Electric Experiments for Technology

Second Edition

by Sid Antoch

Electric Experiments for Technology

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The Portland Community College Electronics Engineering Technology Program, in Portland, Oregon, and the following instructors, also influenced the creation of the experiments in this lab book: Doug Draper, Mike Farrell, Gary Hecht, and Sanda Williams.

Introduction

Sid Antoch has taught electrical engineering circuits courses at Portland State University and Portland Community College and electrical engineering technology courses at Portland Community College and Tektronix. This lab book is in part the result of this experience.

Experiments in this manual are intended for the laboratory component of an electrical engineering technology electric circuits course. The experiments emphasize the use of spreadsheets and simulation software. Several of the experiments refer to the specific application of a Tektronix TDS type oscilloscope to acquire experimental data. These may be omitted or modified if the lab does not have TDS type oscilloscopes.

Analysis suggestions are provided for each experiment. These may be used as is or may be modified by the instructor according to the lab curriculum requirements. Experiments may be selected according to the accompanying textbook and course emphasis.

LTspice is used exclusively in the second edition because it was found to be easier for students to download and use. More emphasis is placed on single phase and 3-phase power distribution, including distribution losses and power factor compensation.

Most of the labs may be performed using a solder-less breadboard and standard lab equipment. The 3-phase experiments require a low voltage source of 3-phase power. Several options are available. A “Phase Tripler” circuit is presented which students may build on a breadboard. Also a bench top 3-phase voltage source is available from ZAP Studio Electronics as well as an inexpensive circuit board which may be plugged directly into a breadboard. These are described in the appendix.

Equipment List

Digital Oscilloscope with 10X probes, Function generator, Digital Multi-meter.

Solder-less Breadboard. Power Supply: 0-volts to 6-volts and 0-volts to ±15-volts.

Phase Tripler (refer to appendix 2). Motor-Generator Set (refer to appendix 3).

Computer with word processor, spreadsheet, simulation, and data acquisition software.

Parts List

Resistors: 8.2, 10, 47, four 100, 150, three 220, 330, Three 390, 470, 680, 750, two 1K, 1.2K.

Resistors: two 1.5K, 1.8K, 2.2K, 3.3K. 3.9K, 4.7K, 6.8K, 8.2K, five 10K, 15K, 18K, 22K, 33K.

Resistors: 100K, 1Meg, 2.2Meg. All resistors are ¼ watt, 5%.

Power resistor: 10-ohms, 10-watts, 5%.

Trimmer Potentiometers: 100, 5K, 10K, 5%, single turn to fit breadboard.

Capacitors: 1nF, 10nF, 22nF, 47nF, 100nF, 470nF, all 5%, 50-volt minimum.

Capacitors: 1µF, 2.2µF, 4.7µF non-polarized, all 5%, 50-volt minimum.

Inductor: 10mH, 5% (air core). (J.W. Miller 70F102AI).

Inductors: Three 100mH, 5% (iron core, 50mA minimum, 200-ohm resistance maximum).

Light Emitting Diode (LED): Red (other colors may be used).

Transformer: Step-down, 120VAC to 12VAC, about 1-amp, center-tapped.

Audio Output Transformer: 1000-ohms, center tapped, to 8 ohms, 200mW.

Loudspeaker: 8-ohm, 200mW minimum, (2 to 4 inch).

Batteries: Two alkaline batteries (AA 1.5-volt). 6-volt, 4amp-hr, sealed lead-acid battery.

Flashlight bulb and socket: 2.5-volt, 300mA (#14).

On-off switch: (SPST type, toggle or slide).

Incandescent bulb: Type 2182 (14-volt, 80mA).

Analog meter: 1mA < 1000-ohm (or 100µA < 10,000-ohms).

Transistor: 2N3904 or 2N2222

Motor-generator circuit (refer to Appendix 3).

Phase Tripler (refer to Appendix 2).

Contents

History Notes

Experiment 1: Electrical Resistance and the Resistor

Introduction

Ohm's law is the most fundamental equation in electric circuit analysis. It states that the amount of electric current flowing in a circuit is directly proportional to the voltage applied to the circuit, and inversely proportional to its resistance.

$I = \frac{V}{R}$ I is current in amperes, V is potential difference in volts, and R is resistance in ohms.

Resistors are used in electric circuits to control the flow of current. Resistors are commercially available which have a specific amount of resistance and power dissipation ability. The amount of resistance is usually marked on the resistor using a color code. The power dissipation is determined by the physical size of the resistor.

An "ohmmeter" is used to measure resistance. Most ohmmeters are part of an instrument that is also capable of measuring other electrical quantities, such as voltage and current. These are typically called "multi-meters", and since they usually have a digital display, they are called "digital multi-meters" or "DMMs" for short. To use the DMM you need to know how to set it to make the desired measurement (function), and how to set it for best accuracy (range).

Objectives

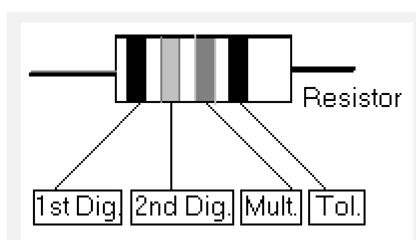
The purpose of this lab exercise is to learn how to measure resistance with the DMM. An error analysis will compare the measured resistor values to the labeled resistor values using a spreadsheet. In addition, you will measure the resistance of series and parallel combinations of resistors, and compare the results to theoretical calculations based on equations provided.

Series and parallel connections will be made using a solder-less breadboard. The object of this part of the exercise is to learn to use the breadboard. *Theoretical knowledge of series and parallel resistor connections is not expected.*

Resistance values are read using the color code given below.

Standard Resistor Color Code

Color	Value	Color	Value
Black	0	Blue	6
Brown	1	Violet	7
Red	2	Gray	8
Orange	3	White	9
Yellow	4	Gold	0.1 / 5%
Green	5	Silver	0.01 / 10%



This color code is for "standard" resistors with an accuracy rating, or "tolerance", of ±5% or ±10%. That is, their value is guaranteed to be within ±5% or ±10% of their labeled value.

Their colors are read from left to right. The first two color bands represent the first two significant digits of the resistor value. The color of the third band represents a multiplier of 10^N, where N is the value represented by the color.

