Lab 2

Voltage Divider Design

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Prepared for:

Professor Pattengale

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Engineering 17L - Circuit Theory Lab Section

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Abstract

The objective of this lab was to design and test a loaded voltage divider network capable of powering three components. Such a configuration can be found in a wide range of applications --

in particular, this lab sought to model a robotic device used for underwater exploration that was supplied from a fixed voltage source. In order to do so, it was necessary to research potential components that both fell into the proper voltage ranges and could be easily modeled by sub-networks of resistors.

The overall purpose was to construct a circuit that modeled these loads, supplying the correct voltage to each component (within a **1%** tolerance). It was also necessary to deliver the correct current and power to each component, while simultaneously minimizing the amount of power wasted. The finalized circuit was also used to investigate the behavior of the voltage divider, such as how it responded to shorts or open circuits.

In the construction and testing of this circuit, it was found that the design of a voltage divider network requires a careful balancing of resistor values, which are inextricably tied to the variables of the load elements. Thus, building a voltage divider requires knowing the properties of the loads in advance. It was also found that the voltage divider is especially sensitive to physical changes, such as damage occurring to a single resistor or load, which in theory could cause a cascading effect that damages other components as well. The results and conclusions are each discussed in their respective sections.

Theory

To avoid ambiguity, several definitions are presented for terms or concepts that are addressed in this lab:

1. Voltage Divider Network: A circuit that is used to deliver multiple voltages from a single power source. Resistors are used to drop the voltage between two nodes, creating a branch that is at a lower potential than the positive terminal of the power source. The values of these resistors are calculated such that a load connected to this branch and grounded is supplied its correct operating voltage.
2. Bleeder Current: Represents the amount of current that is not delivered to any load in the circuit, and a source of wasted power. This is generally minimized to be within 10% of the circuit's total current.
3. Common Ground: A common or "floating" ground is a node or bus in a circuit that is not directly connected to an earth ground - that is, it is not necessarily at a potential of 0 volts. However, a common ground can be used as a reference point from which voltages in other portions of the circuit can be measured. A common ground can be placed anywhere, but for simple circuits is often chosen as the negative terminal of the power source.
4. Negative Voltage: A difference in voltage can be either positive or negative, depending upon where the reference point is taken. In most circuits, this is generally the negative terminal of the battery, which is at the lowest potential. If the ground is chosen as another point at a higher potential, only the change in potential is measured by a DMM, making it possible to measure negative voltages.

To begin designing the circuit, components were researched online that fell within the desired voltage ranges. Additionally, it was required that the power consumption of each device be low, as each load was to be modeled by a sub-network of resistors that were each rated at only $1/8$ W each**.** Once proper components were located, the necessary voltage, current, and power delivered to each was calculated (the derivations for these values are located in **Appendix B)**.

Equipment List

Table 1: Equipment Used in Design and Construction of Circuit

Nomenclature	**Manufacturer**	**Model/Serial #**	**Function**
Assorted Discrete Resistors	R.S.R Electronics, Inc.	5x 1.178kΩ, 4x 5.36kΩ, 3x 1.147kΩ, 2x 5.49kΩ, 1x {1.130kΩ, 1.178kΩ, 760Ω, 732Ω, 619Ω, 442Ω}	Circuit components used to model loads.
Breadboard	Global Specialties?	Model: Archer Universal 276-169A	Foundation of circuit
Circuit Maker	MicroCode Engineering, Inc.	Model: Circuit Maker 6	Calculating theoretical values of circuit variables.
DC Power Supply	BK-Precision	Model: 1630 A	Source of power to circuits.
Digital Multi Meter	GW Multi Meter	Model: GDM 3934	Measuring voltage and current of circuit elements.
Wire Jumper Kit	Jameco Electronics	Model: JE10	Circuit components
Wire Stripper/Cutter	K.Miller Tool Co.	Model: 102	Trimming wire and stripping insulation.

Procedure

I: Building Circuit

1. Acquire a protoboard, wire strippers/ cutters.

2. Acquire scrap pieces of red and black wire.

3. Power up the board by connecting red and (ground) banana plug leads to the two outside of the board.

4. Simulate load A by insert a six resistors (see data for values) in parallel, connect one bus to the positive terminal on the outside of the board and ground the other bus, the positive side of the resistors will be our **Tap/Node A**.

5. Insert six resistors in parallel (see data for values) to simulate $\mathbf{R_1}$, connect one end to the positive terminal on the outside of the board; the empty side of the resistors will be **Tap/Node B**.

