Cornerstone Electronics Technology and Robotics I Lab Manual

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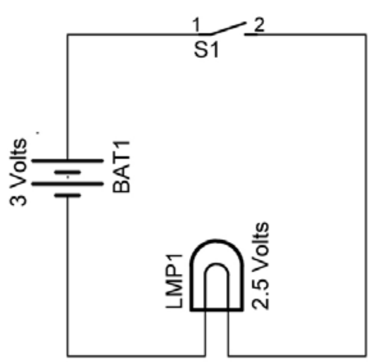
Electronics Technology and Robotics I Week 2
Simple Circuits LAB 1 – Wiring Simple Circuits

- **Purpose:** The purpose of this lab is to acquaint the student with elementary electrical circuit symbols and wiring.

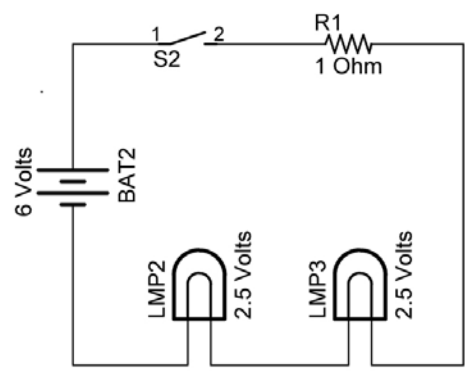
- **Apparatus and Materials:**

    - 1 – 3 Volt Battery Power Supply
    - 1 – 6 Volt Battery Power Supply
    - 1 – 9 Volt Battery Power Supply
    - 2 – 2.5 Volt Lamps
    - 1 – 6 Volt Lamps
    - 1 – 7.5 Volt Lamps
    - 1 – 1 Ohm Resistor (Brown, Black, Gold)
    - 1 – 22 Ohm Resistor (Red, Red, Black)
    - 1 – 68 Ohm Resistor (Blue, Gray, Black)
    - 1 – Knife Switch
    - Alligator Clips

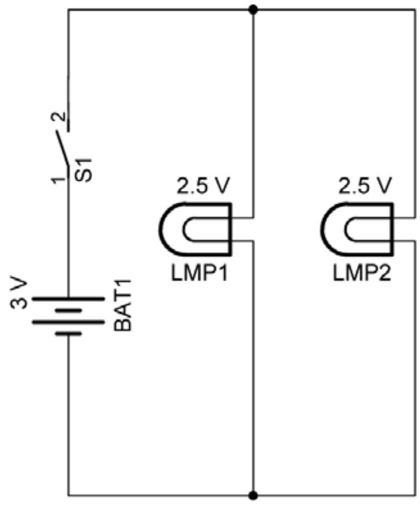
- **Procedure:**
    - Wire the following circuits by connecting alligator clips to the circuit components.
    - Have your instructor check your circuit before closing the switch.



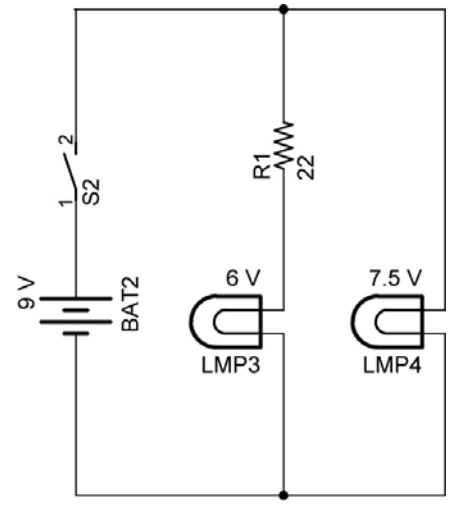
Circuit 1



Circuit 2



Circuit 3



Circuit 4

- **Results:**
  - In Circuit 1, close the switch then disconnect any of the alligator clips and record what happens to the lamp.
  - In Circuit 2, unscrew one of the lamps and record what happens to the other lamp:
  - In Circuit 3, unscrew one of the lamps and record what happens to the other lamp:
  - In Circuit 4, replace the 22 ohm resistor (red, red, black) with a 68 ohm resistor (blue, gray, black) and record the change in the 6 V lamp.

Electronics Technology and Robotics I Week 2
Simple Circuits LAB 2 – Series/Parallel Fountain

- **Purpose:** The purpose of this lab is to have the students build a fountain with nozzles in series and parallel.

- **Apparatus and Materials:**

    - Various PVC Pipe and Fittings
    - PVC Glue
    - 6 – Nozzles

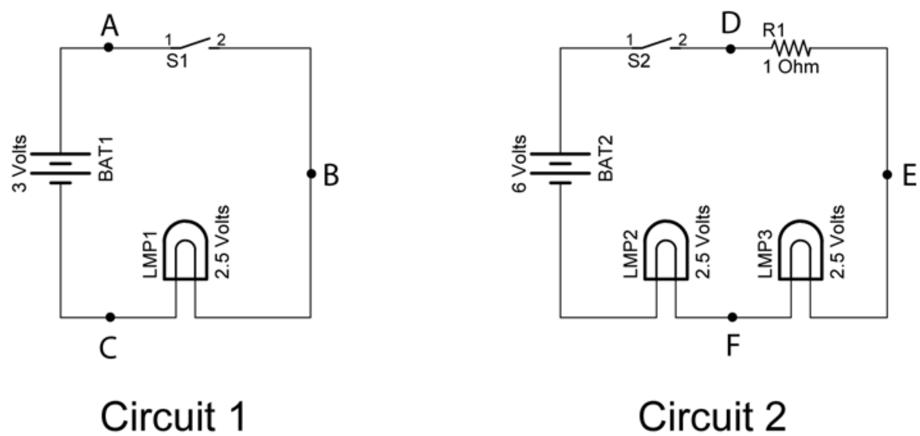
- **Procedure:**
    - Review MSDS for PVC glue.
    - Goggles <u>must</u> be worn when applying PVC glue.
    - Design and build a fountain such that:
        - It is made of 6 nozzles pointing upward.
        - The nozzles tips are spaced in a 1' grid.
        - Nozzles are placed in both series and parallel.
        - The final nozzle layout is in a 1' x 2' rectangular grid.
        - The fountain is sourced from a garden hose.
        - Note: The collection of fittings contains more fittings then is needed to complete the project.

Electronics Technology and Robotics I Week 3
Basic Electrical Meters Lab 1 – Ammeter

- **Purpose:** The purpose of this lab is to acquaint the student with measuring current using an ammeter and to become acquainted with current relationships in a series circuit.

- **Apparatus and Materials:**
  - 1 – Digital Multimeter (DMM)
  - 1 – Battery Holder and Battery
  - 1 – SPST Switch
  - 1 – 1 Ohm Resistor
  - 2 – Lamp Holders
  - 2 – 2.5 V Lamps
  - Alligator Clips

- **Procedure:**
  - Wire the following circuits and then use your ammeter to measure the current at each point labeled.
  - Record your results in the tables below.
  - Write your conclusions regarding your results.



- **Results:**

Point	Current in mA
A	
B	
C	

Circuit 1

Point	Current in mA
D	
E	
F	

Circuit 2

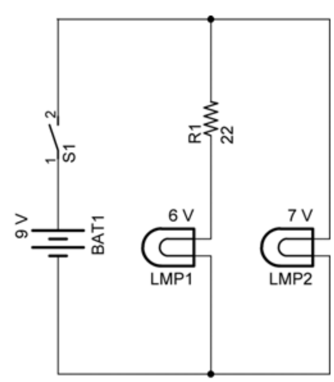
- **Conclusions:**

Electronics Technology and Robotics I Week 3
Basic Electrical Meters Lab 2 – Voltmeter

- **Purpose:** The purpose of this lab is to acquaint the student with measuring voltage using a voltmeter.

- **Apparatus and Materials:**
  - 1 – Digital Multimeter (DMM)
  - 1 – Battery Snap and 9 V Battery
  - 1 – SPST Switch
  - 1 – 22 Ohm Resistor (Red, Red, Black)
  - 2 – Lamp Holders
  - 1 – 6 V Lamp and 1 – 7.5 V Lamp
  - Alligator Clips

- **Procedure:**
  - In the Circuit 3 below, close the switch then measure and record the voltage:
    - Across the battery terminals
    - Across the resistor
    - Across the 6 volt lamp. Add the voltage drops across the resistor and the 6 volt lamp, then compare the sum with the voltage drop across the battery.
    - Across the 7.5 volt lamp. Compare this reading with the voltage drop across the battery.
    - Write your conclusions



Circuit 3

- **Results:**

Component	Voltage in Volts
Battery	
Resistor	
6 V Lamp	
7.5 V Lamp	

- **Conclusions:**

Electronics Technology and Robotics I Week 3
Basic Electrical Meters Lab 3 – Ohmmeter

- **Purpose:** The purpose of this lab is to acquaint the student with measuring resistance using an ohmmeter.

- **Apparatus and Materials:**

    - 1 – Digital Multimeter (DMM)
    - Assortment of Resistors

- **Procedure:**
    - Measure and record the value of each resistor.

