EXPERIMENT III

CIRCUIT ANALYSIS TECHNIQUES, PRACTICAL SUPPLIES AND MAXIMUM POWER TRANSFER

OBJECTIVE: In this experiment, you will measure DC parameters in resistive circuits, and compare your results against prelab simulations and hand calculations using different circuit analysis techniques. The following concepts will be covered:

1. Thevenin and Norton equivalents, source transformation;
2. Node voltage circuit analysis technique,
3. Real (practical) power supplies,
4. Maximum power transfer,
5. Use of DC power supply as an independent voltage source and independent current source,
6. Use of multimeter to measure DC current and voltage parameters in resistive circuits.

EQUIPMENT & COMPONENT LIST:

DC Power Supply
Multimeter
Resistors (100Ω, 2 x 1kΩ, 2.2kΩ, 3.3kΩ, 6.8kΩ, 8.2kΩ, 1k pot).

PRELIMINARY WORK:

0. **Safe use of Programmable DC Power Supply in Constant Voltage and Constant Current Modes**

   Read pages 37-41 of the 3631 DC Supply User's Guide carefully to be comfortable with the configuration of the supply as an independent voltage source and independent current source. Make a note of how to set a *voltage limit* in current source mode, or *current limit* in voltage source mode in order to exercise maximum safety. Current and voltage limits protect your circuit against unexpected component failures, breadboard malfunctions such as short-circuits, and other problems, by asserting an upper bound on the maximum current and voltage that the DC supply can deliver.

1. **Node voltage, Thevenin and Norton transformation techniques:**

   Given the circuit in Figure 3.1 with component values R_1=2 kΩ, R_2=2.2 kΩ, R_3=6.8 kΩ, R_4=3.3 kΩ, R_5=8.2 kΩ, V_S=10 V, I_S=10 mA:

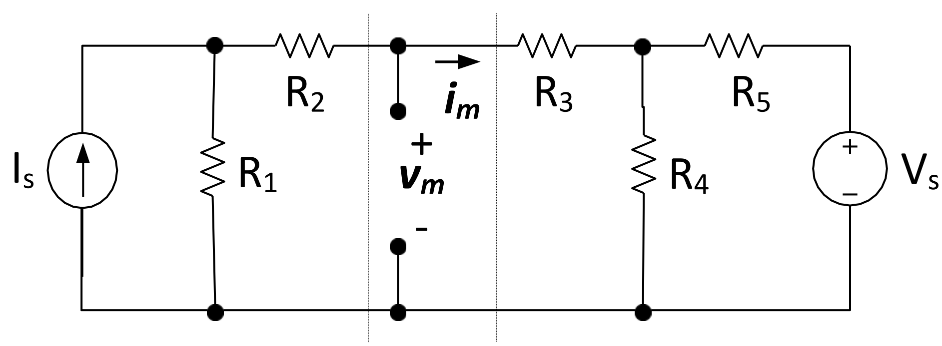

Figure 3.1 Circuit for node voltage, Thevenin and Norton equivalence/transformation.

A. Use node voltage method to determine the value of voltage v_m, and current i_m.

B. Derive a Thevenin equivalent for the portion of the circuit in Figure 3.1 that is to the **left** of v_m terminals.

C. Derive a Norton equivalent for the portion of the circuit that is to the **right** of v_m terminals.

D. Sketch the reduced circuit with the new components and values you identified in (B) and (C), and mark both voltage v_m and current i_m in your sketch.

E. Calculate the values of v_m and i_m in your simplified circuit model from (d) using the node voltage method. Are these values consistent with (A)?

F. **(LTspice)** Run a DC op pt (DC operating point) simulation for the circuit in Figure 3.1 to obtain v_m and i_m. Make sure all circuit nodes, resistor and supply instances are clearly labelled in your schematic in order to make it easier to follow the simulation output report. Include LTspice schematic and simulation result window snapshots to the prelab report.

2. Real (practical) power supplies and maximum power transfer

A. Given the voltage source in the following circuit (Figure 3.2) is a practical (non-ideal) source, do you expect V_o and V_{in} to have the same value? Explain your reasoning.

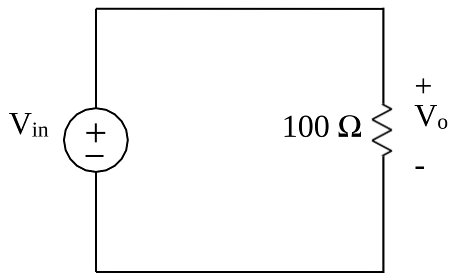

Figure 3.2 Theoretical model of a voltage source with 100 Ω resistive load.

B. The circuit to the left of the terminals a-b in Figure 3.3 models a thermoelectric power supply with internal resistance R_S. R_L represents a load with variable resistance.

- When R_L is disconnected from the circuit, the open-circuit voltage between terminals a-b is measured as 5 V.
- When the terminals a-b are shorted (connected with a wire), 50mA of current is measured through the wire between a and b.