6. Simulate **Load B** by inserting four resistors in parallel (see data for values), connect one side of resistors to **Tap B** and ground the other.

7. Simulate $\mathbf{R_2}$ by inserting two resistors in parallel (see data for values), connect one side to **Tap/Node B**, the other side will be our **Tap/Node C**.

8. Acquire a **618Ω** resistor ($\mathbf{R_3}$) and connect one end to **Tap/Node C** and the other to the floating ground.

9. Acquire a **442 Ω** resistor to simulate **Load C**, connect one end to **Tap/Node C** and ground the other side.

II: Testing Circuit

1. Acquire two DMM, variable voltage source.
2. Connect the first DMM across the variable voltage source and set it to measure DC voltage.
3. Connect the variable voltage source to the protoboard using two double ended banana plugs.
4. Connect a pair of alligator clips to the second DMM and connect the alligator clips to two exposed pieces of wire for probing the circuit. Turn the DMM to measure DC voltage setting.
5. Turn the voltage adjustment knob on the variable voltage source all the way down (counterclockwise).
6. Turn ON the variable voltage source.
7. Slowly turn the dial using the first DMM to measure **24V**.
8. Measure voltage across **Load A, Load B, and Load C** by probing across each one of the load elements. Record data.
9. Redo voltage measurement in the previous step this time using **Tap/Node C** as our floating ground. Record data.
10. Redo voltage measurement in the previous step this time using **Tap/Node B** as our

floating ground. Record data.

11. Measure the current across each circuit element to verify data from last three steps using DMM set to **30mA** setting and properly reconnecting the leads.
12. Turn OFF voltage source.

Results

Table 2: Summary of Load Specifications

Element	Required Voltage (V)	Acceptable Voltage Range (V)
Load 1	24	23.76 – 24.24
Load 2	12	11.88 – 12.12
Load 3	5	4.95 – 5.05

According to the voltage and power requirements of the loads to be modeled, constraints were placed upon how much each element could deviate from its theoretical values. Particularly, the specifications indicated that the voltage across each load element could vary by no more than 1%. **Table 2** summarizes these specifications, indicating the target ranges for voltages across loads 1, 2, and 3 in order to maintain no more than the desired 1% deviation.

I: Resistor Variance

After the circuit was constructed, the model was iterated several times to incorporate the resistors that were available in the class resistor library. While the tolerance of each resistor tended to be low, the physical resistance of each resistor was measured and compared to the documented resistance in order to gauge how much error might be introduced. The following tables document these differences.

Tables 3a, 2b, and 2c: Measured vs. Theoretical Resistance Values for Voltage Dividers

R1						
Actual Resistance (kΩ)	1.129	1.179	1.179	1.178	1.178	1.178
Theoretical Resistance (kΩ)	1.13	1.178	1.178	1.178	1.178	1.178
% Difference	-0.09	0.08	0.08	0.00	0.00	0.00

R2		
Actual Resistance (Ω)	730	747
Theoretical Resistance (Ω)	732	750
% Difference	-0.27	-0.40

R3	
Actual Resistance (kΩ)	618
Theoretical Resistance (kΩ)	619
% Difference	-0.16

Tables 2a, 2b, and 2c reflect the deviation of each of the resistors used in each voltage divider from their documented values, where each column in the table corresponds to one of the parallel resistors used in each sub network. It was generally found that physical deviations, such as those due to the resistor's construction, contributed very little error. This was particularly true at higher values of resistance. Lower resistance values contributed a higher relative deviation, but the overall error from resistor imperfections amounted to less than **0.5%**.

The measurements were repeated for the resistor networks used to model loads 1, 2, and 3, and are summarized in the following tables:

Table 4a, 3b, and 3c: Measured vs. Theoretical Resistance Values for Modeled Loads

L1						
Actual Resistance (kΩ)	5.33	5.34	5.33	5.33	5.49	5.49
Theoretical Resistance (kΩ)	5.36	5.36	5.36	5.36	5.49	5.49
% Difference	-0.56	-0.37	-0.56	-0.56	0.00	0.00

L2				
Actual Resistance (kΩ)	1.147	1.149	1.149	1.179
Theoretical Resistance (kΩ)	1.147	1.147	1.147	1.178
% Difference	0.00	0.17	0.17	0.08

L3	
Actual Resistance (Ω)	442
Theoretical Resistance (Ω)	442
% Difference	0.00

Comparison of the load resistors to theoretical values resulted in a similar case, although it was found that some of the resistors in the **5 kΩ** range tended to have a much higher error associated with them. However, it was still the case that the overall error produced by the resistor networks was low, and these values were kept in the final model.

