## Project #2 – Thevenin Equivalent Circuit and Maximum Power Transfer

### Lab Objectives

1. Analyze DC Circuits by analytical means.
2. To use a circuit simulation package to analyze a multiple-source DC Circuit.
3. Use data analysis and plotting packages to plot data obtained by experimentation.
4. Generate results and plots to demonstrate circuit principles.
5. Perform DC measurements in simple and relatively complex circuits.
6. Properly follow a schematic to construct basic circuits.
7. To become familiar with the design tools necessary to create your own printed circuit boards (PCBs), sometimes called printed wiring boards (PWBs).
8. Improve competency with soldering, current and voltage measurements.
9. Develop proficiency in the application of Ohm's Law and Kirchhoff's laws of voltage and current through power calculations.

### Pre-Laboratory Preparation

Prior to your scheduled laboratory meeting time the following items need to be completed in addition to reading the entire lab handout to understand which sections are done individually, which are team and what the schedule for this lab is. Contact your instructor with questions ASAP!

#### Research

1. Review your class notes and the textbook sections covering Thevenin's Theorem and the concept of maximum power transfer.

#### On Line Learning

1. Review the short "Tips for Designing PCBs" article that can be found here: https://www.expresspcb.com/tips-for-designing-pcbs/
2. Download, install and spend some time experimenting with the ExpressPCB program also found at the link above.
3. Find and review a video on YouTube on:
   a. Through-Hole Soldering Techniques

#### Preparation for the Prelab Quiz

1. Determine the Thevenin Equivalent circuit seen by the load (looking into terminals a-b) for the circuit shown in Figure 1. R4 is part of the circuit, not the load.
2. Using this equivalent circuit, calculate $V_L$ for:
   a. Load 1 connected ($S_1$ pressed), explain the value you chose for the voltage drop across $D_1$.
   b. Load 2 connected ($S_2$ pressed)
3. Using the load voltage values calculated in step 2 determine $I_{L1}$ and $I_{L2}$ as well as the power dissipated by Load 1 and Load 2.
4. Using Multisim, simulate the circuit shown in Figure 1 for each load connection and determine $V_L$, $I_L$ and $P_L$ for each case.
   a. Check the simulation results against your calculations.
5. Place your calculations and simulation results from steps 1 through 4 into an appropriate data table so that you can access this information quickly for the online prelab quiz. You will have 10 minutes to complete the prelab quiz at the start of lab.

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## DC Circuits Lab Procedure

**<u>PART 1 – PCB Design Using ExpressPCB (Individual work, Project 2, Week 1 of 2)</u>**

1. Design a PCB in the ExpressPCB program using the following constraints and information to implement the circuit shown in Figure 1:
    a. You will design a 3 "X by 3.5 " Y double-sided pcb with no silkscreen layer. All your parts will be mounted on the top layer and the majority of your traces will be on the bottom layer. Use at least 0.030" wide track when connecting your components.
    b. The traces in your layout must all be horizontal, vertical or at 45 degree angles
    c. **Power Supplies** – Voltages $E_1$ and $E_2$ will be supplied by the laboratory power sources. Use a 0.070" round pad with a 0.033" hole for each source connection. When you populate your design, solder a piece of appropriately sized and colored hookup wire for each supply terminal into your board.
    d. **Resistors** - Use the component "Resistor – 0.50 watt (lead spacing 0.5 inch) for the resistors.
    e. **Switches** - The switches can be found at the very end of the component list in ExpressPCB. Use "Switch – 6mm Push button (Omron B3F-1022), Digikey SW403-ND". Go to ww.digikey.com to find the wiring diagram for the switch. Note: The switch layout and placement is important, it is not a "square" part and needs to be placed in the proper orientation.
    f. **LED** - Use the component "LED – T1" in ExpressPCB. The symbol has two terminals like a resistor but light is only generated in an LED when current flows from anode to cathode. The anode is the curved side of the symbol (round hole), and the cathode is the flat side (square hole). Like the switch, proper placement is critical.
    g. When connecting your components, keep in mind which voltages and currents you will be measuring in lab. Place plenty of through-hole test points so that these voltages and currents can be easily measured without cutting 'track' to break the circuit or trying to hold test leads on the board with multiple hands.
2. Use the text tool to write your name, date, revision number, lab section, day and time on the board. Place text only on the top copper layer.
3. Prepare your design for printing and approval. Make sure your design fits within a 3" (x-direction) by 3.5" (y-direction) border with a 0.2" setback on all edges. To help facilitate this, set the yellow border per your instructor's direction and place an "index" mark at the upper-left corner of your design. **Have your instructor sign-off on your layout.**
4. <u>You will populate a similar board during open-lab time **BEFORE** coming to week 2 of this project lab.</u>