The fourth band is always gold or silver, which indicates a tolerance of ±5% or ±10%. The first band is never gold or silver. *So to read a resistor's value correctly, the gold or silver band must be on the right.*

For example, a resistor whose first band is red, second band is yellow, third band is orange, and fourth band is gold, has a value of 24,000 ohms (24×10^3), and a tolerance of 5%.

Resistance Measurement

A digital multi-meter (DMM) will be used for measuring the resistance values. The instructor may explain the operation of the instrument before you use it for the first time. You may also check to see if an instruction manual is available for the instrument. The DMM may have buttons and/or switches to its function and range.

Set the function to "OHMS". Some meters are capable of automatically setting the range to get the most accurate reading, which is related to the number of significant digits displayed. You should be able to get at least three significant digits of accuracy. Experiment with the range settings when making the measurements specified in the procedure below.

The power rating of each resistor is determined by its physical size. Smaller dimensions represent a smaller power handling capability. A sample of several different size resistors should be available in the lab. A very common power rating is ¼ watt. If a ¼ watt resistor dissipates more than ¼ watt it will get excessively hot and may burn out.

Procedure

Equipment and Parts

DMM and Breadboard.
Resistors: 1K, 4.7K, 10K, ¼ watt, 5% or 10% tolerance.

Part A: Measurements and the Spreadsheet

Do not touch the metal tips of the DMM probes when making measurements.

1. Use the resistor color code to select the 1K, 4.7K, and 10K resistors. Determine their tolerance. Measure the values of the resistors with the DMM to at least three significant digits.

2. Enter the results into a spreadsheet. Calculate the deviation of each resistor's measured value compared to its labeled value. Calculate the percent deviation of each resistor's measured value from its labeled value. Refer to the example on the next page. Note that starting a spreadsheet's cell with an equal sign indicates the cell contains a formula.

Use the spreadsheet layout shown below to do the calculations.

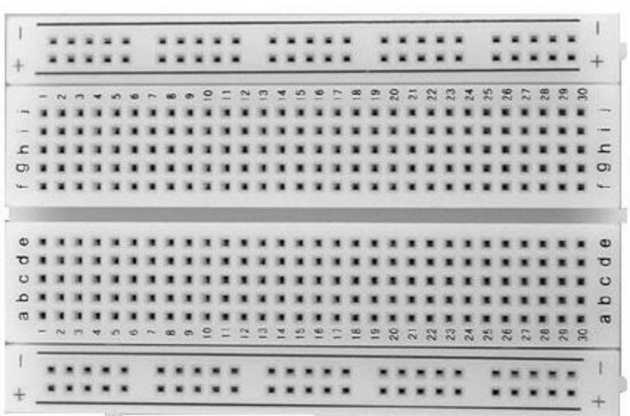
	A	B	C	D	E	F
1	Resistor	Labeled Val.	Measured Val.	Deviation	Labeled %	Measured %
2	1	1000				
3	2	4700				
4	3	10000				
5						
6						

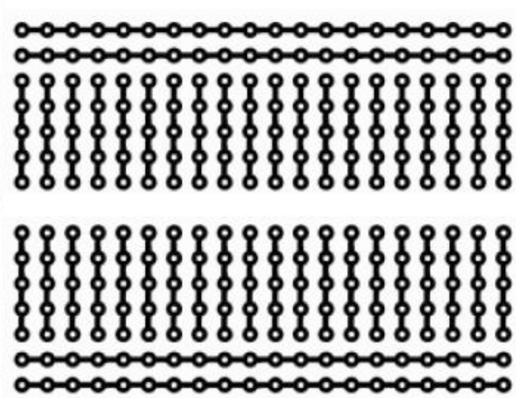
Deviation: =C2-B2   Percent deviation: =(D2/B2)*100
Enter the expression for deviation into cell D2 and percent deviation into cell E2. Use the “fill down” feature of the spreadsheet to calculate rows 3 and 4.

Part B: Series and Parallel Connections

Before starting this exercise (and the other exercises in this manual) you need to have a way of connecting electronic parts together into a circuit. An easy and very common method to quickly connect parts together is to use the “solder-less breadboard”, also called a “prototyping board” or “protoboard”. The board has holes 0.1 inches apart into which component leads can be inserted.

Solder-less breadboards are available from a variety of manufacturers and sources, in a variety of sizes, but they all have the same arrangement of the holes and connections



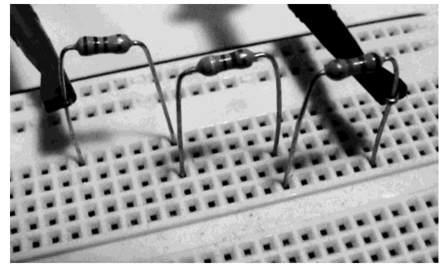


The picture above on the left shows a typical breadboard. Components such as resistors, capacitors, transistors, integrated circuits, and wires can be plugged into it. The picture above on the right shows how the holes are connected. You should memorize these connections.

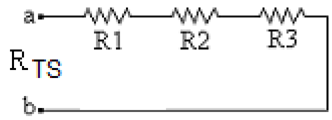
Components such as resistors can be connected in series, parallel, and in a combination of series and parallel. The following exercises show how to connect resistors in series and parallel, and how to measure the resistance of the series and parallel combinations.

The measurements will be compared to the theoretically expected values using the equations provided. If a measurement does not agree with the calculation, check the breadboard connections and the labeled values of the resistors.

1. Connect your 1K, 4.7K and 10K resistors in series. Measure the resistance, R_{TS}, of the combination as shown in the circuit's schematic diagram below. A connection example is shown on the right.



Ohmmeter leads connect between points a and b.