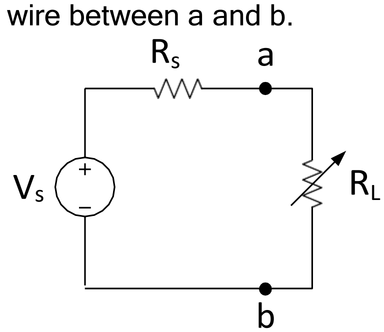

Figure 3.3 Model emulation of a thermoelectric power supply with internal resistance R_S and external resistive load R_L.

a. Calculate the values of V_s and R_s for this thermoelectric power supply based on the provided information? Show your calculations.

b. What is the value of load resistance R_L for which maximum power is transferred from the power supply to the load?

c. What is the value of the maximum power delivered to the load for the condition specified in part (b)?

d. **(LTspice)** Construct the circuit in Figure 3.3. Set the value of $\boldsymbol{V_s}$ and $\boldsymbol{R_s}$ with the values you calculated in part (a). Define load resistance as a parameter RL using curly brackets {RL} as you did in the last lab. Run a DC (DC op pt) simulation with parameter sweep spice directive '**.step param….**' to obtain a plot of $\boldsymbol{R_L}$ power dissipation vs. $\boldsymbol{R_L}$ resistance value. You may sweep from 25 Ω to 175 Ω with 5 Ω step size. Include snapshots of the schematic and simulation results to your prelab report. How does your result compare to the calculation in (b) above?

EXPERIMENTAL WORK:

Note: There are four demonstrations in this laboratory. Once you are done with any of the demos, please have one of the lab instructors take a look at your setup and measurement in order to get credit for this portion of the lab. You may be asked questions about your demonstration.

Hint: It is a good idea to always measure the value of the resistors before using them so that you can update your prelab calculations with the actual resistance numbers when you compare against measurements – the error in resistor values may explain part of the calculation-to-measurement discrepancies you observe in the lab.

1. **Node voltage, Thevenin and Norton transformation techniques**

Setup the circuit of Figure 3.1 with the provided component and supply values in prelab Exercise 2. Set the current compliance (current limit) value for the voltage source to 20 mA. Set the voltage compliance (voltage limit) value for the current source to 20 V.

a. **Measure** $\boldsymbol{v_m}$ and $\boldsymbol{i_m}$ values using the multimeter. Fill in Table 1, and explain any discrepancies among calculated, simulated, and measured.

Demo 1: Demonstrate your circuit setup and measurements to the lab instructor.

Table 1

Calculated $\boldsymbol{v_m}$ in Prework 1.A (V)	Calculated $\boldsymbol{i_m}$ in Prework 1.A (mA)	Simulated $\boldsymbol{v_m}$ in Prework 1.F (V)	Simulated $\boldsymbol{i_m}$ in Prework 1.F (mA)	Measured $\boldsymbol{v_m}$ (V)	Measured $\boldsymbol{i_m}$ (mA)

b. **Measure** the Thevenin resistance $\boldsymbol{R_{Th}}$ and Thevenin voltage $\boldsymbol{v_{Th}}$ parameters directly for the portion of the circuit to the left of $\boldsymbol{v_m}$ terminals. You may disconnect some of the wires and reconfigure the supplies when doing this.

c. **Measure** the Norton resistance $\boldsymbol{R_N}$ and Norton current $\boldsymbol{i_N}$ parameters directly for the portion of the circuit to the right of $\boldsymbol{v_m}$ terminals. You may disconnect some of the wires and reconfigure the supplies when doing this.

d. Fill in **Table 2**, using calculations from prelab 1.B and 1.C, and above measurements. **Comment** on any differences between expected (calculated) and measured.

Demo 2: Demonstrate your circuit and measurement setup to the lab instructor.

Table 2

Calc. $\boldsymbol{v_{Th}}$ (V)	Calc. $\boldsymbol{R_{Th}}$ (Ω)	Calc. $\boldsymbol{i_m}$ (mA)	Calc. $\boldsymbol{R_N}$ (Ω)	Meas. $\boldsymbol{v_{Th}}$ (V)	Meas. $\boldsymbol{i_m}$ (mA)	Meas. $\boldsymbol{R_{Th}}$ (Ω)	Meas. $\boldsymbol{R_N}$ (Ω)

2. Real (practical) power supplies and maximum power transfer

Build the circuit of Figure 3.3 using the calculated power supply parameters in prelab 2.B(a). DC supply is emulating the thermoelectric generator, and $\boldsymbol{R_S}$ resistor is emulating the internal resistance of the thermoelectric device in this experiment. **Make sure you use the same compliance limits as before for the DC power supply.**

a. **Record** current through the load resistance ($\boldsymbol{i_L}$) and the voltage across the load resistance ($\boldsymbol{v_L}$) for load values given in **Table 3**. If you cannot form resistor networks to match the provided resistance values exactly, try to get as close as possible. **Calculate and record** the power ($\boldsymbol{p_L}$) dissipated at $\boldsymbol{R_L}$ for each value.

Table 3

R_L (Ω)	i_L (mA)	v_L (V)	p_L (mW)
25			
50			
75			
100			
125			
150			
175			

b. **Sketch a graph** of $\boldsymbol{p_L}$ as $\boldsymbol{R_L}$ changes, using Table 3. Is this graph consistent with the prelab expectations? **Explain**.

Demo 3: Demonstrate your circuit and maximum power point measurement to the lab instructor.