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## Part 2 – PCB Build/Test (IN OPEN LAB - Between week 1 and 2 of the project, Individual work)

1. Once you purchase your blank PCB (see Ken or Chris and bring the DC lab fee in Tiger bucks) and BEFORE WEEK 2 of this lab, you need to carefully populate AND test your PCB:
   a. Note that the left-hand side of this PCB contains the circuitry shown in Figure 1 and is very similar to the board you designed during week 1.
   b. PAY VERY CAREFUL ATTENTION to the orientation of S1, S2 and D1. Placing any of these components in the incorrect orientation guarantees trouble reworking your board later and much more time in the lab.
   c. Make sure D1 lights up when you press S1 and that you have the correct voltage across RL2 when S2 is pressed.
   d. The right-hand side circuitry on your PCB contains an LED flasher circuit that uses R-C timing and two BJTs for switching. See Figures 3 and 4 for the schematic and PCB layout for this circuitry.
   e. Note that there are a few discrepancies on this side of the PCB (Schematic -> PCB):
      i. LED2 -> D2
      ii. LED3 -> D3
      iii. V1 -> E2
   f. The footprints for R6 through R9 are smaller than those used on the left-hand side of the PCB, you may have to bend the resistor leads under slightly when placing these components.
   g. PAY VERY CAREFUL ATTENTION to the orientation of the LEDs, BJTs and electrolytic capacitors while populating this side of your PCB. Incorrect placement guarantees rework issues later.
   h. Make sure your LEDs flash when you apply 12V to the E2 terminals on your board.
2. Now that you have populated and tested both sides of your PCB, spend some time thinking about how both circuits work and how to modify the flashing rate or LED brightness of the flasher circuit. You may want to consider simulating your flasher circuitry to get a better understanding of it before coming to lab for project #2, week 2.

## Part 3 – PCB Measurements (Project 2, week 2 of 2)

1. Individual - **Demonstrate your functional board (both circuits) to your lab instructor/TA for signoff.**
2. Team – Pick one working PCB from your team and measure $V_L$, $I_L$ and determine $P_L$ for Load 1 and for Load 2.
3. Team - Create a data-table showing your calculated, simulated and measured values for all three parameters measured above. Include a percent-error column using your simulated values as the basis.
   a. Explain any significant discrepancies on the same piece of paper as your data table.
   b. Include one set of sample calculations on the same sheet of paper as your data table.

## Part 4 – Thevenin Equivalent Circuit Measurements (Team)

1. Build the Thevenin Equivalent Circuit you determined in pre-lab on a protoboard.
   a. Use the closest standard resistor value for $R_{TH}$.
2. Measure $V_L$, $I_L$ and determine $P_L$ for Load 1 and for Load 2.

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3. Create a data-table comparing your measured values for all three parameters measured above in the original and Thevenin equivalent circuits. Include a percent-error column using your original circuit measurements as the basis.
4. Explain any significant discrepancies on the same piece of paper as your data table.
5. Include one set of sample calculations on the same sheet of paper as your data table.
6. Using your Thevenin equivalent circuit, perform the following:
   a. Attach a Decade-Resistance Box as the circuit load.
   b. Vary the load resistance from 10 ohms to 10k-ohms and <u>taking at least ten data points</u> **<u>per decade</u>**, measure $V_L$ and $I_L$.
   c. Using $V_L$ and $I_L$, determine $P_L$ for each load resistance.
7. Create a data-table showing your values for all three parameters determined above.
8. Using your data table, create three separate and properly labeled and scaled plots <u>on the same piece of paper</u> showing:
   a. The load voltage as a function of load resistance.
   b. The load current as a function of load resistance.
   c. The load power as a function of load resistance.