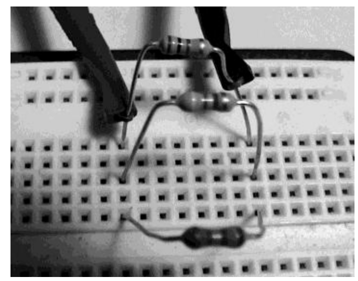
R_{TS} = ____________________ (measured total series resistance)

2. Calculate the theoretical resistance of this series combination as given the equation:

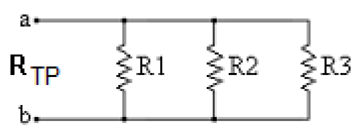
$$R_{TS} = R1 + R2 + R3.$$

Use the measured values of the resistors from part A. Enter the equation into your spreadsheet and have the spreadsheet do the calculation. Also enter the measured value into the spreadsheet as shown in the example spreadsheet on the next page.

3. Connect the 1K, 4.7K and 10K resistors in parallel as shown in the diagram below and picture on the right. Measure the resistance, R_{TP}, of the parallel combination.



Ohmmeter leads are connected between points a and b.



R_{TP} = ____________________ (measured total parallel resistance)

4. Calculate the resistance of this parallel combination using the equation below.

$$\frac{1}{R_{TP}} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \quad \text{so that } R_{TP} = \frac{1}{\left(\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}\right)}$$

Use the measured values of the resistors from part A. Enter the equation into your spreadsheet and have the spreadsheet do the calculation. Also enter the measured value of the series resistance and the measured value of parallel resistance into the spreadsheet as shown in the example spreadsheet below.

	A	B	C	D	E	F
1	Resistor	Labeled Val.	Measured Val.	Deviation	Labeled %	Measured %
2	1	1000	996	-4	0.05	-0.4
3	2	4700	4760	60	0.05	1.276595745
4	3	10000	9720	-280	0.05	-2.8
5						
6						
7		Calculated Val.	Measured Val.	Deviation	% Deviation	
8	Series	15476	15390	-86	-0.555699147	
9	Parallel	759.3125376	762.2	2.8874624	0.380273246	

Equation in B8: =C2+C3+C4 Equation in B9: =1/(1/C2+1/C3+1/C4)

LAB REPORT

1. Open a word processor document and save it as: “Experiment 1 Report”. Use the following format:

   Student name and lab partner name (if applicable).
   Course number: Lab experiment number and name.

   Example:

   George Jones and Sally Smith

   EET111: EXPERIMENT 1: Electrical Resistance and the Resistor

2. Copy your spreadsheet results and paste them into the document.

   The instructor will specify how to turn in the report. You may just need to show the resulting document on the lab computer, or the instructor may also ask for additional analysis, including a more comprehensive lab report.

History Note:

Georg Simon Ohm (17 March 1789 – 6 July 1854) was a German physicist. As a high school teacher, Ohm began his research with the recently invented electrochemical cell, invented by Italian Count Alessandro Volta. Using equipment of his own creation, Ohm determined that there is a direct proportionality between the potential difference (voltage) applied across a conductor and the resultant electric current. This relationship is now known as Ohm's law.

From Wikipedia, the free encyclopedia

Experiment 2: Flashlight Circuit Measurement and Simulation

Introduction

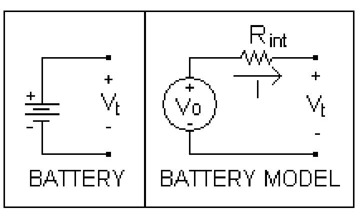
Batteries are a common source of stored electrical energy. Batteries are available in a wide variety of physical sizes, voltage ratings, and capacity ratings.

The voltage rating relates the battery's ability to cause electric current to flow in an electric circuit. Ohm's law states that electric current is directly proportional to voltage.

Capacity rating is usually expressed in units of "amp-hours". It is the product of the battery current in amperes and the length of time the current is delivered in hours. The capacity rating of a battery depends on the battery type and on its physical size. It also depends on the discharge rate (how fast or slow the battery is discharged).

Another battery property is "internal resistance". A battery's internal resistance reduces the amount of energy that can be extracted from a battery. Some of the battery's voltage is dropped across the battery's internal resistance resulting in lower battery output voltage.

Energy is dissipated by the battery's internal resistance as heat. The energy dissipated is proportional to the square of the battery's output current, so higher currents will decrease the energy (amp-hours) obtainable from the battery. A simple model of a battery is shown below.



Vo in the battery model represents an "ideal" voltage source. The battery terminal voltage, V_t, is equal to Vo when no current is drawn from the battery (V_t = Vo).

This is referred to as the "open circuit" voltage. V_t is given by the equation: $V_t = Vo - I R_{int}$, where I is the current in amperes.

A very common non-rechargeable battery is the alkaline type. The alkaline battery is typically used in flashlights, portable radios, and other portable electronics. Two alkaline batteries will be used in this lab exercise.

Objectives

The objectives of this lab include an introduction to the battery as a voltage source, an introduction to voltage measurement, and an introduction to a simple flashlight circuit. Circuit simulation software will be used to simulate this lab exercise in experiment 3.

Procedure

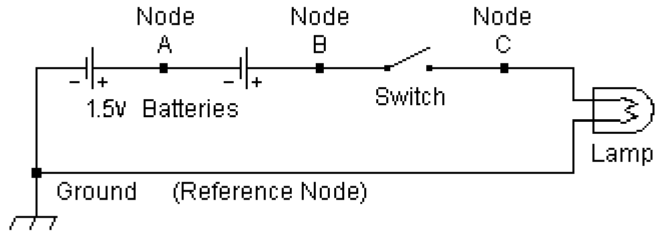
Equipment and Parts
Digital Multi-meter, two alkaline batteries (AA 1.5V). Flashlight bulb and socket, 2.5V, 300mA (#14). On-off switch (SPST type, toggle or slide). Computer with circuit simulation software (Appendix 4 describes this flashlight circuit built on a pine board)

Observe the following precaution before proceeding with this exercise:
Do not short circuit a battery. Connecting a low resistance across the battery terminals can result in excessive current, which will not only discharge the battery quickly, but it may also cause the battery and the wires to dangerously overheat. Batteries are relatively safe when treated properly.

Flashlight Circuit

1. Your circuit should be connected and labeled as shown on the right. Make sure that the switch is in the off position.

   There are 4 nodes identified for voltage measurements: A, B, C, and Ground.



2. Set the digital multi-meter (DMM) to measure DC voltage. Set the “range” for the most accurate measurement (most significant digits). Connect the black lead (negative reference) of the DMM to the circuit’s ground node.