- **Results:**

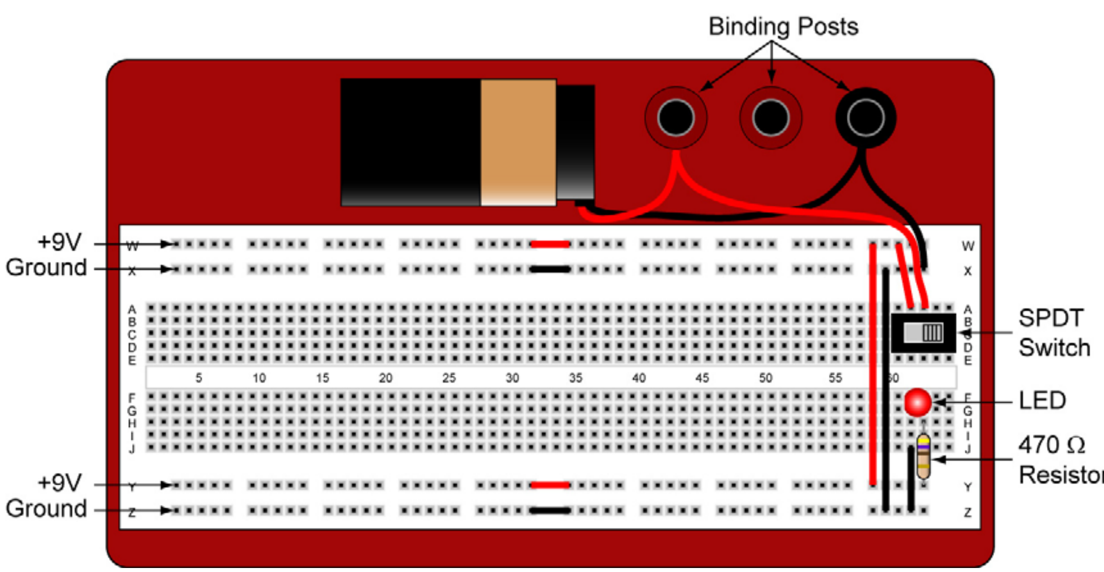
Resistor	Resistance in Ohms
A	
B	
C	
D	
E	
F	
G	
H	

Electronics Technology and Robotics I Week 3
Solderless Breadboard LAB 1 – Power to the Breadboard

- **Purpose:** The purpose of this lab is to have the student wire the breadboard for a +9 V and + 5 V power strips.

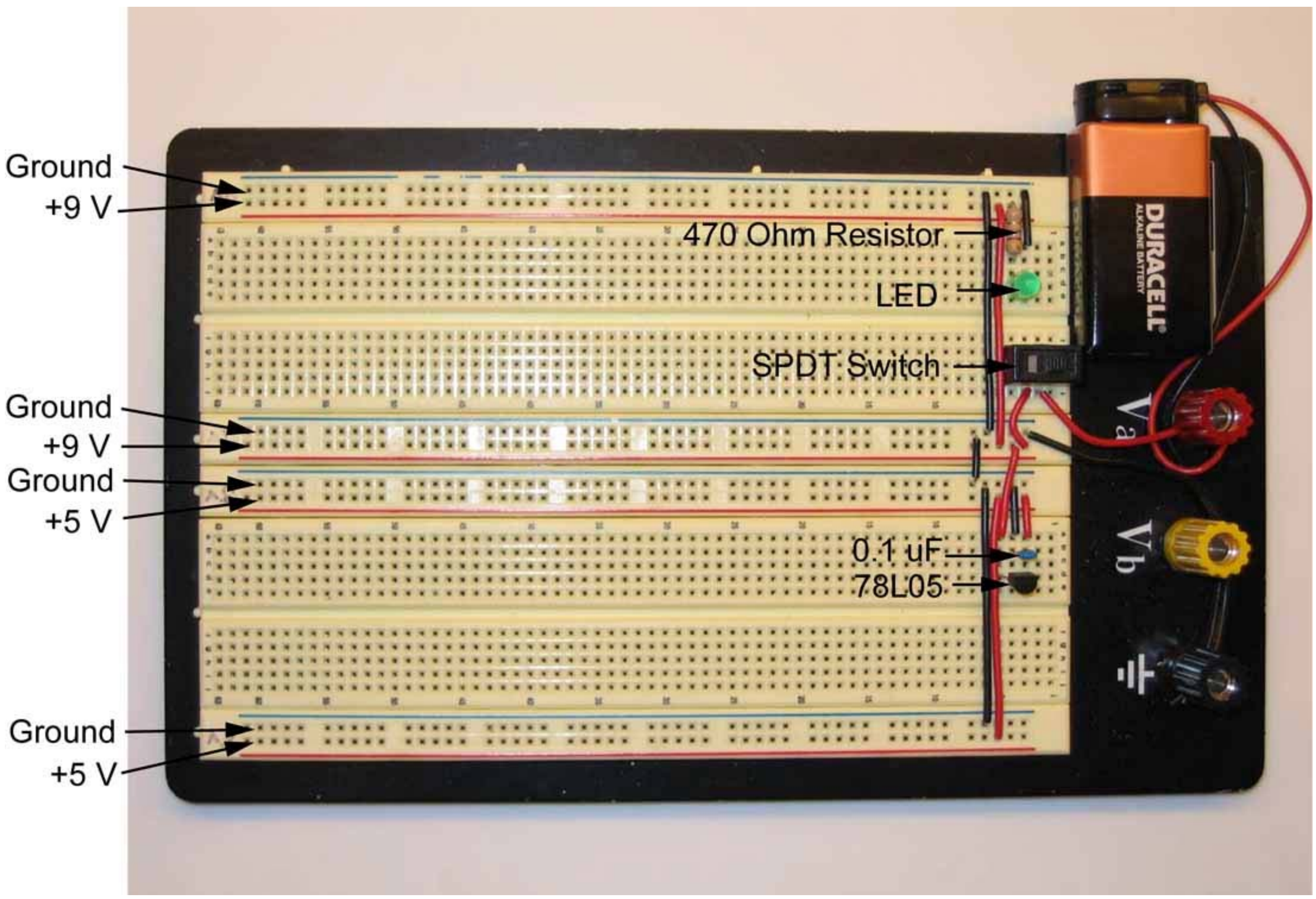
- **Apparatus and Materials:**
    - 1 – 840 Pin Solderless Breadboard (Radio Shack #276-169)
    - 1 – 1660 Pin Solderless Breadboard (Electronix Express #03MB104)
    - 1 – 9 Volt Battery
    - 1 – 9 Volt Battery Snap
    - 1 – SPDT Switch (Electronix Express #17SLDH251)
    - 1 – LED
    - 1 – 470 Ohm Resistor (Yellow, Violet, Black)
    - 1 – 78L05 Voltage Regulator
    - 1 – 0.1 µF Capacitor
    - # 22 Solid Wire (Black and Red)

- **Procedure:**
    - 840 Pin Solderless Breadboard:
        - Power to binding posts: Install the battery snap and wire to the binding posts.
        - Layout the switch, LED, and resistor.
        - Power to buses: Connect the binding posts to the breadboard as shown.
        - Connecting the bus strips: Connect the top two bus strips (+9 V and Ground) to the bottom two bus strips.
        - Power indicator LED: Install the final connections as shown. Be sure that the flat side of the LED is facing toward ground.
        - Check voltages at points on the two bus strips.



840 Pin Solderless Breadboard Setup

- 1660 Pin Solderless Breadboard:
  - Power to binding posts: Install the battery snap and wire to the binding posts.
  - Layout the switch, LED, resistor, voltage regulator, and capacitor.
  - Power to buses: Connect the binding posts to the breadboard as shown.
  - Connecting the bus strips: Connect the top four bus strips as shown. **Make sure that the only connection between the +9 V bus strips and the +5 V bus strips is the common ground connection. The only +9 V lead to the +5 V circuit is the connection to the 78L05 voltage regulator.**
  - Power indicator LED: Install the final connections as shown. Be sure that the flat side of the LED is facing toward ground.
  - Check voltages at points on the four bus strips.



Electronics Technology and Robotics I Week 4
Ohm's Law Lab 1 – Measurements and Calculations

- **Purpose:** The purpose of this lab is to have the student apply Ohm's Law to several circuits and then verify the calculated results.

- **Apparatus and Materials:**

  - 1 – Digital Multimeter (DMM)
  - Circuits by the Instructor

- **Procedure:**
  - Use Ohm's law to analyze Circuits 1 - 6. Measure and record the quantities in the white cells of Table 1 then using Ohm's Law, calculate the unknown quantities of the shaded cells.
  - Copy the calculated quantities from Table 1 into the shaded cells in Table 2.
  - Measure those unknown quantities using a DMM and compare with the calculated values.
  - Determine the differences in Table 2.

- **Results:**

Ohm's Law Calculated			
Circuit	Voltage in Volts	Resistance in Ohms	Current in A
1			
2			
3			
4			
5			
6			

Table 1

Ohm's Law Measured				
Circuit	Unknown Quantity	Calculated	Measured	Difference
1	Voltage			
2	Resistance			
3	Current			
4	Voltage			
5	Resistance			
6	Current			

Table 2

- **Conclusions:**

- **Challenges:**
  - Design a voltage source where the single load resistance is 100 ohms and the current through the resistor is 50 mA.