II: Completed Voltage Divider

After the circuit was constructed and verified to work properly, values for the voltage across every element and the current through each element was collected. This was used to confirm that the voltages delivered to each load were within specifications, and also to calculate the power being delivered to them using the power equation, $P = iV$. The measurements are summarized in **Table 5**.

Table 5: Measured Voltage and Current through Circuit Elements

Measured Values						
Element	**R1**	**R2**	**R3**	**Load 1**	**Load 2**	
Voltage (V)	11.91	7.12	4.97	23.99	12.08	
Current (mA)	60.5	19.02	7.94	26.42	40.71	
Power (mW)	721	135	39.5	633.8	491.8	

From these measurements, it was found that the voltages were within the specifications outlined in **Table 2**. From these measurements, the total current and percentage of current that is bled off through $\mathbf{R_3}$ can be calculated as follows:

$$I_{\text{Load1}} = 26.42\ mA, I_{\text{Load2}} = 40.71\ mA, I_{\text{Load3}} = 11.06\ mA$$

$$\Rightarrow I_{\text{Total}} = \sum I_{\text{Load}} = 78.19 mA$$

$$\frac{I_{Bleeder}}{I_{\text{Total}}} \times 100\% = 10.15\%$$

And so the results indicate that the bleeder current was equal to about **10.2%** of the total current drawn, which was within the desired specifications.

A model identical to the physical circuit was constructed in Circuit Maker, and theoretical values were obtained for each element as well. These values are summarized in **Table 5.**

Table 6: Theoretical Voltage and Current Values from Circuit Maker

Theoretical Values						
Element	**R1**	**R2**	**R3**	**Load 1**	**Load 2**	**Load 3**
Voltage (V)	11.93	7.107	4.966	24	12.07	4.966
Current (mA)	61.18	19.26	8.023	26.66	41.92	11.24
Power (mW)	730	137	40	640	506	56

These values were then compared to the measured values, and the percent differences were examined. The variations in each individual element are summarized in **Table 7.**

Table 7: Differences between Measured and Theoretical Values

Percent Differences						
Element	**R1**	**R2**	**R3**	**Load 1**	**Load 2**	
%Difference, Voltage	-0.17	0.18	0.08	**-0.04**	**0.08**	
%Difference, Current	-1.11	-1.25	-1.03	-0.90	-2.89	
%Difference, Power	-1.28	-1.07	-0.95	-0.94	-2.81	

Thus, each load was delivered the correct amount of voltage, within an extremely small margin of error. Load 1 was under its specified voltage by **0.04%**, while Loads 2 and 3 were over their voltages by **0.08%**.

An interesting result from **Table 7** is the fact that while the voltages delivered to each element deviated very little, it was still possible for the currents, and thus the power delivered, to deviate significantly. In our model, this would not have proved to be problematic, as each element was receiving less current (and thus less power) than its specified values, but it is feasible that the actual values could slip above theoretical values, potentially overloading an element.

This can become especially problematic in a voltage divider circuit, in which the resistances are carefully balanced against one another. If an element were to either short or open a circuit path by overloading, the remaining elements in the voltage divider network would experience drastic changes in their voltage, current, and power levels. This is discussed in more detail in the Conclusion.

III: Moving Commons

Further measurements were taken as the common was moved from the circuits ground at node **D** to nodes **C** and **B**, as shown in **Figure 1** on page **11**. Voltage readings between the new common and other nodes were measured, which is summarized in **Table 8**.

Table 8: Voltage Measurements With Respect to New Commons

	Measured Voltage (V)	
Divider	**Common C**	**Common B**
Node A	19.04	-12.08
Node B	7.12	**N/A**
Node C	**N/A**	-7.11
Node D (Ground)	-4.97	-12.09

From this data, voltages across each divider was calculated when the meter was placed at either common. The results were tabulated for the data taken from each common used (both nodes **C** and **D**) and compiled in **Table 9.**

Table 9: Calculated Voltages across Elements When Common is Varied

	Calculated Voltage (V)		
Element	**Common C**	**Common B**	**Percent Difference (%)**
R1	11.92	12.08	-1.32
R2	7.12	7.11	0.14
R3	4.97	4.98	-0.20

An interesting result of these calculations is that the while in theory, the voltage across any two elements should have been nearly identical regardless of where the common was placed, using an inner node as a common introduced slight differences. While the error was negligible when measuring directly between two elements (such as the measurement from nodes **B** to **C** to obtain the voltage for $\mathbf{R_2}$**)**, there was a noticeable difference in the calculated voltage across multiple elements (for example, in the case of $\mathbf{R_1}$ above).