   Before proceeding to the next step, be absolutely sure that the DMM is set to measure voltage. The batteries are capable of supplying enough current to damage the DMM if the DMM is set to measure current when it is connected directly to a battery. Also, make sure the voltage across each battery’s terminals is approximately 1.5 volts. If the voltage is significantly lower, you may need to replace the battery before proceeding.

3. Make sure that the circuit works by turning the switch on and off (the lamp should go on and off). With the switch off, use the red (positive reference) meter lead to measure and record the voltages: V_A at Node A, V_B at Node B, and V_C at Node C.

   Switch Off: V_A = ____________ V_B = ___________ V_C = _____________

4. Turn the switch on (lamp on) and immediately measure and record the voltages: V'_A at Node A, V'_B at Node B, and V'_C at Node C. The voltages will decrease over time as the batteries are drained. Turn the switch off after making these measurements. The apostrophe simply indicates that, for example, X’ is not the same variable as X. X’ would be pronounced, “x prime”.

   Switch On: V'_A = __________ V'_B = ____________ V'_C = _____________

5. The battery current can be measured by setting the DMM to measure current. Set the DMM to the 2 ampere current range. Ask the lab instructor for help if you are unsure of how to do this. To measure current, you must break, or open, a connection and reroute the current through the meter.

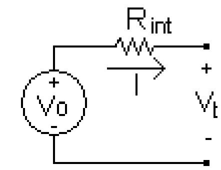
6. With the flashlight circuit switch off, connect the black lead (negative) of the meter to node C and red lead to node B. The lamp should light and the meter will read the flashlight circuit current, I. Record the current below:

   I =_____________ A.

7. You should observe the following:

a. V_A and V_B decreased between steps 3 and 4.

b. V_C is 0 when lamp is off, and equal to V_B when lamp is on.



BATTERY MODEL

Consider the battery model on the right. Vo is the unloaded battery voltage, V_B, from step 3. V_t is the loaded battery voltage, V'_B, from step 4. The battery's terminal voltage is given by $V_t = Vo - I R_{int}$.

The battery's internal resistance for the battery model can be calculated from the equation below on the left and for the flashlight circuit using the equation on the right.

Battery Model: $R_{int} = \frac{Vo - V_t}{I}$	Flashlight Circuit: $R_{int} = \frac{V_B - V'_B}{I}$

Analysis

1. Calculate the internal resistance of your batteries, R_{int}. This is the total resistance of the two batteries in series. using the equation on the right above.

R_{int} =_______________ Ω.

2. Calculate the lamp's effective resistance using Ohm's law: $R_L = V'_C / I$.

R_L =______________ Ω.

3. Use the open circuit terminal voltage and the internal resistance of your batteries to calculate the instantaneous current that would flow through the battery if the battery were shorted (0Ω connected across it). Consider the internal battery resistance and Ohm's law.

I_{Short} =______________ A.

4. Calculate the battery life of your flashlight circuit if the batteries are rated at 2 amp-hours for typical flashlight applications.

Life =______________ Hrs.

Experiment 3: LTspice Simulation of the Flashlight Circuit

Introduction

Circuit simulation software is commonly used to test and analyze the operation of circuit designs on a computer. There are two popular simulation programs that may be downloaded for free: OrCAD PSpice evaluation version, and LTspice. All the examples in this lab book use LTspice.

LTspice Circuit Simulation

LTspice IV may be downloaded for free from Linear Technology's website:
http://www.linear.com/designtools/software/

You can also download a manual and a "getting started guide". There are no limits on the schematic size or number of components used. It is easy to use, easy to save your work, and it is used at a number schools and universities.

Drawing the Circuit

1. Start the *LTspice* program. In the main menu bar, click on File and then click on *New Schematic*.

2. Create the new schematic. Left click on the resistor symbol and drag and place the resistor, R1. Repeat to get and place resistor R2.

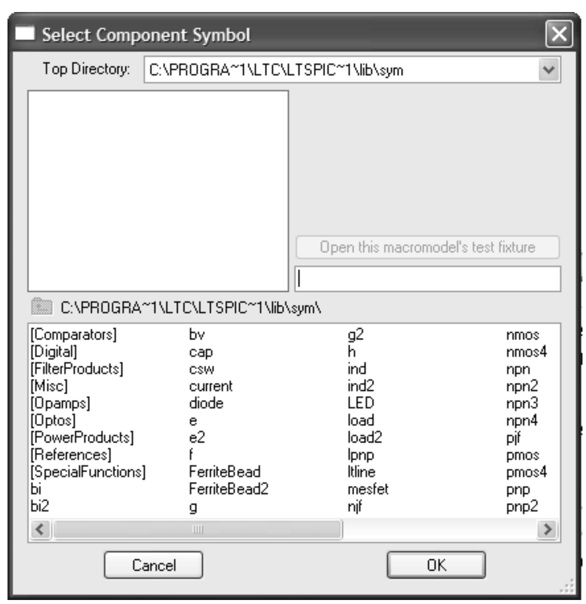
   Selected components may be rotated by using "CTRL" and "R" keys on the keyboard. Components may be deleted using the "scissors" in the main menu.

   Right click on each "*R*" of each resistor. Change the values to the measured values of the resistances from your experiment.

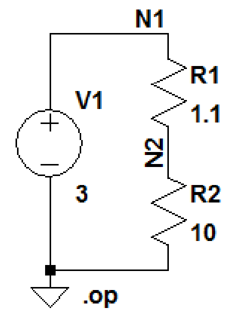
   R1 is the battery's internal resistance and R2 is the resistance of the light bulb.

3. Left click on the gate symbol between the diode and the hand in the main menu to get the dialog box shown on the right.

   Select the part *voltage* and place it in the schematic. Set the value of V1 to the measured open circuit voltage of your batteries.



Left click on the ground symbol and place it under V1 as shown on the right.