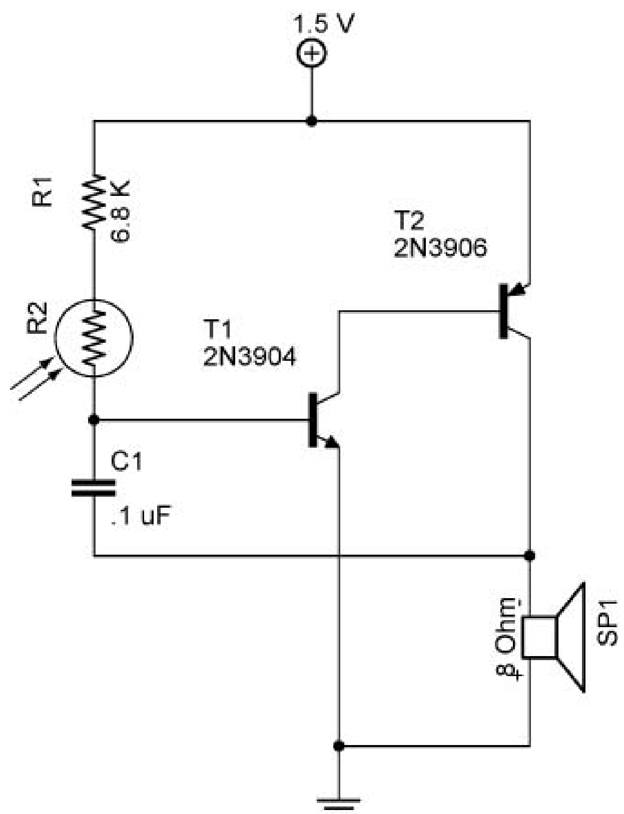
Electronics Technology and Robotics I Week 4
Ohm's Law Lab 2 – Local/Global Circuit Changes

- **Purpose:** The purpose of this lab is to acquaint the student with the fact that a change in the value of one circuit component can affect the operation of the entire circuit.

- **Apparatus and Materials:**

  - 1 – Digital Multimeter (DMM)
  - Circuit Provided by Instructor

- **Procedure:**
  - Using an audible light probe circuit, demonstrate that a local change in one resistor implies a global change, i.e., change in the operation of the entire circuit.



Circuit 1 - Audible Light Probe Circuit

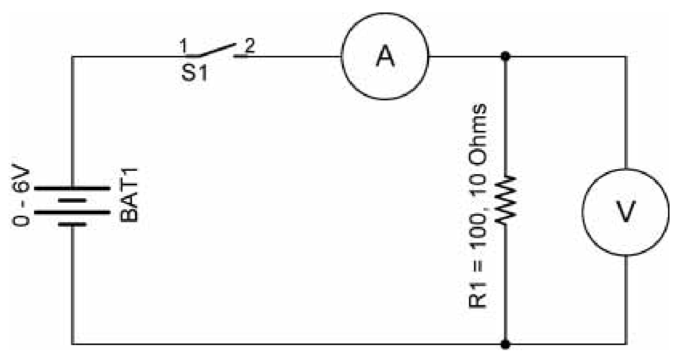
Electronics Technology and Robotics I Week 4
Ohm's Law Lab 3 – Graphing Ohm's Law

- **Purpose:** The purpose of this lab is to acquaint the student with graphing electrical variables and how slope represents a quantity.

- **Apparatus and Materials:**

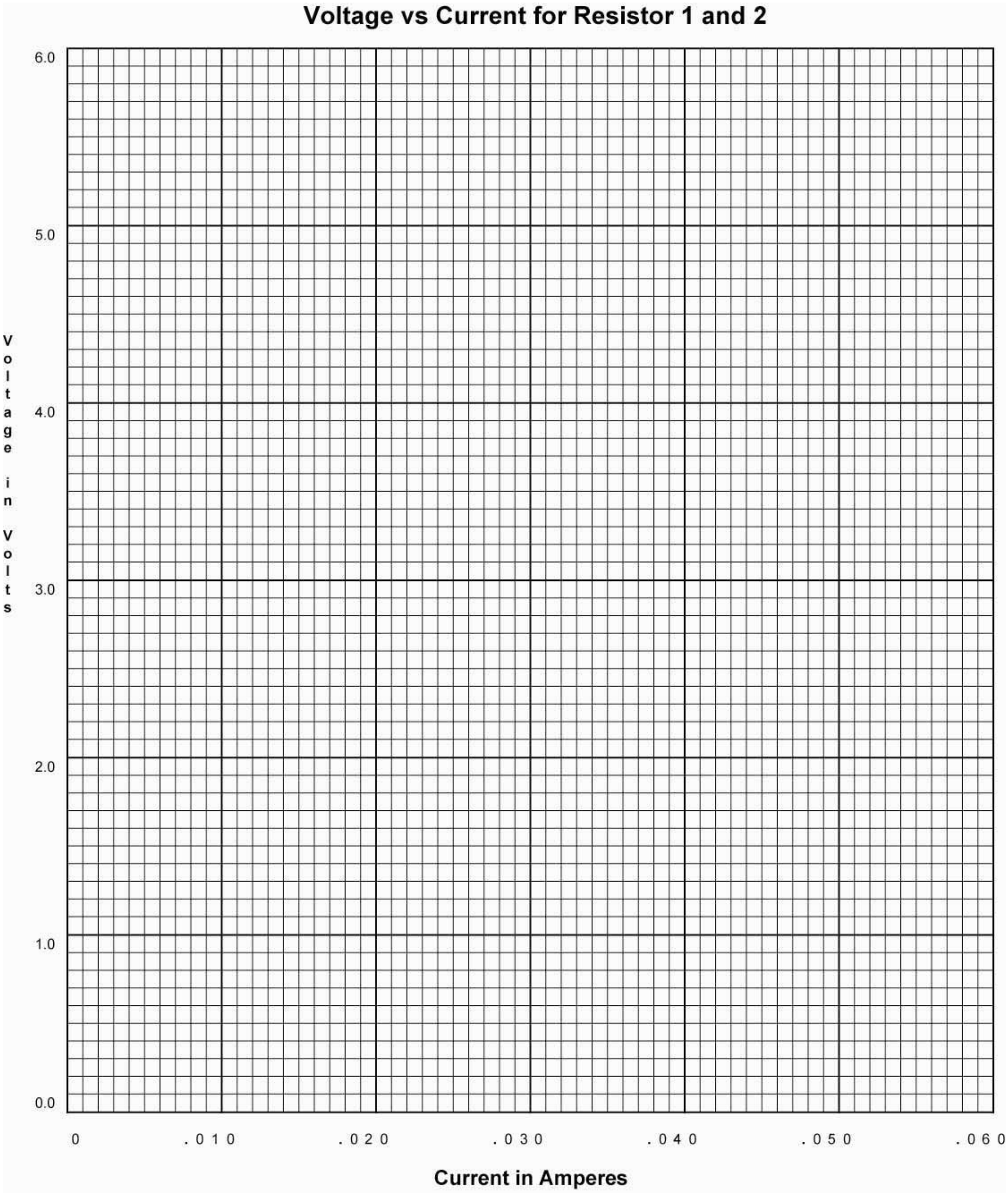
    - 1 – Solderless Breadboard
    - 2 – Digital Multimeters (DMM)
    - 1 – DC Power Supply
    - 1 – SPST Switch
    - 1 – 10 Ohm Resistor
    - 1 – 100 Ohm Resistor

- **Procedure:**
    - Wire Circuit 2 using a breadboard.
    - Change the value of the power supply from 0 to 6 volts in increments of 1 volt.
    - Using the graph provided, plot the value of the current and voltage at each voltage increment.



Circuit 2

- **Results:**



- **Conclusions:**

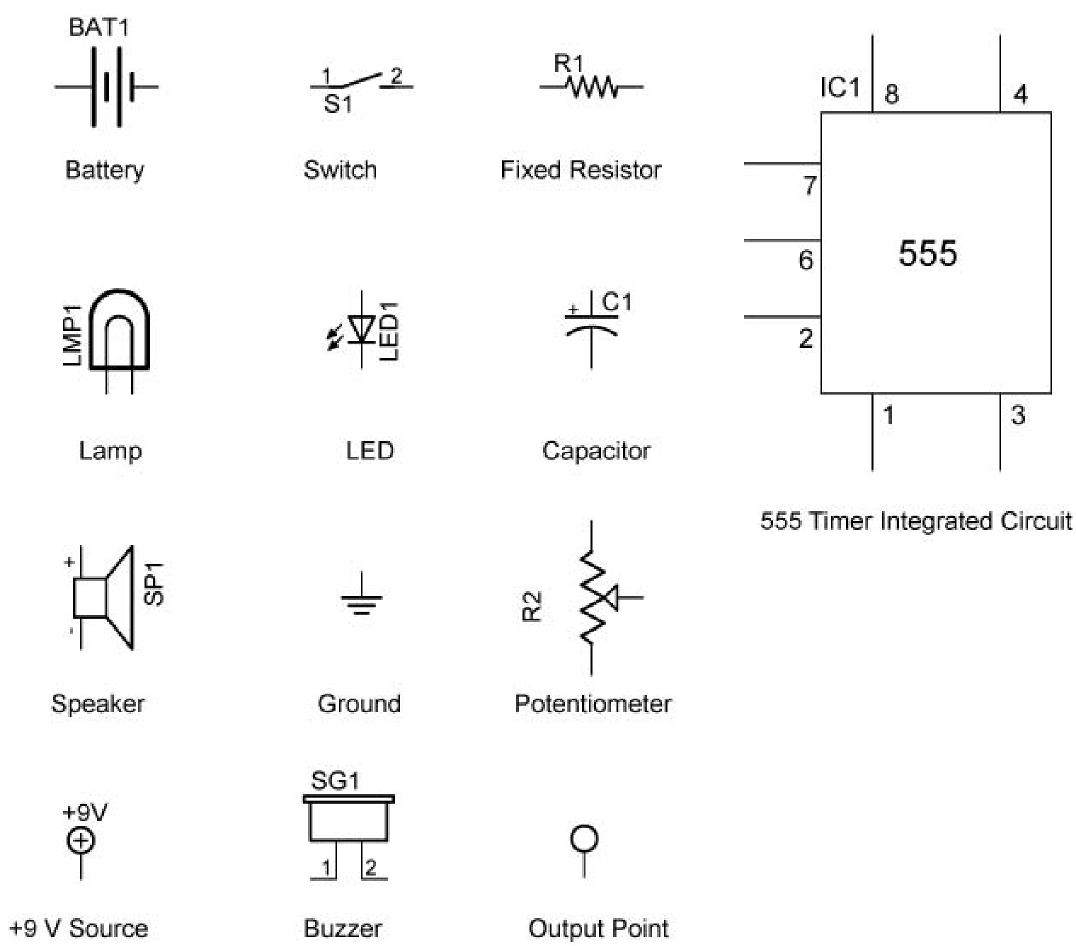
Electronics Technology and Robotics I Week 5
Schematics Lab 1 – Drawing Schematics

- **Purpose:** The purpose of this lab is to have the student practice drawing schematics.
- **Apparatus and Materials:**
  - 1 – Digital Multimeter
  - 7 Circuits Provided by the Instructor
- **Procedure:**
  - Draw schematics for the 7 circuits displayed.
    - In Circuit 6, measure the voltage between Point A and ground. Compare it to the source voltage.

