MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.002 – Electronic Circuits
Fall 2002

Problem Set 3

Issued: September 18, 2002 **Due: September 25, 2002**

Reading Assignment:

- A&L Chapter 5 for Thursday, September 19.
- A&L Chapter 6 for Tuesday, September 24.

Problem 3.1: Two networks N_1 and N_2 are described by their terminal relations as shown in Figure 1. The terminals are connected together (a-b, a'-b') and a $1k\Omega$ resistor is placed across the common terminals. Find v_1 $(= v_2)$, i_1 and i_2.

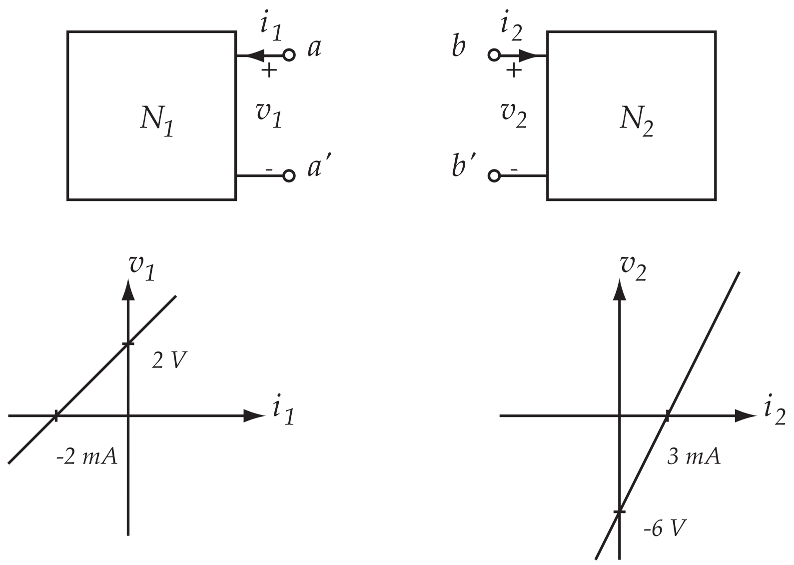

Figure 1: Networks for Problem 3.1

Problem 3.2: Consider the network shown in Figure 2.

(A) Find v by superposition, i.e., determine $v = v_A + v_B$ where v_A is the voltage due to the $2mA$ source acting alone and v_B is the voltage due to the $4V$ source acting alone.

(B) Determine the power dissipated in the $2k\Omega$ resistor whose voltage across you found in part (A).

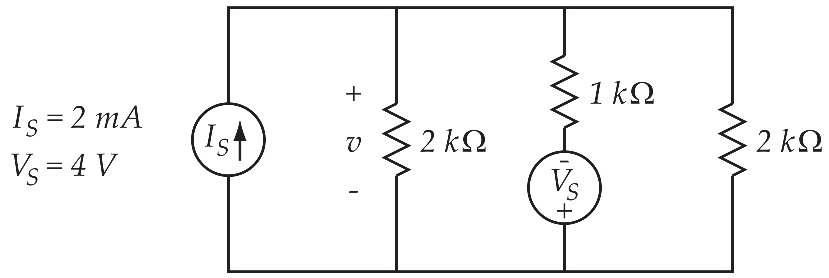

Figure 2: Network for Problem 3.2

(C) Does the principle of superposition apply to power, i.e., is $p = p_A + p_B$ where p_A is the power dissipated across the $2k\Omega$ resistor with the $2mA$ source acting alone and p_B is the power dissipated with the $4V$ source acting alone? Explain why or why not.

Problem 3.3: The nonlinear device in the circuit shown in Figure 3 has the v-i relation

$$i = v^3$$

where i is in mA when v is expressed in V. (The units of the current source are also in mA.)

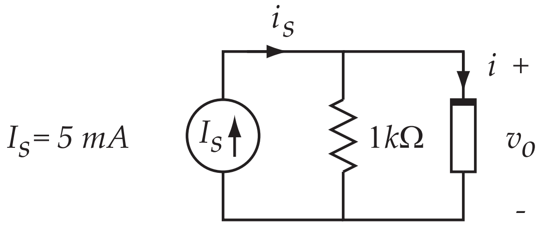

Figure 3: Network for Problem 3.3

(A) Find a cubic equation whose solution determines the voltage v_O.

(B) Solve the cubic equation that you obtained in part (A) by any method you choose (e.g., computer, iteration, Newton's root method) and find the circuit's operation point.

(C) Draw an incremental circuit valid at the operating point found in (B) and calculate the incremental resistance v_o/i_s seen by the source.

Problem 3.4: When a semiconductor diode is heavily doped with impurities, the i-v relationship can exhibit a region of negative incremental conductance, i.e., a region where $di/dv < 0$. The origin of this effect lies in a quantum-mechanical phenomenon known as "tunneling" and a diode exhibiting this effect is known as a tunnel diode. The tunnel diode was invented by the Japanese scientist Leo Esaki in 1958 and for this and related work Esaki received the Nobel prize for Physics in 1973.

The symbol and i-v characteristic of a tunnel diode are shown in Figure 4.