4. Left click on the "pencil" in the main menu to connect the components.

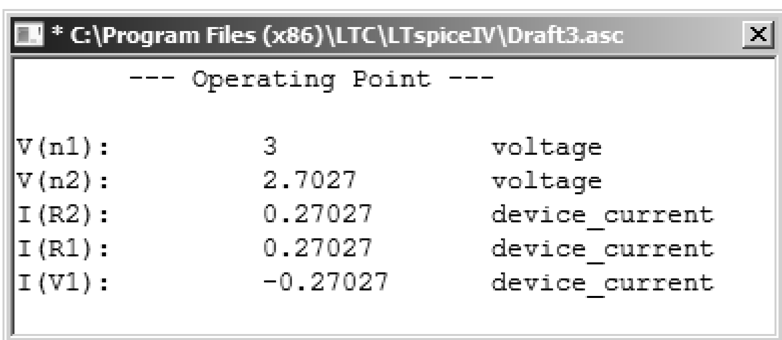
5. Left click on the "*A*" between the ground symbol and the resistor symbol in the menu bar to label the nodes *N1, N2,* and *N3* as shown on the schematic. Save your project before going further.

Experiment with some of the other menu items, such as the scissors to delete components and wires, the "hands" on the right side of the menu bar to move and drag components, the "undo" and "rotate" icons to the right of the hands.

6. Click on Simulate in the main menu and select Edit Simulation Cmd.
Select <u>DC op pnt</u>. Click on <u>ok</u>. A ".op" command will appear which can be placed anywhere on the schematic.

7. Click on Simulate and select <u>*Run*</u>. If there are no errors, you will see an "*Operating Point*" file as shown below.

The results below show that the lamp current is 0.27A and the lamp voltage is 2.7V. The power dissipated by the lamp is: P = I V = .27(2.7) = 0.73W.



Analysis

1. Compare the results of your simulation to your measured values by calculating the percent difference between the measured and simulated values of circuit current and lamp voltage.

2. Use the values of V1, R1, and R2 in your simulation circuit model to calculate the lamp current. Compare the calculated current to the simulated current and the measured current. Express the percent difference between the calculated current and the simulated current. Express the percent difference between the calculated current and the measured current.

3. Lab report option: Open a word processor document. Title it as follows:
Your Name Course Number Date Experiment Name and Number.

4. Use “copy and paste” to copy the schematic diagram of your circuit simulation into the document. Label the diagram. Use “copy and paste” to copy the output file of your simulation and paste only the analysis results into the document.

5. Label your schematic and simulation results. Express the results of your measurements, calculations, and simulation in a short paragraph.

6. The lab instructor may ask for a printed copy of your document, an emailed copy, or may just ask to see it displayed on the lab computer.

History note:

Count Alessandro Giuseppe Antonio Anastasio Volta (18 February 1745 – 5 March 1827) was an Italian physicist known especially for the invention of the battery in 1800.

From Wikipedia, the free encyclopedia

Experiment 4: Power Supplies and Batteries

Introduction

Workbench type DC power supplies are used to power experimental circuits in laboratories, as substitute power supplies for circuits on a test bench, as well as for many other applications. The typical bench power supply for general electronics applications will have several variable output voltages.

The typical power supply may have a variable 0 to 20V source with a positive output with respect to ground and a variable 0 to 20V source with a negative output with respect to ground. The maximum current for these may be about 1A. In addition, it may have other sources that may be utilized.

Rechargeable lead-acid batteries are a very common voltage source. This battery is available in a variety of forms: wet cell, sealed lead-acid, and gel cell. The wet cell is typically what you'll find in an automobile. This battery contains sulfuric acid and must be handled carefully.

The sealed lead acid battery is designed to be "maintenance free". It has the advantage of being "non-spill-able", but one must be extra careful when charging it. The gel cell battery has a "gelled" lead-acid electrolyte. When charging any lead-acid battery, one must be careful not to overcharge the battery. Overcharging can result in battery damage and may be dangerous.

Lead-acid batteries are used in cars, boats, and aircraft. They can supply large currents for short periods to start engines. They can be recharged hundreds of times. Lead-Acid batteries are also used to store power from wind generators and solar panels.

Other common rechargeable batteries include the Nickel-Cadmium, Nickel-Metal Hydride, and Lithium-Ion. These batteries are typically used in cell phones and notebook computers.

The table below compares typical characteristics of a variety of battery types. Actual characteristics of specific batteries depend on the manufacturer and technology.

Battery Type	Chargeable	Battery Volts / Size for Specs	Amp-Hrs	Cycles	Comments
Sealed Lead-Acid	Yes	6.6V / 70 mm by 47 mm by 102 mm	4.2	800	No Memory Effect
Nickel-Cadmium	Yes	1.2V / D 32 mm dia. by 62 mm long	2	500	Memory Effect
Mag-Nickel Hydride	Yes	1.2V / D 32 mm dia. by 62 mm long	4	500	Some Memory Effect
Lithium Ion	Yes	3.7V / 18.3 mm dia. by 50 mm long	1.2	500	No Memory Effect
Lithium	No	3.0V / 17 mm dia.by 45 mm long	2.5	1	non-rechargeable
Alkaline	No	1.5V / D 32 mm dia. by 62 mm long	10	1	non-rechargeable

Objectives

This lab is an introduction to DC power supplies and lead-acid rechargeable batteries. The charging and discharging characteristics of a small 6V lead-acid battery will be investigated.

Procedure

Equipment and Parts
DMM, DC Power Supply, and Breadboard. Resistor: 10Ω, 10W, 5%. 6V, 4A-Hr, sealed lead-acid battery.

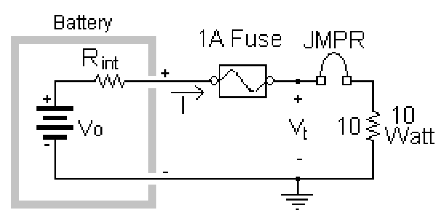
Part A: Lead-acid Battery Discharging

Please observe the following precaution before proceeding with this exercise:

Do not short circuit a battery. Connecting a low resistance across the battery terminals can result in excessive current, which will not only discharge the battery quickly, but it may also cause the battery and the wires to dangerously overheat. Batteries are relatively safe when treated properly. As a an extra precaution, a 1A fuse is connected in series with the battery.

The battery is modeled as an ideal source (Vo) in series with its internal resistance (R_{int}) .