      Source Voltage = ______________________________

      Point A to GND = ______________________________

    - Use the integrated circuit (IC1) below when drawing Circuit 4, the electronic cricket.
  - Symbols Needed:



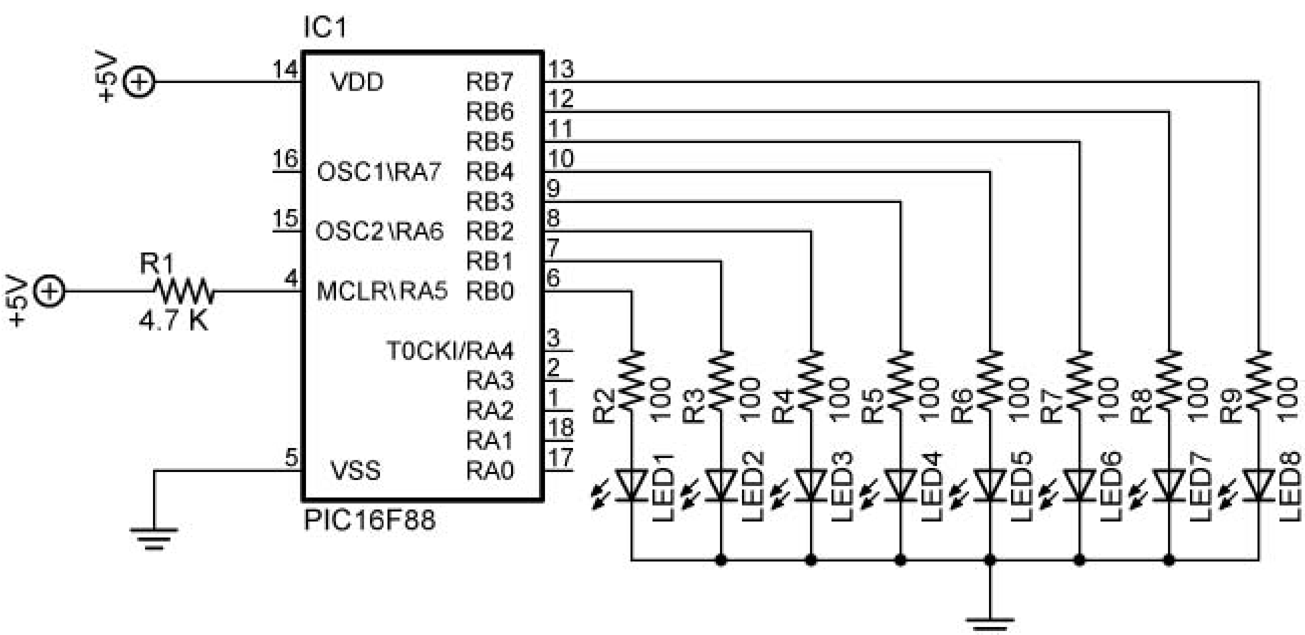
Electronics Technology and Robotics I Week 5
Schematics Lab 2 – Bounce1.pbp

- **Purpose:** The purpose of this lab is to have the student practice wiring a circuit from a schematic drawing.

- **Apparatus and Materials:**

  - 1 – Breadboard with +5 V Power Source
  - 1 – PIC16F88 with PicBasic Pro Program: http://www.cornerstonerobotics.org/code/bounce1.pdf
  - 1 – 4.7 K Resistor
  - 8 – LEDs
  - 8 – 100 Ohm Resistors

- **Procedure:**
  - Wire the circuit Bounce1:



Bounce1

Electronics Technology and Robotics I Week 6
Printed Circuit Boards Lab 1 – Photofabrication of PCB

- **Purpose:** The purpose of this lab is to acquaint the student with:
  - PCB layout using dry transfers, and
  - The process of chemical photofabrication.

- **Apparatus and Materials:**
  - 1 – Solderless Breadboard
  - 1 – 1/32" Presenitized Copper-Clad Single Sided Circuit Board (Allied Electronics #661-0595 (18"x12" x 1/32"))
  - PC Transfers
  - 1 – M.G. Chemicals Etchant Process Kit M.G. Cat #416-E (Electronix Express # 03416E); (http://www.mgchemicals.com/products/416e.html)
  - 1 – M.G. Chemicals Exposure Kit M.G. Cat #416-X (Electronix Express # 03416X); (http://www.mgchemicals.com/products/416x.html)
  - M.G. Chemicals Developer M.G. Cat #418 (Electronix Express # 03418500ML); (http://www.mgchemicals.com/products/418.html)
  - M.G. Chemicals Ferric Chloride Etchant, M.G. Cat #415 (Electronix Express #03151L(1Liter) or #034154L(4 Liter)); (http://www.mgchemicals.com/products/415.html)
  - 6 – Red LED's
  - 1 – SPDT 0.1" Center Mini Slide Switch (Electronix Express #17SLDH251)

- **Procedure:**
  - Wire the circuit in the schematic below.
    - Measure the voltage drop across the battery and each LED. Record the results in Table 1.
    - In the conclusions, compare the total voltage drop of the LEDs with the battery.
    - Add another LED to the series and observe the results. Now add a sixth LED to the series and observe the results. What does this reveal about LEDs?
  - Photofabrication of the printed circuit board (PCB):
    - Using dry transfers, layout the circuit on a copper-clad PC board.

- Use the MG Chemical process guide to etch a presenitized copper-clad single sided circuit board:
  - MG Chemicals instructions for complete prototyping process website: http://www.mgchemicals.com/techsupport/photo_inst.html **Pay special attention to the warnings listed on this website.**
  - Use the Exposure Kit to expose the PC board for a minimum of 5 minutes, preferably 10 minutes.
  - Develop the board in one part developer to ten parts tepid water. Lightly brush the resist with a foam brush. Development should be completed within one to two minutes.
  - Immediately neutralize development action by rinsing the board with water.
  - Etch your board using the Etching Kit and the ferric chloride etchant. An ideal etching temperature is 50°C (120°F).
  - See illustrated process at: http://www.mgchemicals.com/techsupport/photo_demo.html

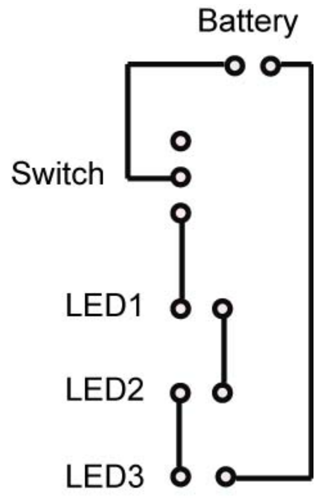
- **Results:**

Part	Voltage Drop	Source Voltage
LED1		
LED2		
LED3		
LED4		
Total:		
Battery		

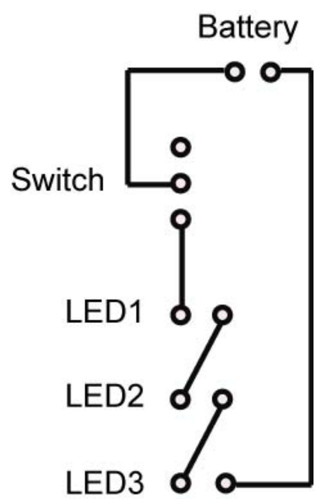
Table 1

- **Conclusions:**

- **Sample PCB Artwork Layouts:**



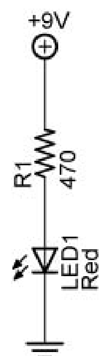
Layout 1



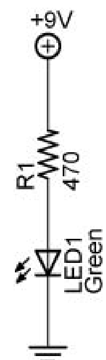
Layout 2

Electronics Technology and Robotics I Week 7
Lighting Lab 1 – LED Voltage Drops

- **Purpose:** The purpose of this lab is to have the students test a variety of different colored LEDs to see if color affects the voltage drop.
- **Apparatus and Materials:**
  - 1 – Breadboard with 9 V Battery
  - 2 – Digital Multimeters
  - 1 – 470 Ohm Resistor, Use the Same Resistor for Both Circuits
  - 1 – Red LED
  - 1 – Green LED
- **Procedure:**
  - Wire Circuits 1 and 2 as shown and measure and record the voltage drops across resistors and each LED sample.



Circuit 1



Circuit 2

- **Results:**

Voltage Drops					
Circuit	**LED Sample**	**Source Voltage**	**Voltage Drop Resistor in Volts**	**Voltage Drop LED in Volts**	**Voltage Drop Resistor + LED**
1	A				
(Red)	B				
	C				
	Ave.				
2	D				
(Green)	E				
	F				
	Ave.				