IV: Shorting/Opening R2

Lastly, the effects of shorting and opening $\mathbf{R_2}$ were examined. Its specified voltage drop was **7.00 V**. When $\mathbf{R_2}$ was shorted, the voltages across **Loads 2 and 3** were both equal to **9.89 V**, resulting in an **18%** decrease in the voltage across Load 2, and **41%** increase in voltage across Load 3. While Load 2 may or may not be adversely affected by a decreased voltage, the voltage across Load 3 would almost certainly overload the component.

Similarly, when $\mathbf{R_2}$ was opened, the voltage across **Load 2** was increased to **14.37 V**, or a **19%** increase. The voltage across Load 1 remained the same, and the opening the circuit dropped the voltage across **Load 3** to zero. This condition resulted in a similar problem as described above, demonstrating that a single component failure in a voltage divider can easily damage other components in the network du to voltage spikes.

Conclusion

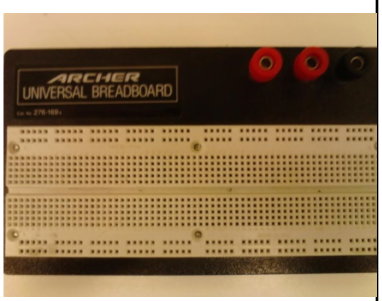
The three different loads that were in our circuit have different operation voltages specifically required by each manufacturer as defined by their data sheet. We only used one 24V voltage source to power the entire circuit, because of that our circuit has two separate voltage dividers that were designed to decrease the voltage to 12V at **Node A** and 5V at **Node C** in order to provide safe power to our three loads. The first voltage divider worked the best with only 0.75% error that was introduced by small error in the six resistors that made up the **R1** and our measuring device the DMM. Second voltage divider produced an error 1.7% because aside from resistor tolerances and measuring equipment the second voltage divider was built on the faulty foundation of **R1**. Even though the voltage drops across **R1** or **R2** were not required to be within the 1% tolerance like the loads **A-C** they provide us with information of how/ why our errors in loads **A-C** were introduced.

Our circuit was built simulating an underwater robot hence the 1% tolerances to insure the functional integrity of the robot. Like most real world circuits ours had a bleeder resistor (**R3**) connected to our floating ground to provide some regulation of the power supply's output voltage and to make sure there is no residual charge in the circuit after its been turned off. The bleeder current was designed to pass 11.06mA or 10% of the max current developed in our circuit. Our common reference point ground was the common point that served as the return path for electric current developed in our circuit. This point would also be considered the floating ground because it's not actually connected to the physical earth, it simply serves as a reference point between high and low potential. The importance of this common reference point for us was the fact that we used it measure the most important data in this experiment which is the voltage across each one of the load that had to be within 1% of calculated/ theoretical value. The voltage across the first load was almost identical with the theoretical with 0.08% error which came about because the variable voltage source could not be fine-tuned to remain constant of 24V. For the remainder of the two loads the error between theoretical and experimental values were identical to each other and twice the error produced in the in the **Load A**. the error in **Loads B-C** can be traced back to the error in the voltage dividers at **Tap/Node B-C** as has been discussed earlier. We can see from the results in this lab how even the small error in the early stages of the circuit can snowball as the circuit grows larger and more complex.

The function of resistors **R1** and **R2** has been shown to divide voltage to safe levels by splitting at a node. To analyze the deeper impact that voltage dividing resistors such as **R2** have on our circuit we can analyze two extreme cases. If **R2** was theoretically remove **R2** then only **Load C** and the bleeder resistor (**R3)** will essentially be detached from the circuit, as consequence **Load B** will see a spike in voltage/ current because the voltage drop across **R1** will decrease, leaving only **Load A** unaffected. Taking the other extreme case we can theoretically short-circuit **R2** and analyze the effects on this labs circuit. In this case **R3** and **Load C** will most likely get fried as the increased voltage will cause a power surge in both circuit elements. First resistor will also see a current increase and in return provide less voltage to **Load B**, Similarly to the last case **Load A** will remain unchanged.

