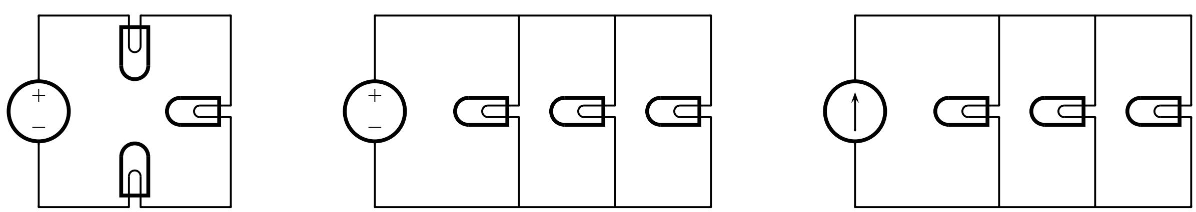
Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science

6.002 – Circuits & Electronics
Spring 2008

Problem Set #2

Issued 2/13/08 – Due 2/20/08

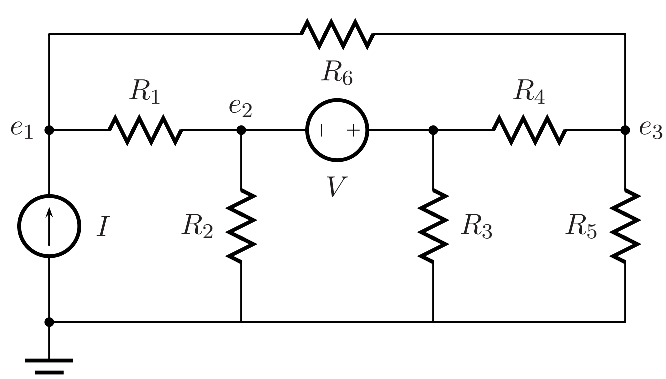
Exercise 2.1 (1 Point): In each circuit shown below, three light bulbs are driven by a single source. In two of the circuits the source is a voltage source, and in the other it is a current source. Assume that one of the three light bulbs burns out and becomes an open circuit. Do the other two light bulbs get brighter, get dimmer, or exhibit no change in intensity? Why?



Exercise 2.2 (1 Point): Using the node method, develop a set of simultaneous equations for the network shown below that can be used to solve for the three unknown node voltages in the network. Express these equations in the form

$$G \begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = S$$

where G is a 3×3 matrix of conductance terms and S is a 3×1 vector of terms involving the sources. You need not solve the set of equations for the node voltages.



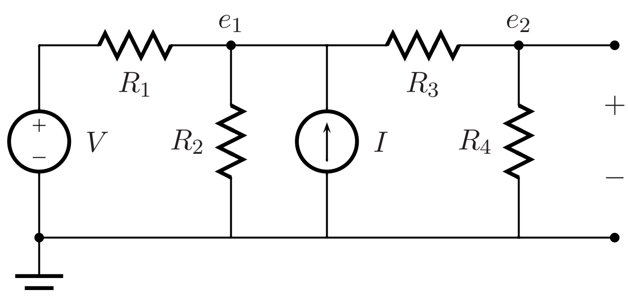
Problem 2.1 (2 Points): Parts (A) through (C) of this problem analyze the network shown below by two methods: superposition and the direct application of the node method. You should compare for yourself the work required to analyze the network by these two methods. For Parts (A) through (C), assume that the port is left open.

(A) First, use superposition to determine e_1 and e_2. That is, superpose the two partial node voltages obtained with only single sources active to find the total node voltages. Remember that a zero-valued voltage source is a short circuit, and a zero-valued current source is an open circuit. Hint: rather than employing the node method twice, once for each partial analysis, consider employing alternative simpler analyses involving the use of parallel and series resistor combinations, and voltage and current dividers.

(B) Second, use the node method to directly determine e_1 and e_2 in total.

(C) Compare the solutions to Parts (A) and (B). The two solutions should be the same.

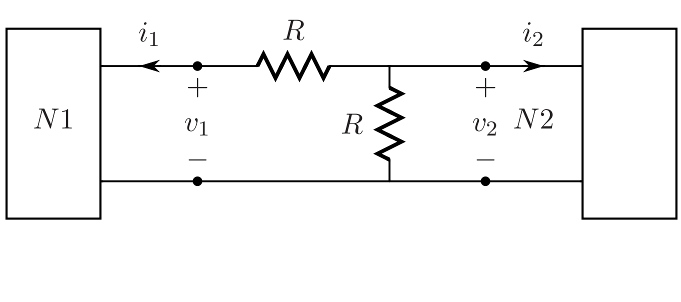
(D) Determine the Thevenin and Norton equivalents of the circuit as viewed from the port.

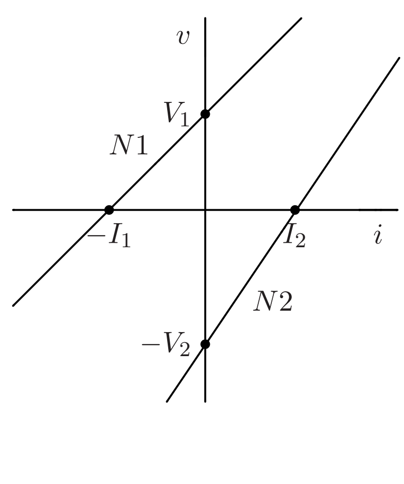


Problem 2.2: Two networks, N1 and N2, are described graphically in terms of their i-v relations, and connected together through two resistors, as shown below.