1. Connect the circuit on the right with the jumper, JMPR, open (battery is not connected to the 10Ω load resistor).



Vo is the open circuit battery voltage. V_t is the battery terminal voltage. R_{int} is the battery's internal resistance.

2. Measure and record Vo by measuring V_t when the 10Ω load resistor is not connected. V_t = Vo when load is not connected. Use a battery whose voltage is between 6V and 6.6V.

Vo = ______________________

When the jumper is connected, the battery will discharge through the load resistor and V_t < Vo. A discharge current of about 0.6A will flow and create a voltage drop across the battery's internal, R_{int}.

3. Connect the jumper to the battery at t = 0. Measure and record $V_{t(0)}$. Leave the jumper connected. Measure and record $V_{t(20)}$ at t = 20 minutes. If a stopwatch is not available, the website onlinestopwatch.com can be used.

Time	t = 0 minutes, $V_{t(0)}$	t = 20 minutes, $V_{t(20)}$
Voltage V_t		

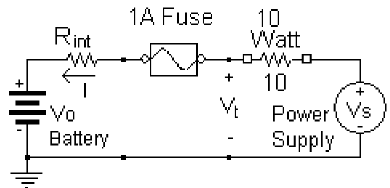
Disconnect the jumper when done.

Part B: Lead-acid Battery Charging

<u>Please observe the following precaution before proceeding with this exercise:</u>

Be extremely careful to not overcharge a rechargeable battery. It is dangerous to overcharge batteries because the chemical reactions can emit dangerous gasses, chemicals and heat, which may cause the battery to burst or explode.

<u>A 6V battery whose terminal voltage exceeds 6.6V is in danger of being overcharged.</u>



1. Connect the circuit on the right, but do not connect the 10Ω resistor yet. Set Vs to 12.0V using the DMM.

   Vo is the open circuit battery voltage. V_t is the battery terminal voltage. R_{int} is the battery's internal resistance.

2. Measure and record V_t. V_t = Vo in this case because the battery is disconnected.

   Vo = ____________________

3. Connect the 10W 10Ω resistor at t = 0. Make sure that Vs is still 12.0V. Measure and record $V_{t(0)}$ at t = 0 and $V_{t(20)}$ at t = 20 minutes.

   You may consider doing something else while the battery is charging, such as the analysis of part A. But do not forget to disconnect the battery from the power supply in exactly 20 minutes.

Time	t = 0 minutes, $V_{t(0)}$	T = 20 minutes, $V_{t(20)}$
Voltage V_t		

Disconnect the circuit when done.

Analysis, Part A

1. Calculate R_{int} using the values of Vo and V_t at t = 0.
2. Calculate the average value of V_t:

$$V_{t(ave)} = \frac{V_{t(0)} + V_{t(20)}}{2}$$

3. Calculate the average discharging current, I_{ave}, using the measured value of your 10Ω resistor.

$$I_{ave} = \frac{V_{t(ave)}}{10}$$

4. Use the average values calculated above to calculate the amount of energy delivered to the load in 20 minutes in joules and in watt-hours.

5. Calculate the amount of energy dissipated by the battery's internal resistance in joules and in watt-hours during the 20 minutes of discharge.

Analysis, Part B

1. Calculate R_{int} using the values of Vo and V_t at t = 0.
2. Calculate the average value of V_t:

$$V_{t(ave)} = \frac{V_{t(0)} + V_{t(20)}}{2}$$

3. Calculate the average charging current, I_{ave}, using the measured value of your 10 Ω resistor.

$$I_{ave} = \frac{V_{t(ave)}}{10}$$

4. Use the average values calculated above to calculate the amount of energy delivered to the battery in 20 minutes in joules and in watt-hours.

History note:

André-Marie Ampère (20 January 1775 – 10 June 1836) was a French physicist and mathematician who is generally regarded as one of the main discoverers of electromagnetism. The SI unit of measurement of electric current, the ampere, is named after him.

From Wikipedia, the free encyclopedia

Experiment 5: Voltage, Current, and Power

Introduction

Electrical devices which do work consume energy. Power is the rate that energy is consumed. Equations describing the relationship between power, energy, voltage, and current are given below. P is power in watts, W is work (energy) in joules, I is in amperes, and V is in volts:

$$P = \frac{dW}{dt} \qquad P = IV \qquad V = IR$$

The first equation is a calculus expression stating that power is simply the rate at which energy, or “W”, is changing with respect to time, or “t”.

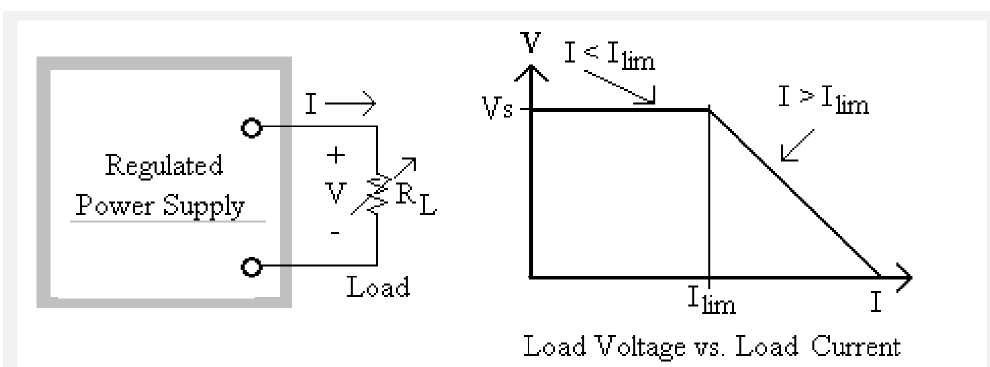
All electric power sources are basically sources of potential difference or voltage. Examples include batteries, generators, solar cells, and power supplies.

A typical lab power supply has variable (adjustable) voltages from 0 to about 30V at a maximum current of about 1A. Maximum ratings are often printed on the front panel. Note what maximum voltages and currents are available from your power supply. You may refer to the instrument’s manual, if available, for more details.

Voltage Sources

Voltage sources used in circuit analysis are usually "ideal" sources. By ideal we mean that the value of the voltage of the source does not change regardless of how much current it supplies. Practical sources are limited in the amount of current they can supply.