- **Conclusions:**

Electronics Technology and Robotics I Week 7
Lighting Lab 2 – Forward/Reverse Bias

- **Purpose:** The purpose of this lab is to acquaint the students with forward and reverse bias of LEDs.

- **Apparatus and Materials:**

    - 1 – Breadboard with 9 V Battery
    - 2 – Digital Multimeters
    - 1 – 470 Ohm Resistor
    - 1 – Red LED

- **Procedure:**
    - Wire Circuits 3 and 4
    - Record the results and write your conclusions

Circuit 3
Forward Biased

Circuit 4
Reversed Biased

- **Results:**

Circuit	Results
3	
4	

- **Conclusions:**

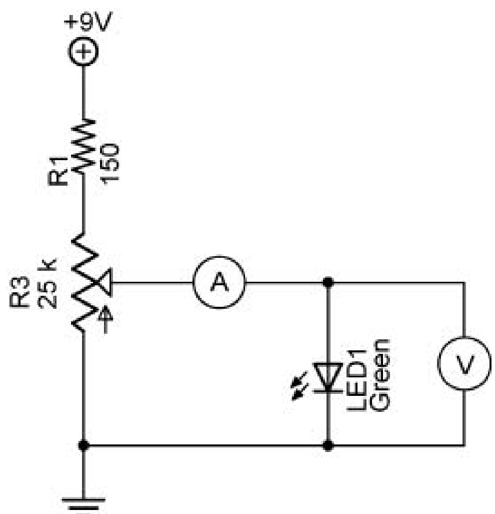
Electronics Technology and Robotics I Week 7
Lighting Lab 3 – Voltage/Current Curve

- **Purpose:** The purpose of this lab is to have the students plot a V-I characteristic curve for an LED.

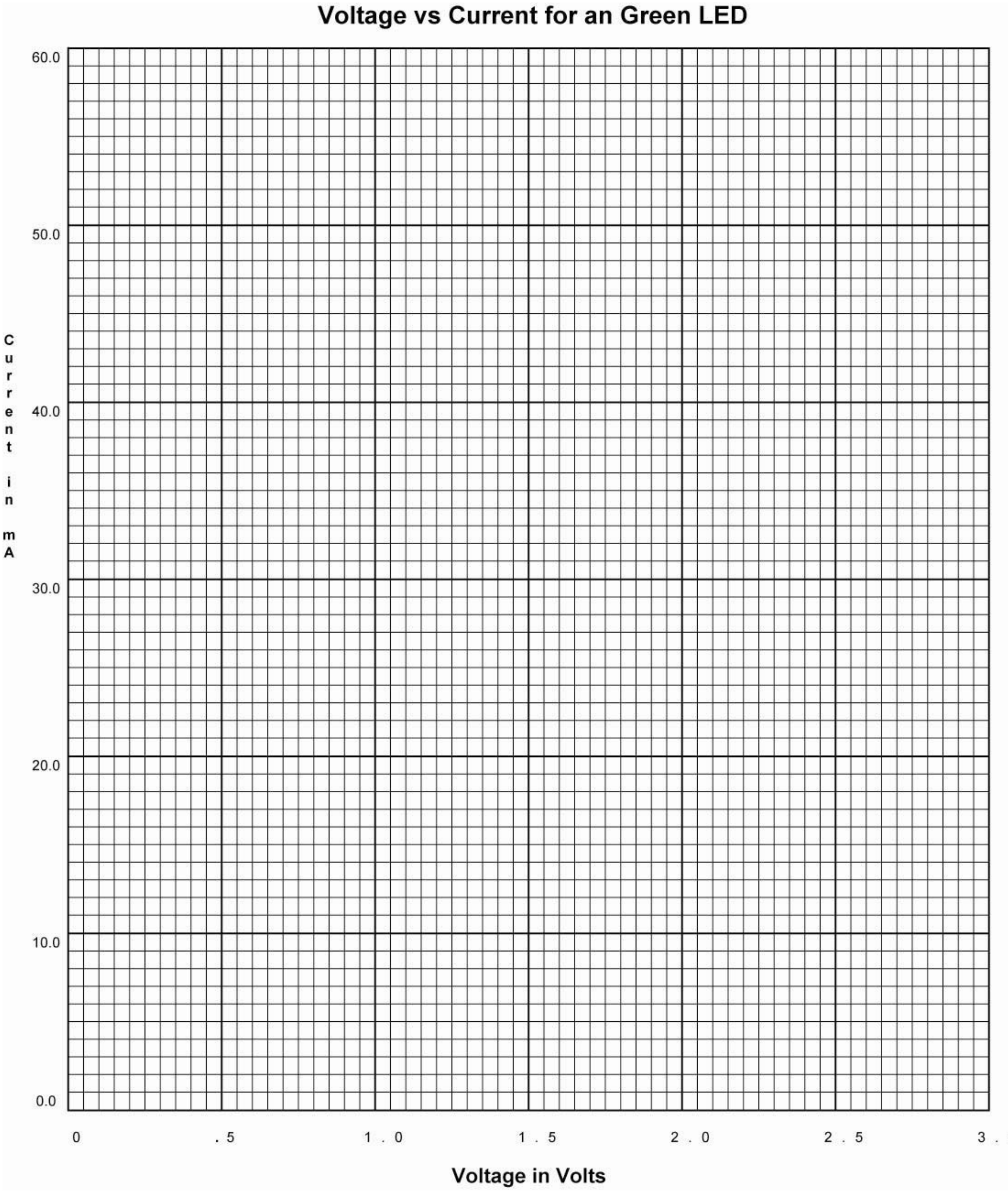
- **Apparatus and Materials:**

    - 1 – Breadboard with 9 V Supply
    - 2 – Digital Multimeters
    - 1 – 150 Ohm Resistor
    - 1 – 25K Tripot
    - 1 –Green LED

- **Procedure:**
    - Wire the following circuit
    - Vary the voltage from 0 to +2.5 volts. Plot the voltage vs. current curve using the attached graph.
    - Observe as the instructor reverse biases the LED to -30 volts.



- **Results:**



Voltage vs Current for an Green LED
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Current in mA
0
.5
1.0
1.5
2.0
2.5
3.0
Voltage in Volts

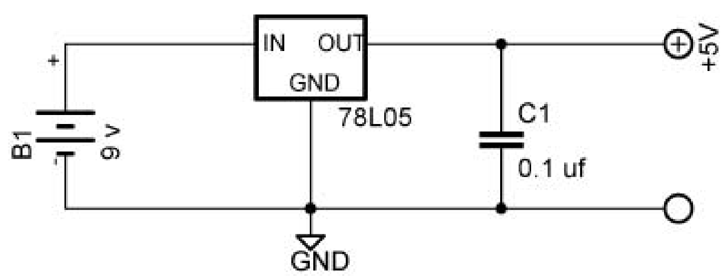
Electronics Technology and Robotics I Week 7
Lighting Lab 4 – Stroboscopic Circuit

- **Purpose:** The purpose of this lab is to have the students practice assembling practical circuits.