Appendix

Section A: Equipment Photographs

Components	Photographs	Components (cont.)	Photographs (cont)
Assorted Discrete Resistors		Digital Multi Meter	
Breadboard		Wire Stripper/Cutter	
DC Power Supply		Various Lengths of Wire	

Section B: Circuit Diagrams

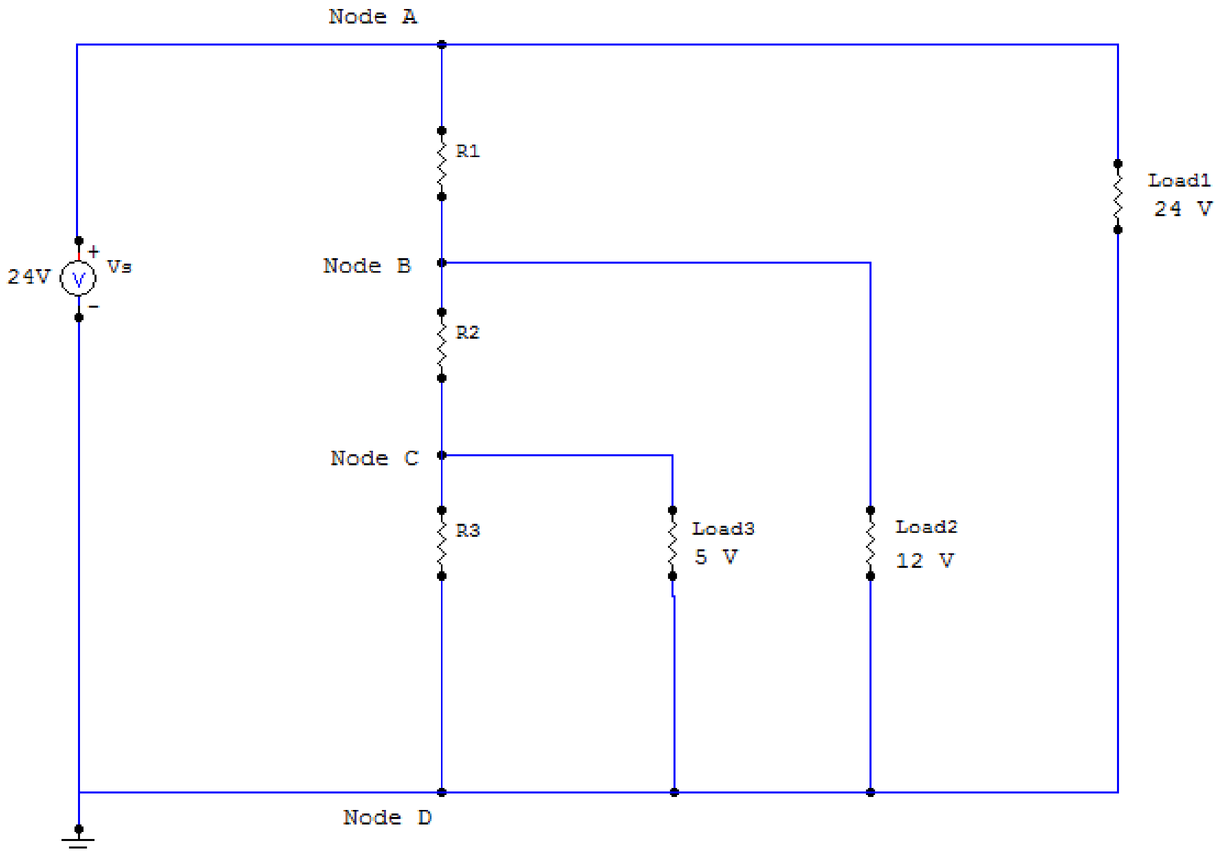


Figure 1: Reference Circuit Diagram

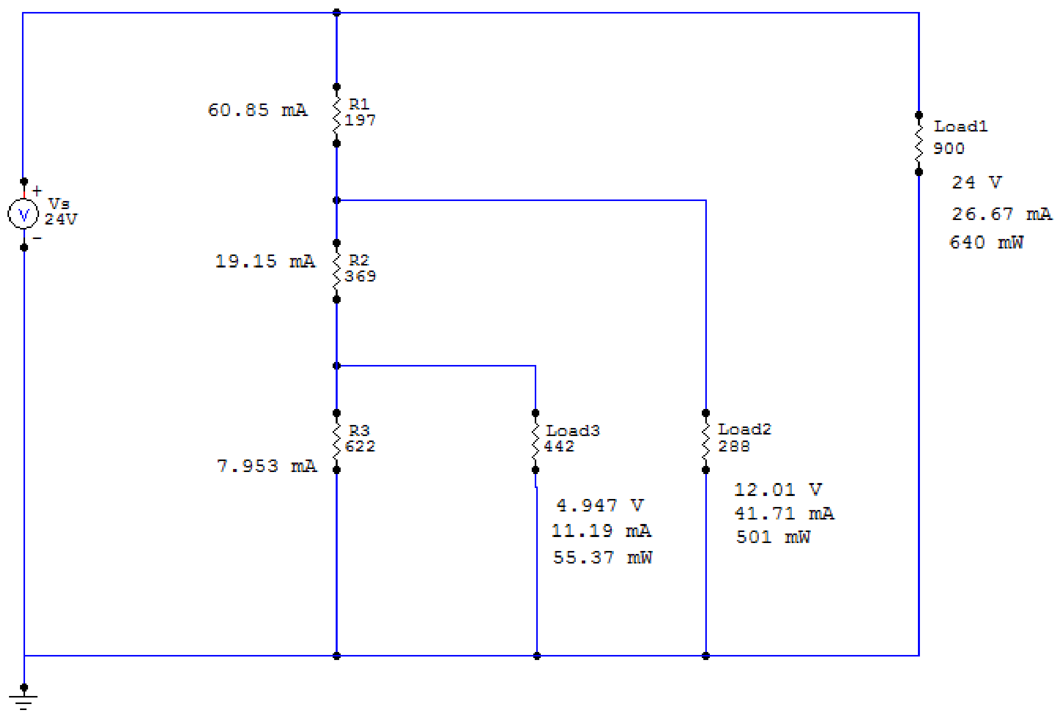


Figure 2: Theoretical Circuit with Equivalent Resistances

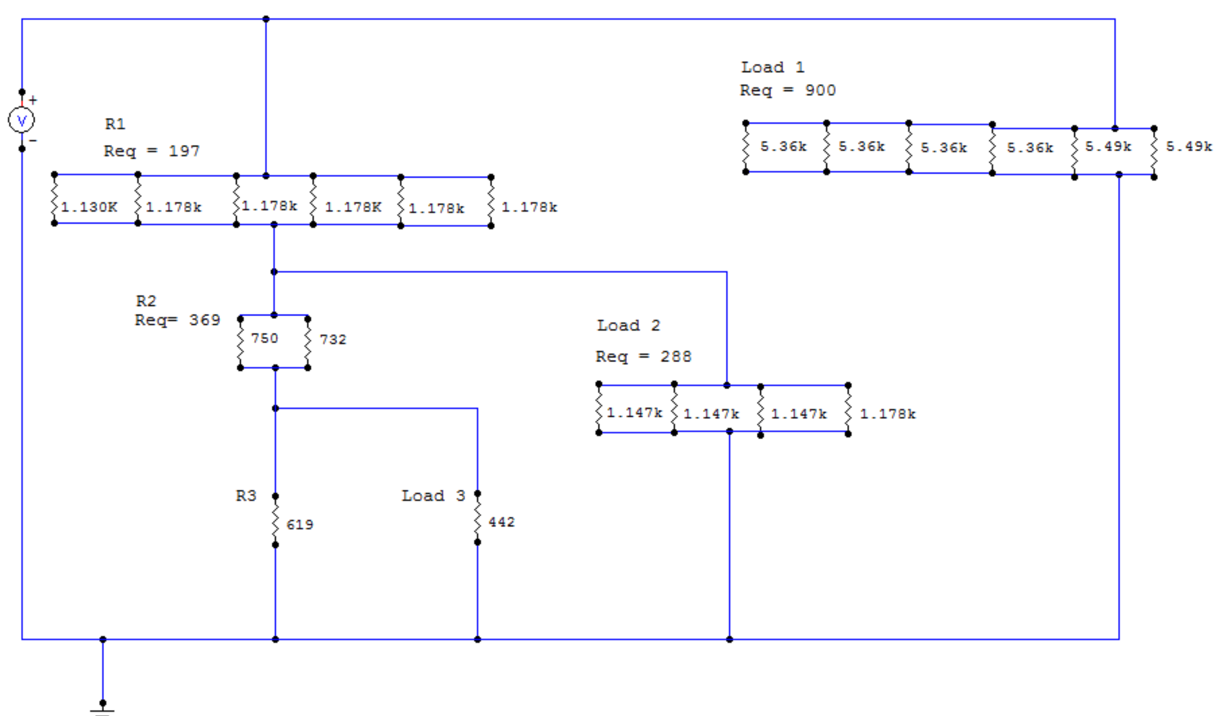


Figure 3: Theoretical Circuit Using Available Resistors

Section C: Derivations