A voltage-regulated power source will supply a constant output voltage, V_S, when the output current, I, is less than its maximum limit, I_{lim}. Some power supplies have an adjustable current limit, I_{lim}, and they will supply a constant output voltage for load currents less than I_{lim}. Refer to the graph below.



A power supply will be used to supply power to a light emitting diode (LED) in part A and to a light bulb in part B. The voltage versus current characteristics and power dissipation of both will be measured and compared.

Voltage Measurement

The DMM will be used to measure voltage. *To measure voltage the meter leads are connected across (in parallel with) the device.* Voltage is measured between two nodes. Voltage is a potential difference. You are measuring the potential difference between two nodes.

Current Measurement

To measure current the meter must be connected in series with the circuit so that the current flowing through the ammeter is the same as the current flowing through the circuit. The circuit must be temporarily disconnected to insert the ammeter in series with it.

Current can also be determined by measuring the voltage drop across a known resistance and calculating the current flowing through it using Ohm's law. Current through an LED and an incandescent lamp will be determined from the voltage measured across a series connected resistor.

Objectives

The voltage versus current graph of a resistor is a straight line. The resistance of a resistor is constant and does not change with the current through it. This experiment will show that this is not the case for LEDs and light bulbs. Objectives of this exercise include gaining experience with voltage measurement, spreadsheet calculations, and spreadsheet graphing.

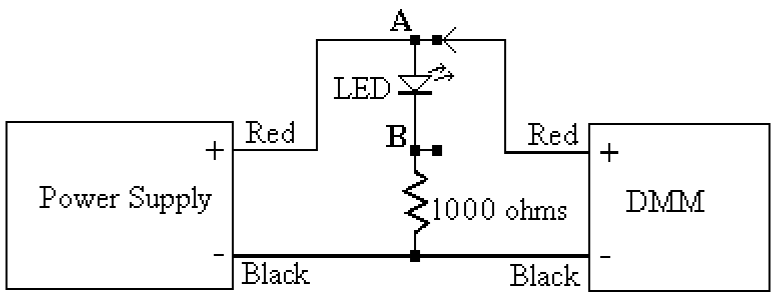
Procedure

Equipment and Parts

Power supply, DMM, and Breadboard
Resistors: 10Ω and 1000Ω (1/4 watt, 5%).
Light bulb: Type 2182 (14V, 80mA). Light Emitting Diode (LED).

Part A: I versus V for an LED

1. Connect the circuit below. The positive lead of the LED is the anode. It is the longer lead and it should be connected to point A on the diagram below. Turn on the power supply and set the voltage to zero. Set the DMM function to volts and set the range to 20V.



2. The red DMM lead will be moved between points A and B follows:

   (a) Set the power supply voltage to exactly 0.0V (as read on the DMM). The DMM's red lead should be connected to point A.

   (b) Move the DMM's red lead to point B. Measure and record the voltage at B.

   (c) Repeat steps (a) and (b) for voltages at point A) of:
   1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, and 12.0V.

Create a spreadsheet table as shown below. You will have 13 rows of data.

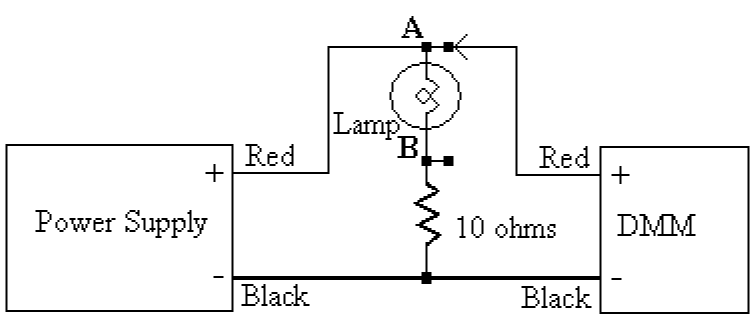
	A	B	C	D	E
1	Volts at A	Volts at B	Volts LED	A LED	Watts LED
3	0	0	0	0	0
4	1				
5	2				

C4 has: =A4–B4 D4 has: =B4/1000 E4 has: =C4*D4

You can automatically fill a column of data. For example, select cell C4, then click the mouse on the bottom right corner of the cell, and drag the mouse down to fill all of the rows of that column. This can also be done with copy and paste using ctrl+c and ctrl+v.

Part B: I versus V for a Lamp

1. Connect the circuit below. The lamp is not "polarized". Its leads can be connected in either direction. Make sure that the power supply output voltage is set to zero. Set the DMM function to volts and set the range to 20V.



2. The Red DMM lead will be moved between points A and B as follows:

   (a) Set the power supply voltage to exactly 0.0V (as read on the DMM). The DMM's red lead should be connected to point A.

   (b) Move the DMM's red lead to point B. Measure and record the voltage at B.

   (c) Repeat steps (a) and (b) for voltages (as read by the DMM at point A) of:
   1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, and 12.0V.

Create a spreadsheet table as shown below. You will have 13 rows of data.

	A	B	C	D	E
1	Volts at A	Volts at B	Volts Lamp	A Lamp	Watts Lamp
3	0	0	0	0	0
4	1				
5	2				

C4 has: =A4–B4   D4 has: =B4/10   Cell E4 has: =C4*D4

Analysis

1. Use the spreadsheet to graph the current versus voltage characteristics of the LED. Current is on the vertical axis and voltage is on the horizontal axis. Label the graph.

2 Use the spreadsheet to graph the current versus voltage characteristics of the lamp Current is on the vertical axis and voltage is on the horizontal axis. Label the graph.

3. The resistance of the device at a point on the graph is equal to the value of the voltage at that point divided by the value of the current at that point. Use the spreadsheet to calculate the resistance for each row in column F.

   Plot the resistance of the LED as a function of power dissipation using your spreadsheet data (resistance on vertical axis).

   Plot the resistance of the lamp as a function of power dissipation using your spreadsheet data (resistance on vertical axis). Why does the resistance of the lamp change as more power is dissipated by it?