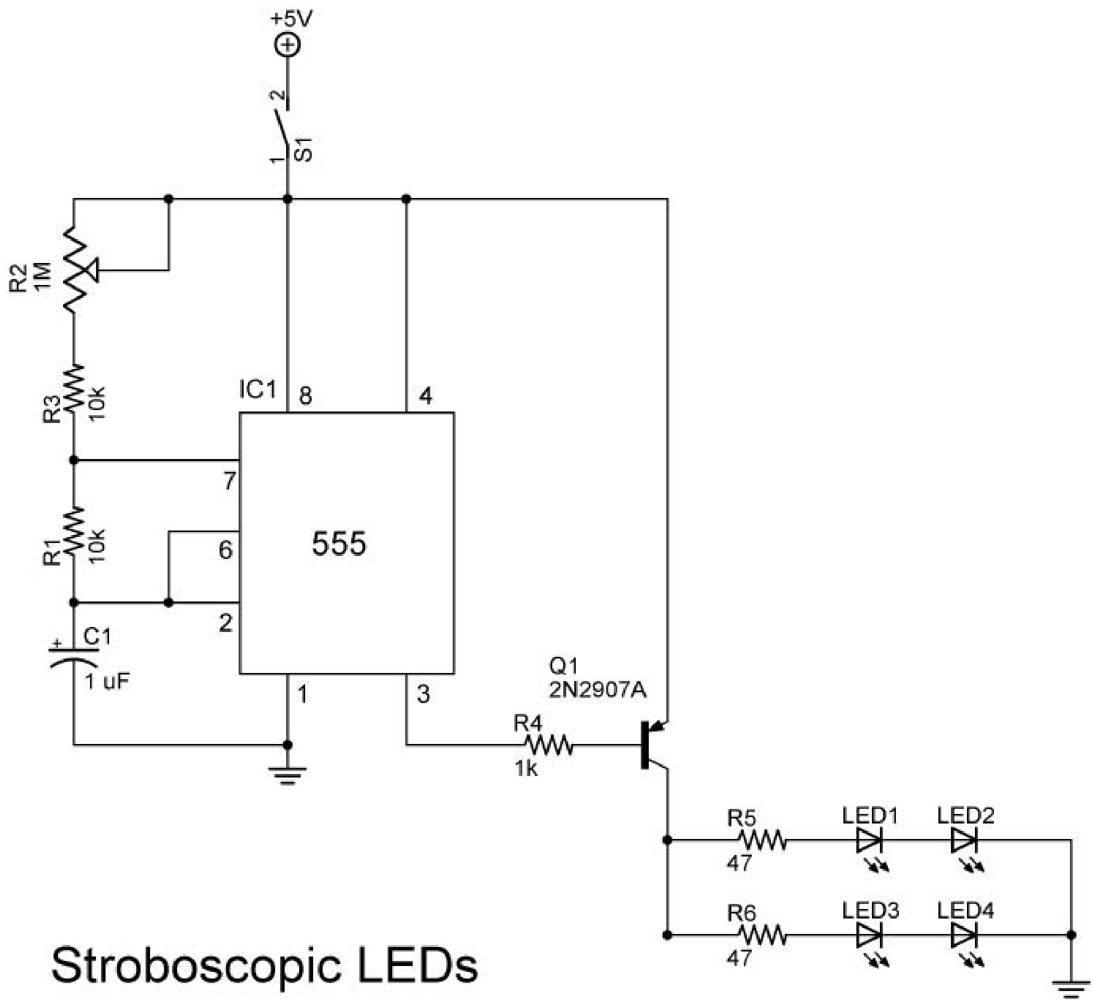
- **Apparatus and Materials:**

  - 1 – Breadboard with 9 V Supply
  - 1 – 78L05 Voltage Regulator
  - 1 – 0.1 μF Capacitor
  - 1 – 1 μF Capacitor
  - 2 – 10 K Ω Resistor
  - 1 – 1 K Ω Resistor
  - 2 – 47 Ω Resistor
  - 1 – 1 M Ω Tripot
  - 1 – 2N2907A PNP Transistor
  - 1 – 555 Timer
  - 2 –Green LEDs
  - 2 – Red LEDs

- **Procedure:**
  - Wire the following 5 volt regulator and stroboscopic LED circuits.
  - Adjust R_2 to change the timing of the stroboscope.
    - 5 Volt regulator circuit:



- Stroboscopic Circuit:



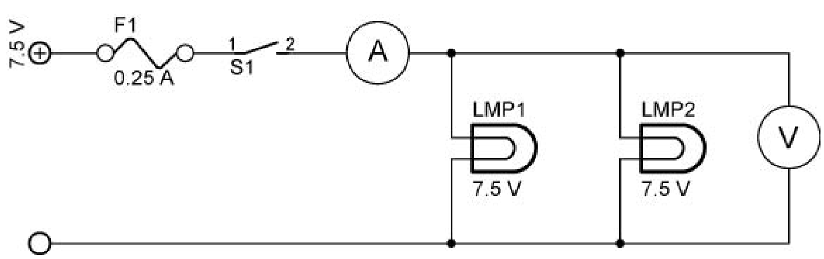
Electronics Technology and Robotics I Week 7
Switches, Connectors, Protection Devices Lab 1 – Fuses

- **Purpose:** The purpose of this lab is to acquaint the student with the function of a fuse.

- **Apparatus and Materials:**

    - 1 – DC Power Supply
    - 1 – 0.25 A Fuse (Radio Shack #270-1002)
    - 2 – 7.5 V Lamps
    - 2 – Lamp Holders
    - 2 – Digital Multimeters
    - 1 – Knife Switch
    - Alligator Leads

- **Procedure:**
    - Wire the circuit below using alligator leads.
    - Insert the Lamp 1 only and adjust the DC power supply to bring the lamp to the 7.5 V rating. Record the current reading when the lamp is at 7.5V.
    - Insert Lamp 2 lamp and adjust the DC power supply to bring both lamps to their 7.5 V rating. Watch the current readings as you increase the voltage.
    - If necessary, add a third lamp in parallel to "blow" the fuse.
    - Write your conclusions



- **Results:**

Lamps in Circuit	Current in A
Lamp 1 Only	
Lamp 1 + Lamp 2	
Lamp 1 + Lamp 2 + Lamp 3	

- **Conclusions:**

Electronics Technology and Robotics I Week 8
Resistor Lab 1 – Resistor Color Code

- **Purpose:** The purpose of this lab is to acquaint the student with the resistor color code and tolerance calculations.

- **Apparatus and Materials:**

  - 10 – Fixed Resistors Labeled 1 – 10

- **Procedure:**
  - Using the resistor color code, determine the value of 10 resistors and record the values in the table below.
  - Calculate the limits that are within tolerance
  - Measure the resistance of each resistor and compare with the coded value.

- **Results:**

Resistor	Coded Value	Product of Tolerance x Value	Upper Limit	Lower Limit	Measured Value
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

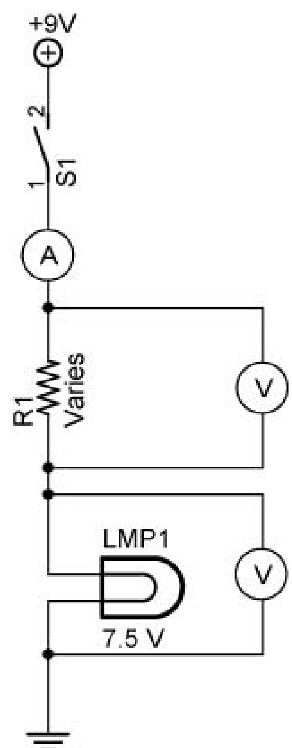
- **Conclusions:**
  - Are the measured values of each resistor within the tolerance limits?

Electronics Technology and Robotics I Week 8
Resistor Lab 2 – Resistors and Current

- **Purpose:** The purpose of this lab is to demonstrate to the student that resistors restrict current and that an increase in resistance increases the voltage drop across the resistor.

- **Apparatus and Materials:**
  - 1 – Breadboard with 9 V Supply
  - 3 – Digital Multimeters
  - 1 – 1, 10, 22, 47, 68, and 100 Ohm Resistor
  - 1 – 7.5 V Lamp with Lamp Base
  - 1 – SPDT Switch

- **Procedure:**
  - Assemble the circuit below on the breadboard using 1, 10, 22, 47, 68, and 100 ohm resistors as R1.
  - Measure the current for each change in resistor value.
  - Calculate the voltage drop across R1 using Ohm's law.
  - Now measure the voltage drop across R1 and the lamp.
  - Compare the calculated voltage drop across R1 with the measured value.
  - Add the measured voltage drops across R1 and the lamp to get the total measured voltage drop.
  - Compare the total measured voltage drop with the measured source.
  - Note the brightness variation in each case.



- **Results:**

Voltage Drops Lab 2						
Circuit	R1	Current	Calculate Voltage Drop R1	Measured Voltage Drop R1	Measured Voltage Drop LMP1	Total Measured Voltage Drop
1						
2						
3						
4						
5						
6						

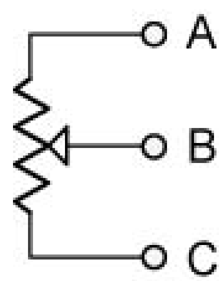
- **Conclusions:**
  - Is the calculated voltage drop across R1 close to the measured voltage drop across R1?
  - As the value of R1 is increased, what happens to the voltage drop across R1?
  - As the value of R1 is increased, what happens to the brightness of the lamp? Why?

Electronics Technology and Robotics I Week 8
Potentiometer Lab 1 – Potentiometers

- **Purpose:** The purpose of this lab is have the student read tripot values and to help the student understand the function of a potentiometer.

- **Apparatus and Materials:**
    - 7 – Tripots furnished by the instructor
    - 1 – Digital Multimeter
    - 1 – 5 K Ohm Potentiometer

- **Procedure:**
    - Read and record the labeled values of 7 tripots. Measure the resistance of each tripot using a DMM and record its value.
    - Testing potentiometers:
        - Test for maximum resistance of the potentiometer with a DMM, and compare with value printed on the side of the potentiometer.
        - Turn the potentiometer shaft and then flip the DMM leads. How does the maximum resistance value of the potentiometer react?
        - Using the DMM, measure and record the resistance R_{AB}, R_{BC}, and R_{AC} at three different positions of the potentiometer.



- **Results:**
    - Tripot Values:

Tripot	Printed Value	Measured Value
1		
2		
3		
4		
5		
6		
7		

- Testing potentiometers:

Potentiometer Test			
	Position 1 (Ohms)	**Position 2 (Ohms)**	**Position 3 (Ohms)**
R_{AB}			
R_{BC}			
R_{AC}			

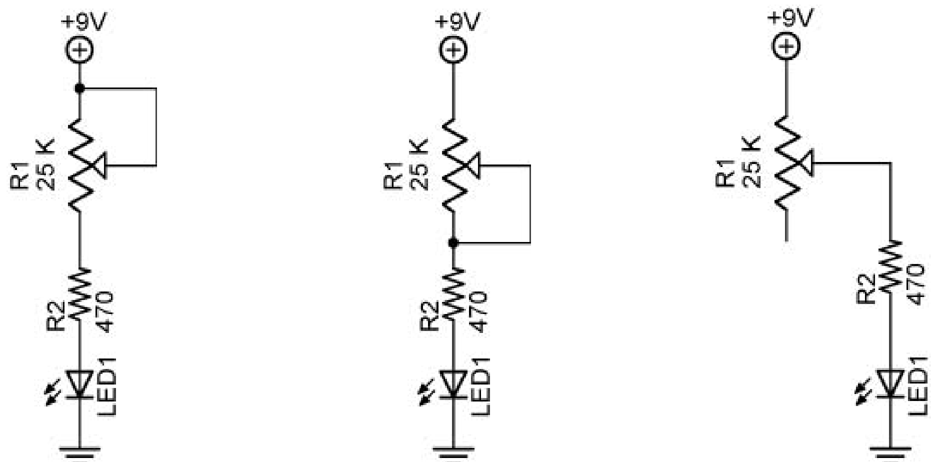
- **Conclusions:**
  - In the potentiometer test, how does R_{AC} relate to R_{AB} and R_{BC}?
  - Is R_{AC} consistent in the potentiometer test?