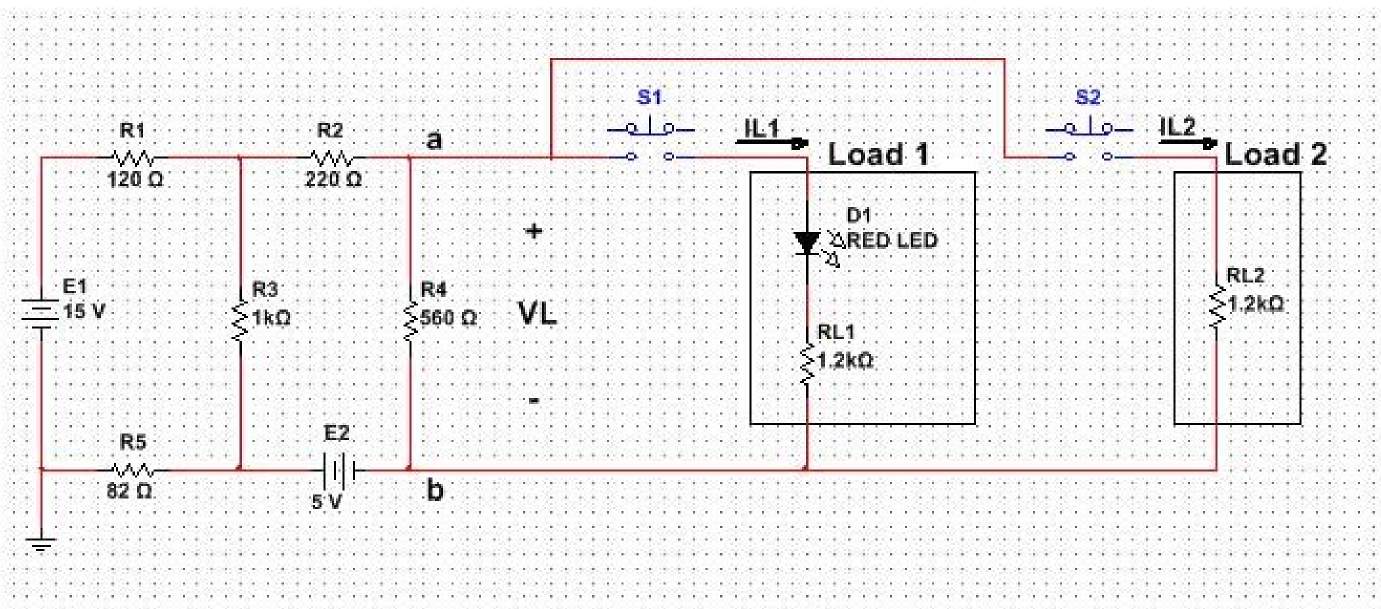


**Figure 1 - Original Circuit with Two Loads Shown (PCB)**

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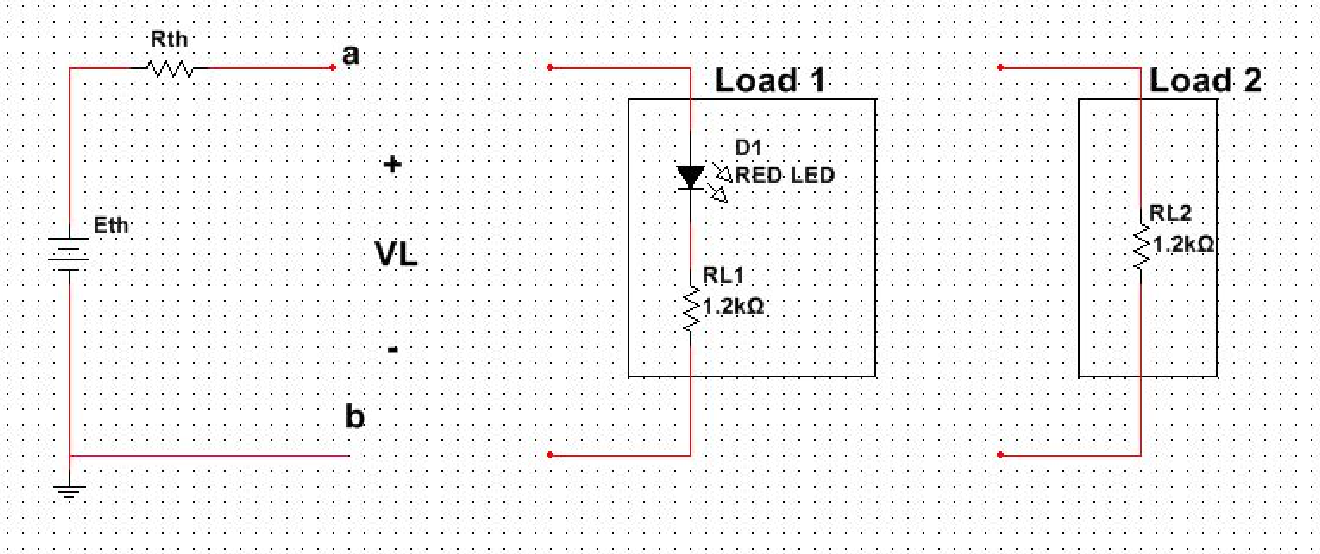


