EXPERIMENT 3: SOME DC CIRCUIT THEOREMS 9/17/03

In this experiment we will carry out measurements that illustrate Thevenin's theorem, Norton's theorem, the superposition theorem, and the reciprocity theorem. We will also observe what happens to these theorems when circuits contain non-linear elements.

The circuit to be examined is enclosed in a box with three ports (terminal pairs). At the end of the experiment the box will be opened, the circuit sketched, and the components' values labeled. You will then calculate some of the measured quantities for comparison. Use a DMM for all voltage measurements and an Electrometer for the current measurements. To reduce errors caused by the input resistance of the ammeter, use the 10^{-1} A full scale setting (which gives $R_A = 10\ \Omega$) and use the multiplier to increase the meter sensitivity. Be sure to check and adjust the zero of the ammeter at frequent intervals, and in particular each time you change the multiplier setting. Start with the switch in the R position. (You may be able to save some time by doing step 6 as you go along.)

NOTE: The theorems do not hold unless you short circuit all unused ports.

1. Short port #2, apply a variable voltage V_1 at port #1, and measure the current I_3 at port #3 for $0 \leq V_1 \leq 20$ V in 2 V steps. Plot the results and determine if the circuit is linear. Should Thevenin's theorem apply?

2. Next we will measure the Thevenin and Norton parameters for this circuit with V_1 held fixed.

   (a) Set V_1 to 20 V and then measure the open-circuit voltage (Voc) and the short-circuit current I_{SC} at port #3. Calculate the Thevenin equivalent voltage (V_T) and resistance (R_T) and the Norton equivalent current (I_N). In the following steps we will measure R_T by three other methods.

   (b) Insert a variable 0.5% resistor R in series with the ammeter at port #3, and measure the voltage across R plus the ammeter (with the DMM) and I as a function of R. Tabulate R, V, and I for 10 points that make roughly equal size steps in V. Make a plot of I vs. V, draw a line through the points with a ruler, and determine R_T from the slope of the line.

   (c) Short the ammeter and vary R until V_R = Voc/2. The value of R for which this occurs is equal to the output impedance of the circuit and is therefore also equal to R_T.

   (d) Disconnect the power supply, short circuit port #1, and use the DMM to directly measure the output impedance of port #3. Compare the four

measurements of R_T in a table. Calculate the percentage error in each measurement, assuming the last value to be the correct one.

3. The next step is to check the superposition theorem. Simultaneously apply voltages $V_2 \simeq 20$ V at port #2 and $V_3 \simeq 15$ V at port #3 and measure the current at port #1. Determine whether the current at port #1 is equal to the sum of the currents due to V_2 and V_3 independently. Remember to short circuit each port when you have voltage source disconnected. Does the superposition theorem hold for this circuit?

4. For a linear circuit, the net current at any port can be expressed in terms of a set of constants (Gij) and the voltages applied across the various ports as follows:

$$I_1 = G_{11}V_1 + G_{12}V_2 + G_{13}V_3$$

$$I_2 = G_{21}V_1 + G_{22}V_2 + G_{23}V_3$$

$$I_3 = G_{31}V_1 + G_{32}V_2 + G_{33}V_3$$

According to the reciprocity theorem Gij and Gji must be equal. Use the following procedure to measure the parameter G_{12}. Short port #3 ($V_3 = 0$), and connect the ammeter to port #1 (so V_1 is also zero) and apply a voltage V_2 at port #2. Record V_2 and I_1, and then calculate G_{12}. Next interchange the voltage source and the ammeter and measure G_{21}. Does the reciprocity theorem hold for this circuit?

5. Measure all 9 G parameters for the circuit (you do not need to worry about the signs). Remember to short circuit the unused ports, and be careful that you do not connect the ammeter across the power supply. Make sure it is clear from your notebook how the measurements were done.

6. Repeat parts 1, 3, and 4 with the switch in the L position.

7. Open the box and make a schematic diagram of the circuit. Calculate V_T, R_T and I_N for the circuit you used in part 2. Also calculate G_{12}, G_{21} and G_{22}. The remaining parameters are as follows (S is a sieman, the unit for the reciprocal of resistance):

$G_{11} = 1.100$ mS $\quad$ $G_{33} = 0.898$ mS

$G_{13} = 0.145$ mS $\quad$ $G_{23} = 0.174$ mS.

Tabulate the measured and calculated values of all the Thevenin and Norton parameters and the G parameters, including the % error. Are the errors reasonable considering the tolerances of the resistors in the circuit?