Electronics Technology and Robotics I Week 8
Potentiometer Lab 2 – Rheostats

- **Purpose:** The purpose of this lab is to help the student understand the function of a rheostat.

- **Apparatus and Materials:**
    - 1 – Breadboard with a 9 V Power Supply
    - 1 – 25 K Ohm Potentiometer
    - 1 – 470 Ohm Resistor
    - 1 - LED

- **Procedure:**
    - Variable brightness LED circuit:
        - Wire each circuit below, adjust R1, and compare the results.



Circuit 1 **Circuit 2** **Circuit 3**

- **Results:**

- **Conclusions:**
    - Does it matter which of the three circuits is used to control the LED?

    - What is the purpose of the 470 ohm resistor?

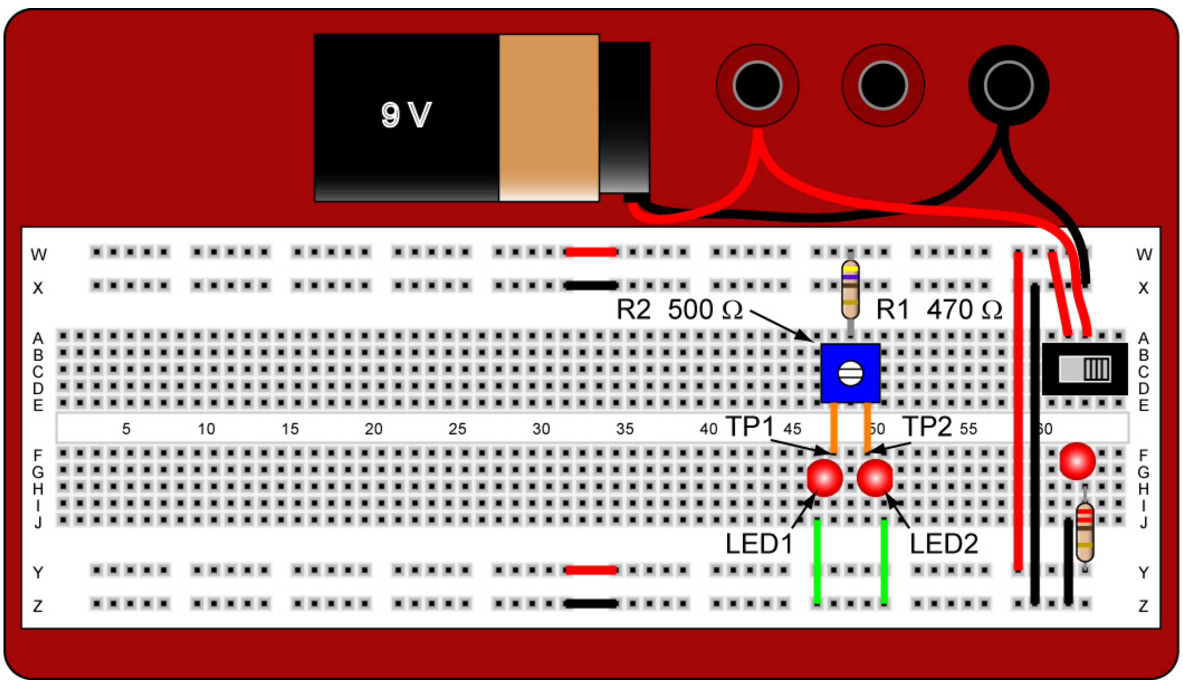
Electronics Technology and Robotics I Week 8
Potentiometer Lab 3 – Brightness Balancing Circuit

- **Purpose:** The purpose of this lab is to have the student begin wiring the control circuit for the robot Sandwich.

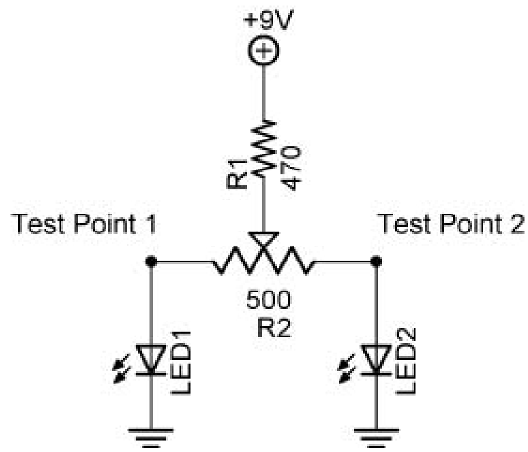
- **Apparatus and Materials:**

  - 1 – Breadboard with a 9 V Power Supply
  - 2 – DMMs
  - 1 – 500 Ohm Potentiometer
  - 1 – 470 Ohm Resistor
  - 2 - LEDs

- **Procedure:**
  - Wire the breadboard circuit below. Place the circuit on the breadboard as shown in the drawing.



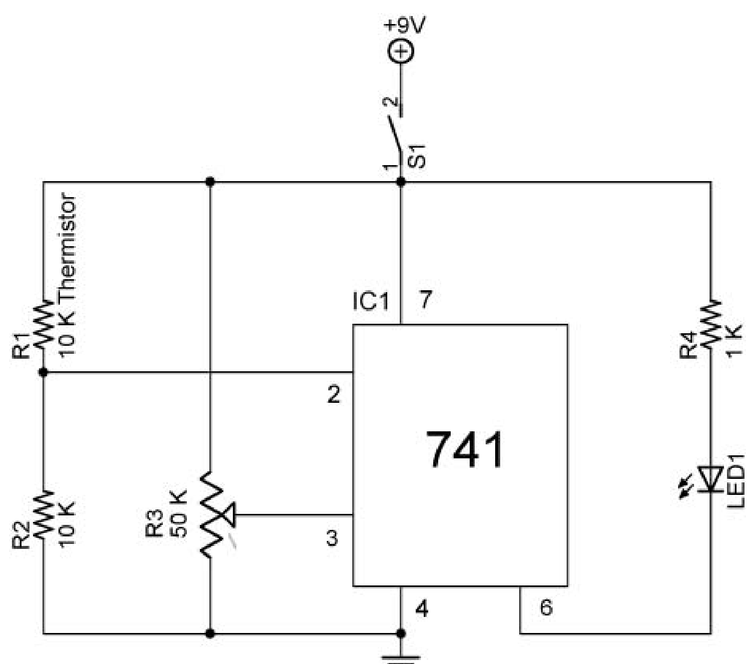
- o By measuring the voltages at Test Points 1 and 2, balance the voltage drops across LED1 and LED2.



Note: The test points will be used in future lessons.

Potentiometer Lab 4 – Thermistor

- **Purpose:** The purpose of this lab is to acquaint the student with the basic operation of a thermistor.
- **Apparatus and Materials:**
    - 1 – Lab Thermometer
    - 1 – Lab Beaker
    - 1 – DMM
    - 1 – Breadboard with a 9 V Power Supply
    - 1 – Switch
    - 1 – 10 K Ohm Thermistor
    - 1 – 10 K Ohm Resistor
    - 1 – 50 K Ohm Potentiometer
    - 1 – 1 K Ohm Resistor
    - 1 – 741 Op Amp Integrated Circuit
    - 1 - LED
- **Procedure:**
    - First, measure the resistance of the thermistor as it is taken from room temperature and placed in a beaker filled with ice water. Note the changes in resistance as it cools.
    - Now using a 10 K thermistor, wire the thermistor circuit found below.
    - At room temperature, adjust R3 until the LED turns off. Place the thermistor between your fingers to heat it up and to turn on the LED.
    - If the LED remains off, reverse the connections to pins 2 and 3 which will reverse the operation.



Thermistor Used in an Op Amp Comparator Circuit

Electronics Technology and Robotics I Week 9
Energy Lab 1 – Power Comparison

- **Purpose:** The purpose of this lab is to acquaint the student with the principles of work and power through competition.

- **Apparatus and Materials:**

  - 1 – 40 Pound Weight
  - 1 – Stop Watch
  - 1 – Tape Measure

- **Procedure:**
  - Measure the distance the students and instructor lift the 40 pound weight.
  - Count the number of lifts each makes in 1 minute.
  - Calculate the power in ft-lbs/min
  - Convert ft-lbs/min to ft-lbs/sec
  - Convert ft-lbs/sec to hp

- **Results:**

Power Comparison			
	Student 1	Student 2	Instructor
Force (lbs)	40 lbs	40 lbs	40 lbs
Distance/Lift (ft)	ft	ft	ft
Lifts/min			
Work (ft-lbs)			
Power (ft-lbs/min)			
Power (ft-lbs/sec)			
Power (hp)			

- **Conclusions:**

Electronics Technology and Robotics I Week 9
Energy Lab 2 – Functions of Gears

- **Purpose:** The purpose of this lab is to acquaint the student with the 5 ways gears can transfer power.

- **Apparatus and Materials:**

    - An assortment of Lego gears, shafts, connectors, and other parts

- **Procedure:**
    - Each student must make a working model illustrating each of the gear functions:
        - Increase/decrease rotational speed with a corresponding decrease/increase in torque.
        - Change the direction of rotation
        - Change the angle of rotation
        - Convert rotational motion to linear motion
        - Change the location of rotation
    - Have the instructor check off each completed task.
    - Build a combination of gears with a 25:1 gear ratio.

