lintel’s products adhere to a static discipline with $V_{OH} = 4.5$ V, $V_{OL} = 0.5$ V, $V_{IH} = 4$ V and $V_{IL} = 0.9$ V. Lintel hires you as an electronics consultant to determine whether it can use Yikes’ gates. Show that the gates violate Lintel’s static discipline under some valid condition, or prove that the gate satisfies the static discipline.

Lintel static discipline satisfied? Justification?
Problem 4  (25 Points)

Figure 5 shows a highly simplified model of a certain type of power converter system.

(4A) Find the node voltages $e_1$ and $e_2$ in terms of $V_A$, $R_A$, $R_B$, $R_C$, and $I_C$. (Assume $i_D = 0$.)

$e_1 = \phantom{0}$

$e_2 = \phantom{0}$
(4B) For this part of the problem, assume $V_A = 5 \text{ V}$, $R_A = 0.5 \Omega$, $R_B = 0.5 \Omega$, $R_C = 1 \Omega$, and $I_C = 2 \text{ A}$. The “overload” behavior of a power converter system is often of interest. What value of $i_D$ (from an external circuit) will make $v_D = 0 \text{ V}$?

$i_D =$
Problem 5  (25 Points)

Current regulator diodes (CRDs) are nonlinear two-terminal elements that are often used for limiting current flow and providing bias currents in electronic circuits. A circuit incorporating a CRD is shown in Fig. 6. The $v_D - i_D$ relationship of a CRD for $v_D > 0$ may be roughly approximated as:

$$i_D = \begin{cases} 
2v_D - 0.2v_D^2 & \text{for } v_D < 5 \text{ V} \\
5 & \text{for } v_D \geq 5 \text{ V}
\end{cases}$$

where $v_D$ is expressed in Volts, and $i_D$ is expressed in mA. This characteristic is illustrated in Fig. 7.

![Figure 6](image)

![Figure 7](image)
(5A) Consider the circuit of Fig. 6 for parameters $v_I = 5 \, \text{V}$, $R_I = 1 \, \text{k}\Omega$. Write an equation relating the voltage $v_D$ to input voltage $v_I$ for this case, and solve for voltage $v_D$. (Note: it is possible to do a rough graphical cross-check on your answer by drawing a load line on Fig. 7.)

$\quad v_D =$
(5B) Assume that \( V_I \) has been adjusted such that the operating point is at \( V_D = 3 \) V. Find the value for the incremental resistance of the CRD by linearizing the expression for \( i_D \) about this operating point. (Recall that the incremental resistance, also called the small-signal resistance, is the ratio of the incremental change in device voltage to incremental change in device current at the specified operating point.)

\[
r_D = \text{ } \]


(5C) Draw the small-signal circuit for the nonlinear circuit in Fig. 6 at the operating point in part (5B). (That is, for $R_I = 1\, k\Omega$, $V_D = 3\, V$.) Make sure to indicate all component values in the small-signal circuit. What is the expected change in output voltage $\Delta V_D$ for a small change in input voltage $\Delta V_I = 0.1\, V$?

Draw and label small-signal circuit model

$\Delta V_D =$