**Figure 2 - Thevenin Equivalent Circuit with Two Loads Shown (protoboard)**

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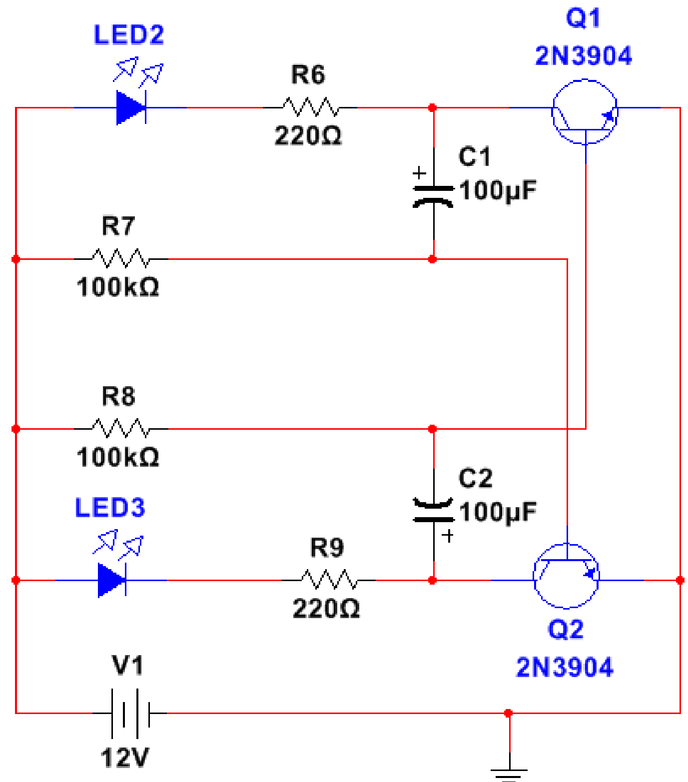