4. Copy each properly labeled graph and paste it into a word document. Your document should have the form below:

   Your Name   Course Number   Date   Experiment Number and Name

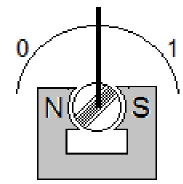
   Circuit diagrams with labeled voltages and currents
   LED Current versus Voltage Graph
   Lamp Current versus Voltage Graph
   LED Resistance versus Power Graph
   Lamp Resistance versus Power Graph

   Brief summary (what you learned from this exercise).

   The above is a short report. The instructor will specify how to turn in the report. The instructor may also ask for additional analysis, including a more comprehensive lab report.

Experiment 6: Analog "D'Arsonval" Meter

Introduction



An analog meter uses magnetic fields to measure electric current. A coil of wire wound on a bobbin creates a magnetic field whose strength is proportional to the wire's current. The bobbin is suspended in between the magnetic field of a permanent magnet as shown in the illustration on the right. The bobbin and attached needle rotate due to the magnetic force between the bobbin and the permanent magnet.

The wire winding has a resistance which determines one of the meter's characteristics. For example, if the winding resistance is 1000Ω, and one milliamp causes "full scale" deflection, its "sensitivity" will be given as "1000 ohms per volt". By Ohm's law, 1V applied to a1000Ω resistor will create a current of one milliamp.

So a 1000Ω, one milliamp meter is also a voltmeter whose full scale voltage is 1V. The voltage range of the meter can be changed to 10V by adding a series resistance that will result in a one milliamp current when the applied voltage is 10V. The total resistance required to limit the current to one milliamp is 10,000Ω. Connecting a 9000Ω resistor in series with the meter makes the meter a voltmeter whose range is zero to ten volts.

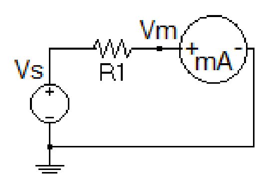
Objectives

Measure the operating characteristics of an analog milliammeter. Use the measured meter characteristics to design a dual range analog voltmeter. Evaluate the performance of the voltmeter.

Procedure

Equipment and Parts
Power supply, DMM and Breadboard. Analog meter, 1mA < 1000Ω (or 100µA < 10,000Ω). R1: 1k, ¼ watt, 5% for 1mA meter (or 10k, ¼ watt, 5% for 100µA meter). Values of resistors R2 and R3 to be determined.

Part A: Meter Characteristics



1. Measure and record the value of R1. R1 is the 1k resistor if using a 1mA meter (or 10k if using a 100µA meter). Set the power supply voltage to zero. Connect the circuit on the right. Vs is a variable power supply (0 to 10V). Connect the DMM to read the voltage, Vm, across the meter.

   R1: _______________

2. Slowly increase the voltage, Vs, until the analog meter reads full scale. Your eye should be directly above the meter's needle to reduce "parallax error". Measure and record the voltage, Vm, across the meter.

Connect the DMM to Vs. Measure and record Vs.

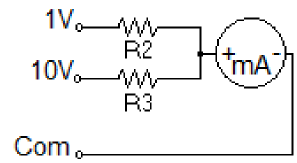
Vm: _______________ Vs: _________________

3. Calculate the actual meter current, I_{ma}, and resistance, R_{ma}, using the voltages, Vm and Vs, and the measured value of R1.

$$I_{ma} = \frac{Vs - Vm}{R1} = \_\_\_\_\_\_\_\_\_\_\_\_\_ \qquad R_{ma} = \frac{Vm}{I_{ma}} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

Part B: Meter Design

1. Use the calculated values of I_{ma} and R_{ma} from part A, step 3, to design a dual range voltmeter circuit, as shown on the right, to measure 1V full scale and 10V full scale. Calculate the required values R2 and R3.



R2: ________________ R3: _________________

Use a series combination of resistors for R2 and R3 so that the resistors used in the circuit have measured values within 1% of the calculated values. Use a high value and low value resistor in series.

For example, if R2 = 930Ω, you could connect the standard values of 910Ω and 22Ω in series to obtain 932Ω. The percent error for this combination is:

$$\% Error = \frac{932 - 930}{930} \times 100\% = 0.215\%$$

Measure the resistance of your series combination. You may need to try another combination if your measured resistance is not within 1% of the required resistance. Note that 1% of 1000Ω is equal to 10Ω.

2. Test the voltmeter circuit by comparing the analog meter readings to the DMM readings as follows:

a) Connect the DMM to the variable power supply. Connect the 1V input range of the analog meter (R2) to the variable power supply. The meters will be in parallel.

b) Carefully set the power supply voltage so that the analog meter reads 0.20V. Observe the analog meter reading from directly above the needle to minimize parallax error.

c) Read the voltage on the analog meter. Record result in the table on the next page.

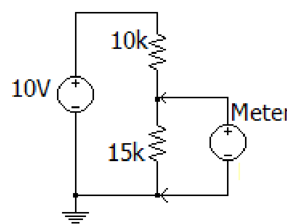
d) Repeat steps (b) and (c) for voltages of 0.40, 0.60, 0.80, and 1.00V.

e) Repeat the procedure for the analog meter's 10V range and record results in the table on the next page (for 2.0, 4.0, 6.0, 8.0, and 10.0V).

1V RANGE				10V RANGE		
Analog Meter	DMM	% Error		Analog Meter	DMM	% Error
0.2				2.0		
0.4				4.0		
0.6				6.0		
0.8				8.0		
1.0				10.0		

Analysis

1. Calculate the sensitivity of the analog voltmeter in ohms per volt on the 1V and 10V range.
2. Calculate the input resistance of the analog voltmeter on the 1V and 10V range.
3. Calculate the percent error for all of the readings and record the results in the table. You could use a spreadsheet to do the calculations.
4. Calculate the average percent error of the analog meter on the 1V and on the 10V range.
5. Assuming that the analog meter is as accurate as the digital meter, calculate the voltage that each meter would read across the 15k resistor given that the digital meter has resistance of 1MΩ and the analog meter has a resistance of 10kΩ. Calculate the percent error for each meter.



6. Use the values of I_{ma} and R_{ma} of the meter to design an analog ammeter with a full scale deflection current of 100mA. Calculate the required value of the shunt resistance (resistance in parallel with the meter). What is the net resistance of the 100mA meter (shunt resistance in parallel with the meter resistance, R_{ma}).