Section D: Pictures

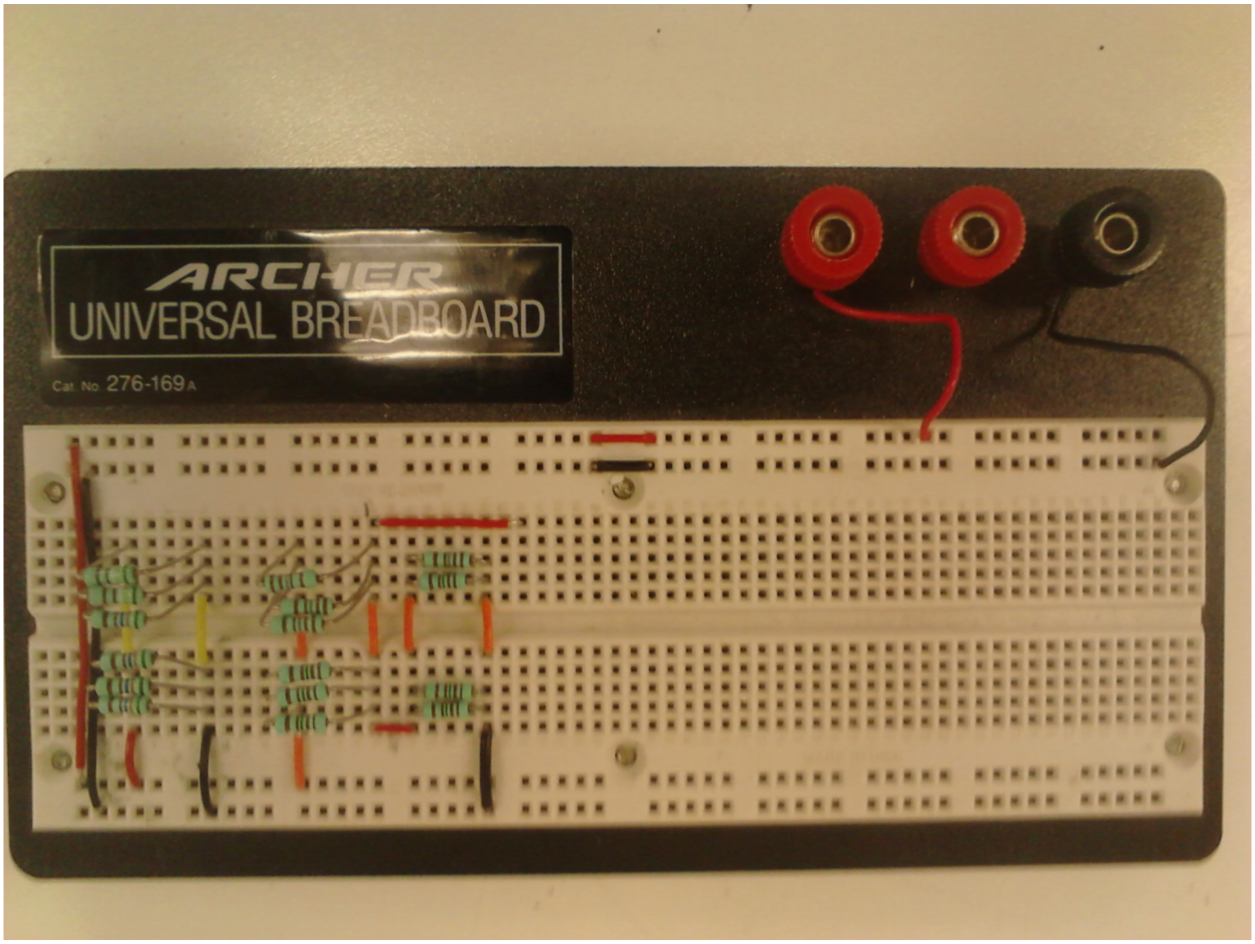


Figure 4: Completed Circuit on Protoboard

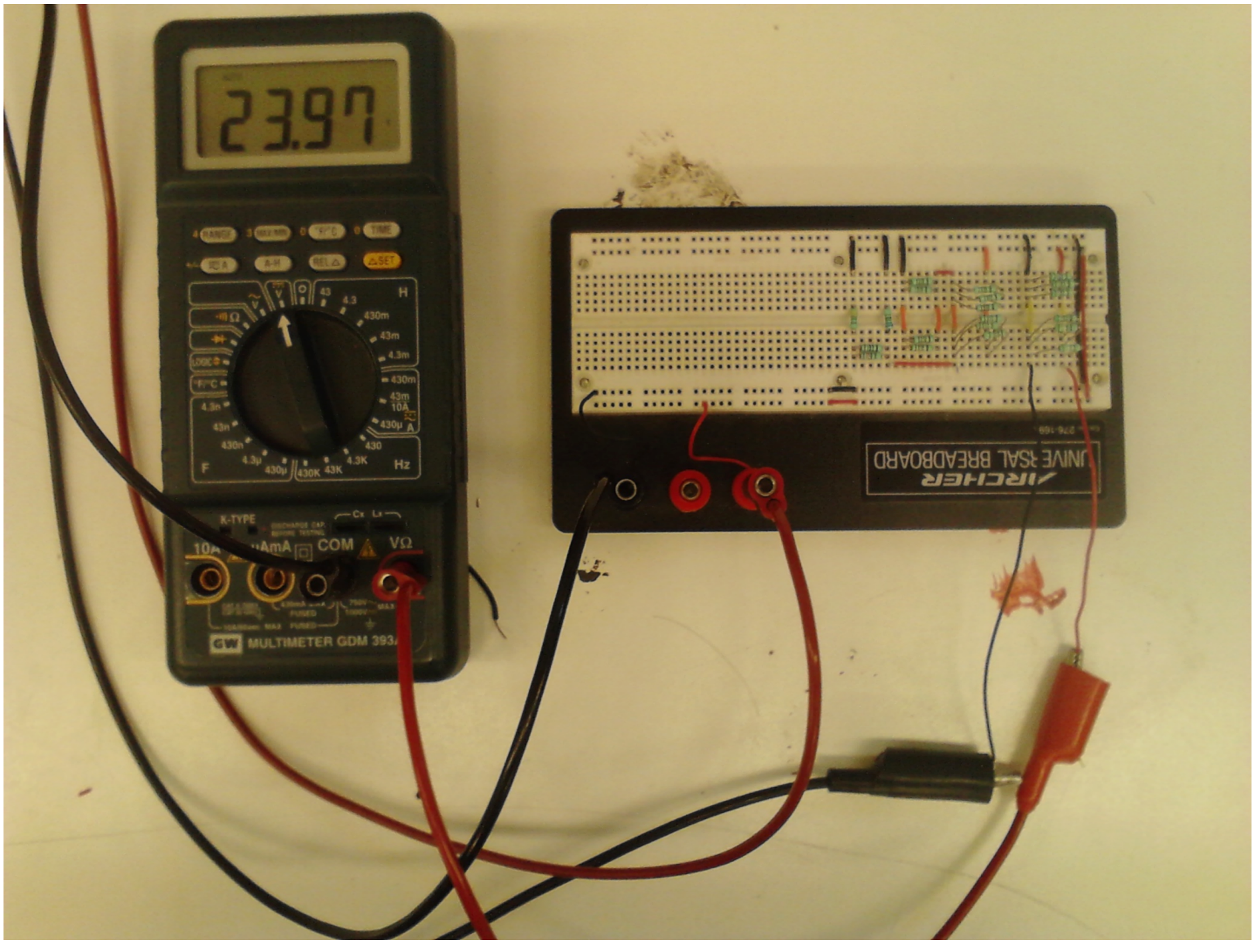


Figure 5: Voltage Over Load 1(Motor)

Section E: References

Nilsson, James W. and Susan A. Riedel. 2011. Electric Circuits. Ninth Edition. Pearson Education, Inc., Upper Saddle River, NJ.

Serway, Raymond and John Jewett. 2010. Physics for Scientists and Engineers. Eighth Edition. Mary Finch Publishing.

"Voltage Dividers." - *Learn.SFE*. N.p., n.d. Web. 02 Mar. 2014.

Section F: Data Sheets