**Figure 3- Flasher Circuit Schematic (right-hand side of prefabricated PCB)**

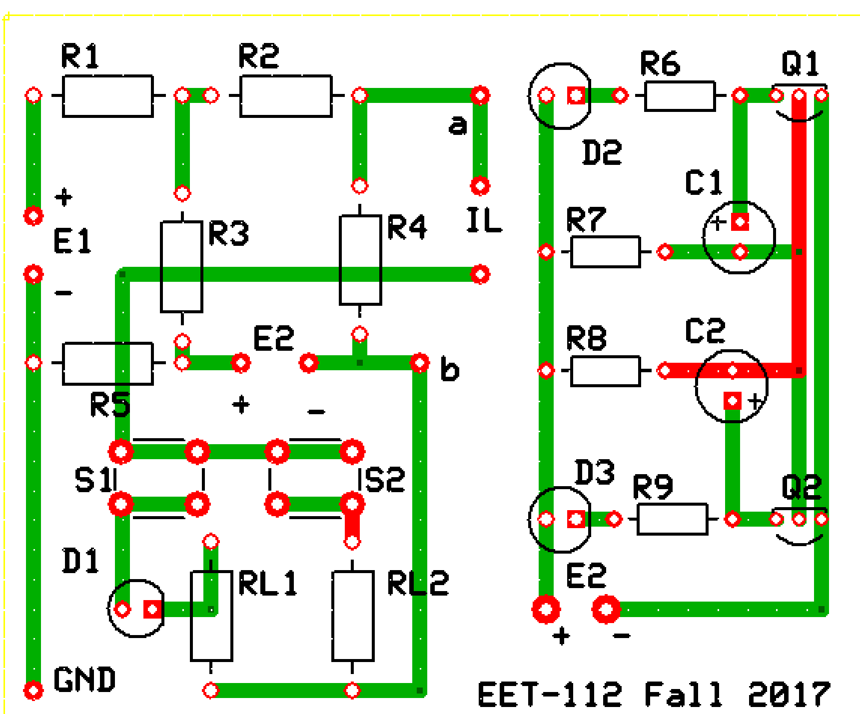


**Figure 4- Flasher Circuit PCB (right-hand side of prefabricated PCB)**

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## Post Lab Requirements:

After lab and during a time specified by your lab instructor, take the post-lab quiz. You may use your prelab, lab work and data as references. Be prepared for questions regarding this lab exercise including Thevenin equivalent circuits, maximum power transfer as well as those on the build, test and operation of the flasher circuit.

Submit your completed documentation as instructed in lab by your instructor.

Your team's submission package will be graded and returned with comments. **Submit ONLY the following (stapled together and in the following order)**:

**1**) Your Project #2 cover/grading sheet with signatures, one per team.

**2**) Your measurements in TABULAR FORM for PART 3.3 (on one page), one per team.

- Include your measured and simulated results for each load AND % error results (using your simulation data as the basis) in one data table with proper units and headings.
- Include the original circuit schematic.
- Include your percent error formula and a sample set of calculations.
- Explain any significant discrepancies.

**3)** Your measurements in TABULAR FORM for PARTS 4.2 through 4.5 (on one page), one per team.

- Include your measured results for each load from the Thevenin Eq. circuit and from the original circuit as well as % error results (using your original circuit results as the basis) in one data table with proper units and headings.
- Include the Thevenin equivalent circuit schematic with your Eth and Rth values, and showing both loads.
- Include your percent error formula and a set of sample calculations.
- Explain any significant discrepancies

**4**) Your data table and all three plots for PARTS 4.6 through 4.8 (3-4 pages) one per team.

- Your data table should include each value of load resistance you used and your data for that value (VL, IL and PL) as well as headings and proper units. Clearly note the value of RL that yields Pmax and what that value of Pmax was on your data table.
- Include the Thevenin equivalent circuit schematic with your Eth and Rth values showing load 2.
- Your three plots should be properly labeled and titled (don't forget units for each axis)
- Clearly show and notate the value of RL that yields Pmax and what that value of Pmax was on or below your plot of "Load Power as a Function of RL." Hint: This specific plot should have a logarithmic x-axis.

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**Team Name and Lab Section:..........................................................................................**

**Team Members Present (printed)**

| First Name, Last Name | Role This Lab | RIT Program | Part 1 Sig | Part 2 Sig |
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## TEAM LABORATORY GRADE

(all work done neatly, legible, complete and all signoffs in place, no missing or extraneous information)

| | |
|---|---|
| PCB Layout – Instructor Signature | **/10** |
| PCB Populate/Test – Instructor Signature | **/10** |
| PCB and Protoboard Measurements (including data tables, calculations and schematics) ............. | **/20** |
| Maximum Power Transfer Plots (three plots, properly scaled with units and labels) ........................ | **/20** |
| Final Team Grade.................... | **/60** |

**Instructor comments:**