(A) The tunnel diode is embedded in the circuit shown in Figure 4. The source voltage $V = 1.5V$. Using graphical analysis, find *all* possible equilibrium values of i and v. Notice that nonlinear

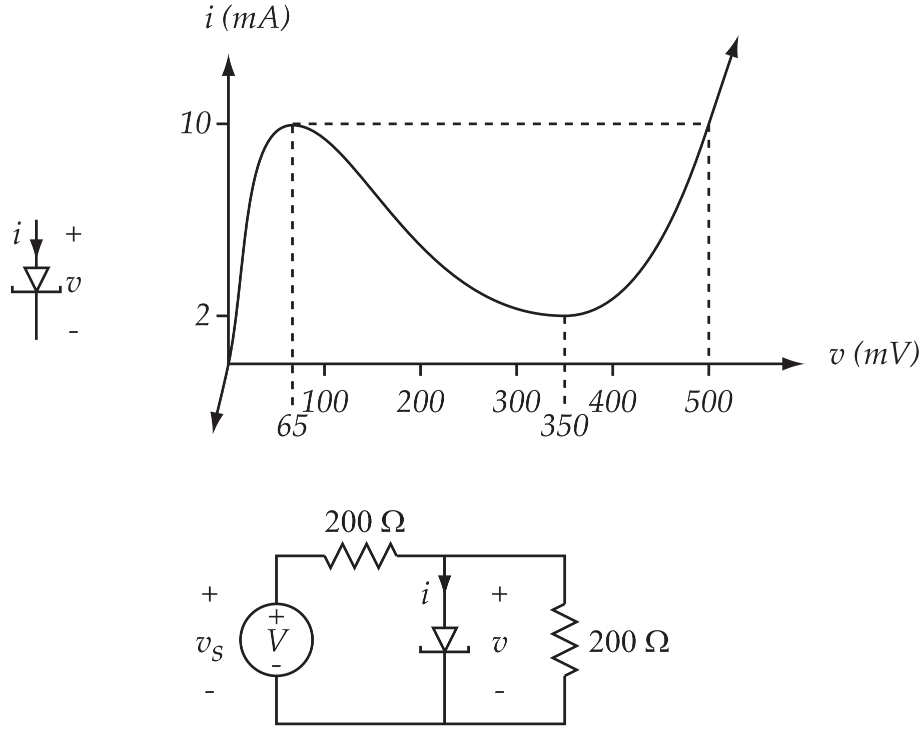

Figure 4: Device and network for Problem 4

devices can lead to multiple network solutions, where each solution corresponds to a set of element voltages and currents that satisfy KVL, KCL and the v-i relations.

(B) Over what range of V do multiple solutions exist?

(C) For each of the operating points found in (A), draw an incremental circuit and calculate the small-signal gain $G = \Delta v / \Delta v_s$.

Problem 3.5: The logic circuit shown schematically in Figure 5 has 4 inputs, A-D, and 3 outputs O_0-O_2. The binary number formed by $O_2O_1O_0$ represents the number of inputs that are high, e.g., if all inputs are high then $O_2O_1O_0 = 100$.

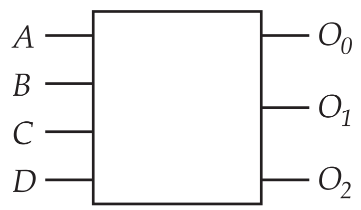

Figure 5: Schematic circuit for Problem 5

(A) Construct the truth table for this logic circuit.

(B) Determine an implementation for the circuit using only NAND and NOR gates. Assume each gate can have multiple inputs.

Problem 3.6: Consider the input/output graph of a buffer shown in Figure 6.

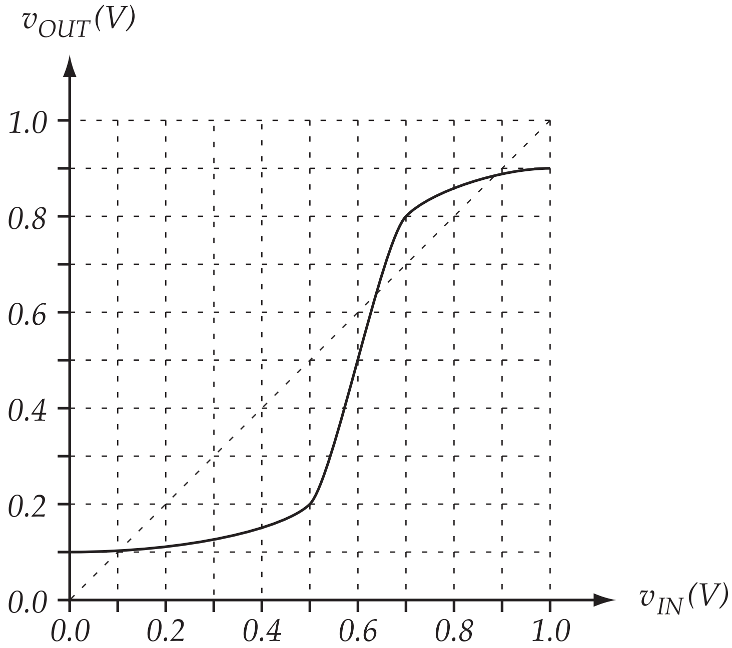

Figure 6: Graph for Problem 6

(A) Ignoring noise, what is the highest value that could be chosen for v_{OL}? What is the lowest value that could be chosen for v_{OH}?

(B) If the noise margin is maximized:

(i) What is the highest value that could be chosen for v_{OL}?

(ii) What is the highest value that could be chosen for v_{IL}?

(iii) What is the maximum noise margin for low inputs?

(iv) What is the lowest value that could be chosen for v_{OH}?

(v) What is the lowest value that could be chosen for v_{IH}?

(vi) What is the maximum noise margin for high inputs?