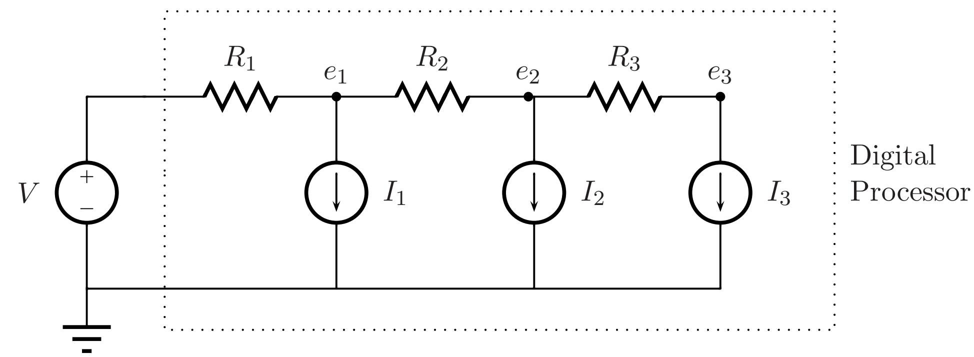
(A) Find the Thevenin and Norton equivalents of N1 and N2.

(B) Find the currents i_1 and i_2 that result from the interconnection of N1 and N2.





Problem 2.3 (2 Points): The circuit shown below models the power distribution network in a digital processor. The voltage source models the external supply that powers the processor, the resistors model the power distribution wiring internal to the processor, and the current sources model the loads presented by the individual parts of the processor. The source values V, I_1, I_2 and I_3 are all positive, as are the three internal node voltages e_1, e_2 and e_3. Further, depending upon whether the corresponding part of the processor is in use or not, I_1, I_2 and I_3 can each take on only the value of either I or zero.



(A) Given the possible values for I_1, I_2 and I_3, what are the maximum and minimum values that e_2 can exhibit? Express your answer in terms of V, I, R_1, R_2 and R_3.

(B) Given the possible values for I_1, I_2 and I_3, what is the maximum power that the voltage source must be able to supply to the processor? Express your answer in terms of V, I, R_1, R_2 and R_3.

(C) If any node voltage inside the processor power distribution network falls below a threshold value e_{Min}, then the part of the processor connected directly to that node will fail to operate properly. Given the possible values for I_1, I_2 and I_3, what is the minimum value for V that guarantees that all parts of the processor will always operate properly? That is, what is the minimum value of V required to guarantee that e_1, e_2 and e_3 never fall below e_{Min}? Express your answer in terms of I, R_1, R_2, R_3 and e_{Min}.

(D) If any node voltage inside the processor rises above a threshold value e_{Max}, then the part of the processor connected directly to that node will be damaged. Given the possible values for I_1, I_2 and I_3, what is the maximum value for V that guarantees that no part of the processor will be damaged? That is, what is the maximum value of V required to guarantee that e_1, e_2 and e_3 never exceed e_{Max}? Express your answer in terms of I, R_1, R_2, R_3 and e_{Max}.

This problem was originally a quiz problem. Therefore, it was intended to be solved with more thinking than writing.

Problem 2.4 (2 Points): This problem makes use of the iLab Microelectronics Device Characterization Laboratory to measure the voltage-current characteristic of a real diode.

As in Problem 1.4, login to the iLab web site, select the Microelectronics Device Characterization Lab Client V7.0 and launch it. Then select *6.002 pn diode* under the *Device* menu. This is the device that you will characterize.

To measure the voltage-current characteristic of the diode, you should connect the n-side of the diode (the side with the vertical bar in the symbol) to ground, and drive the p-side (the side with the arrow in the diode symbol) with a voltage source. Refer to the instructions given in Problem 1.4 for programming the SMUs appropriately. Sweep the voltage of the diode between -1 V and 1 V with a 10 mV step. Set the current compliance to 10 mA. Run the experiment and download the data; again see Problem 1.4 for instructions. Make a note of the temperature of the diode which is given in degrees Kelvin at the top center of the *Results* canvas.

Use your measured voltage and current data for the diode to answer the following questions. As you analyze the data, remember that SMU #1 was set up to limit the diode current to 10 mA, even if the applied voltage attempts to drive a larger current.

(A) The ideal voltage-current characteristic of the pn diode is given by

$$i_{\mathrm{D}} = I_{\mathrm{S}}(e^{v_{\mathrm{D}}/V_{\mathrm{T}}} - 1)$$

where V_{T} is the thermal voltage given by $V_{\mathrm{T}} = kT/q$; $k = 1.38 * 10^{-23}$ J/K is Boltzmann's constant, T is the diode temperature in degrees Kelvin, and $q = 1.60 * 10^{-19}$ C is the electron charge.

Given the measured diode temperature, determine V_{T}.

(B) Over what range of voltage does the measured diode data exhibit $i_{\mathrm{D}} \approx -I_{\mathrm{S}}$? Is this as expected from the theoretical relation given above?

(C) Over what range of voltage does the measured diode data exhibit the exponential relation $i_{\mathrm{D}} \approx I_{\mathrm{S}} e^{V_{\mathrm{D}}/V_{\mathrm{T}}}$? Is this as expected from the theoretical relation given above? Using this exponential branch of the measured data, estimate I_{S}.

The following hints may help in answering Parts (B) and (C) above.

- Parts (B) and (C) can be answered either graphically or numerically. If you choose a graphical method, then you should plot the downloaded data using MatLab, Excel or another program, or print a screen-shot of the graph produced by the lab. Capturing screen-shots is a platform specific activity; consult the lab documentation for Windows- and Athena-specific advice. If you choose a numerical method, then you could process the downloaded data using MatLab, Excel or another program.

- Before answering Parts (B) and (C), you may find it instructive to examine the measured data visually using the client. In this case, a logarithmic y-axis display is probably best used for Parts (B) and (C).