- **Results:**

Task	Completed
Increase/decrease rotational speed	
Change the direction of rotation	
Change the angle of rotation	
Convert rotational motion to linear motion	
Change the location of rotation	

Electronics Technology and Robotics I Week 9
Conversions Lab 1 – Conversion Problems

- **Purpose:** The purpose of this lab is to practice making conversions in class.
- **Apparatus and Materials:**
    - 1 – Pencil
- **Procedure:** Solve the following conversions.

1. 540 min = ? sec
2. 0.1 hr = ? sec
3. 20 ft/min = ? mph
4. 10 in/sec = ? mph
5. 60 mph = ? ft/sec
6. 5 mph = ? in/min
7. 16 watts = ? hp
8. 60 watts = ? ft-lbs/sec

1 minute = 60 seconds
1 hour = 60 minutes
1 foot = 12 inches
1 mile = 5280 feet.
1 horsepower = 746 watts
1 hp = 550 ft-lbs/second

Electronics Technology and Robotics I Week 10
Sources of Electricity Lab 1 – Hand Battery

- **Purpose:** The purpose of this lab is to acquaint the student with the fact that the human body can generate an electrical potential.

- **Apparatus and Materials:**

  - 1 – Digital Multimeter
  - 2 – 5" x 6" Single Sided Copper Clad Circuit Board (Electronix Express # 97BS16)
  - 2 – Aluminum Plate the Size of a Palm
  - Alligator Clips

- **Procedure:**
  - Your skin and two different metals create a battery.
  - Connect an aluminum and a copper plate to the DMM set to 2 volt range. Connect the positive lead to the copper plate.
  - Place one hand on each plate and read the meter.
  - When you touch the two metal plates, the thin film of sweat on your hands acts like the acid in a battery, reacting with the copper plate and with the aluminum plate. In one of these reactions, your hand takes negatively charged electrons away from the copper plate, leaving positive charges behind. In the other reaction, your hand gives electrons to the aluminum plate, causing it to become negatively charged. This difference in charge between the two plates creates a flow of electrical charge, or electrical current.
  - Try using the same type of metal for each plate. Place one hand on each plate and read the meter.
  - You can sometimes get a small current even between two plates made of the same metal. Each plate has a slightly different coating of oxides, salts, and oils on its surface. These coatings create slight differences in the surfaces of the metals, and these differences can produce an electrical current.

- **Results:**
  - Copper/aluminum maximum voltage generated: ______________ V

  - Copper/copper maximum voltage generated: ______________ V

  - Aluminum/aluminum maximum voltage generated: ______________ V

- **Conclusions:**

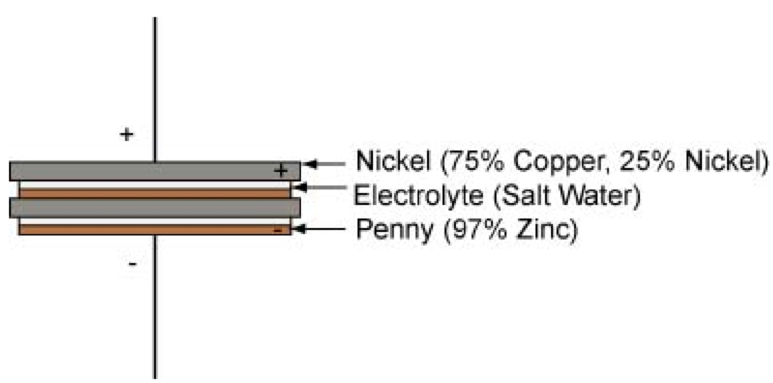
Electronics Technology and Robotics I Week 10
Sources of Electricity Lab 2 – Primary Cells

- **Purpose:** The purpose of this lab is to acquaint the student with several common household items that can produce an electrical potential.

- **Apparatus and Materials:**

    - 1 – Digital Multimeter
    - 1 – Potato
    - 1 – #16 hot-dipped galvanized nail
    - 1 – # 6 bare copper wire
    - 1 – LED
    - 1 – Lemon
    - Several Pennies, Nickels, and Dimes
    - Salt Water Solution
    - Paper Towels
    - 1 – Lasco Dry Cell Kit

- **Procedure:**
    - Construct several voltaic cells that convert chemical energy into electrical energy:
        - Potato: Insert a #16 hot-dipped galvanized nail and a # 6 bare copper wire into the potato. Measure and record the voltage across the electrodes.
        - Lemon/grapefruit: Insert a #16 hot-dipped galvanized nail and a # 6 bare copper wire into the lemon. Measure and record the voltage across the electrodes.
        - Create a voltaic pile using coins and paper towels. Mix salt with water (as much salt as the water will hold) and soak the paper towel in this brine. Then create a voltaic cell by stacking a nickel, paper towel, and penny in the order as shown below. Measure the voltage across the cell. Try a second layer and measure the voltage the pile produces. Then try making a cell using a nickel and dime and measure the voltage.



Voltaic Pile

- Dry cell
  - Assemble a dry cell using Lasco dry cell kit and instructions.
  - A dry cell is a cell with a pasty electrolyte. A wet cell, on the other hand, is a cell with a liquid electrolyte.

- **Results:**
  - Potato (one) voltage: ______________________ V
  - Lemon/grapefruit voltage: ______________________ V
  - Voltaic pile (nickels and pennies) voltage:

Nickel/Penny Voltaic Pile	
# Layers	**Voltage**
1	
2	

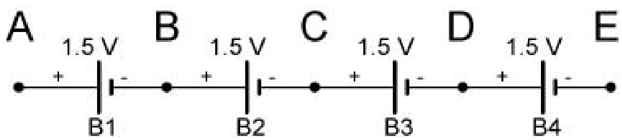
  - Voltaic pile (nickels and dimes) voltage: _______________________ V
  - Dry cell voltage: _____________________ V

Electronics Technology and Robotics I Week 10
Sources of Electricity Lab 3 – Series and Parallel Batteries

- **Purpose:** The purpose of this lab is to acquaint the student with how voltages add when placed in series and parallel.

- **Apparatus and Materials:**
    - 1 – Digital Multimeter
    - 4 – AA Batteries and Battery Holders
    - TBD – Potatoes
    - TBD – #16 hot-dipped galvanized nail
    - TBD – # 6 bare copper wire
    - 1 – LED
    - Alligator Leads

- **Procedure for Series Batteries:**
    - Connect the four AA batteries as shown in the schematic.



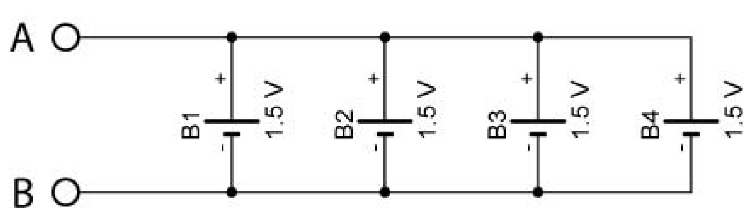
Batteries in Series

- Measure and record the voltages V_{AB}, V_{BC}, V_{CD}, and V_{DE}.
- Calculate the voltages V_{AC}, V_{AD}, and V_{AE} then measure and record the same voltages.
- Compare the calculated and measured results in the conclusions.

- **Results for Series Batteries:**

Individual Voltage	Measured	Added Voltage	Calculated	Measured
V_{AB}		V_{AB}	-	
V_{BC}		V_{AC}		
V_{CD}		V_{AD}		
V_{DE}		V_{AE}		

- **Procedure for Parallel Batteries:**
    - Connect the four AA batteries as shown in the schematic and measure V_{AB}.



- Remove one battery at a time and measure and record V_{AB}.

- **Results for Parallel Batteries:**

V_{AB} Measured	Batteries Connected
	B1, B2, B3, B4
	B1, B2, B3
	B1, B2
	B1

- **Procedure for Parallel and Series Batteries:**
  - Take a potato and insert a #16 hot-dipped galvanized nail and a # 6 bare copper wire to create a “potato cell”.
  - Experiment to find a combination of potato cells in series and parallel that provides enough voltage and current to light an LED.

- **Results for Parallel and Series Batteries:**
  - Draw the schematic of the battery layout used to light the LED.

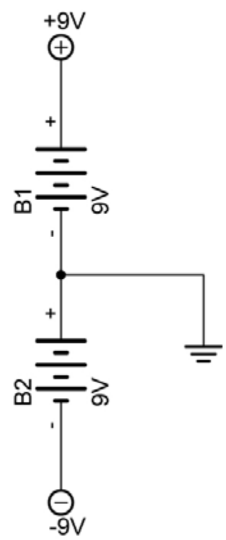
- **Conclusions:**
  - Batteries in Series:
    - Compare the calculated and measured results in the batteries in series experiment.
    - Do the experimental results conform to the formula for batteries in series?
  - Batteries in Parallel:
    - Do the experimental results conform to the formula for batteries in parallel?

Electronics Technology and Robotics I Week 10
Sources of Electricity Lab 4 – Dual Polarity Power Supply

- **Purpose:** The purpose is to acquaint the student with a power supply that furnishes both positive and negative voltages, a dual polarity power supply.

- **Apparatus and Materials:**
    - 2 - 9 V Batteries
    - 2 – 9 V Battery Snaps
    - 1 - Digital Multi-Meter
    - 1 – Alligator Clip Test Lead

- **Procedure:**
    - Use the battery arrangement below to supply +9V and -9V. Connect batteries together using one alligator clip test lead.
    - Use the DMM to verify voltage values shown below. Attach the black common DMM lead to ground for both measurements.



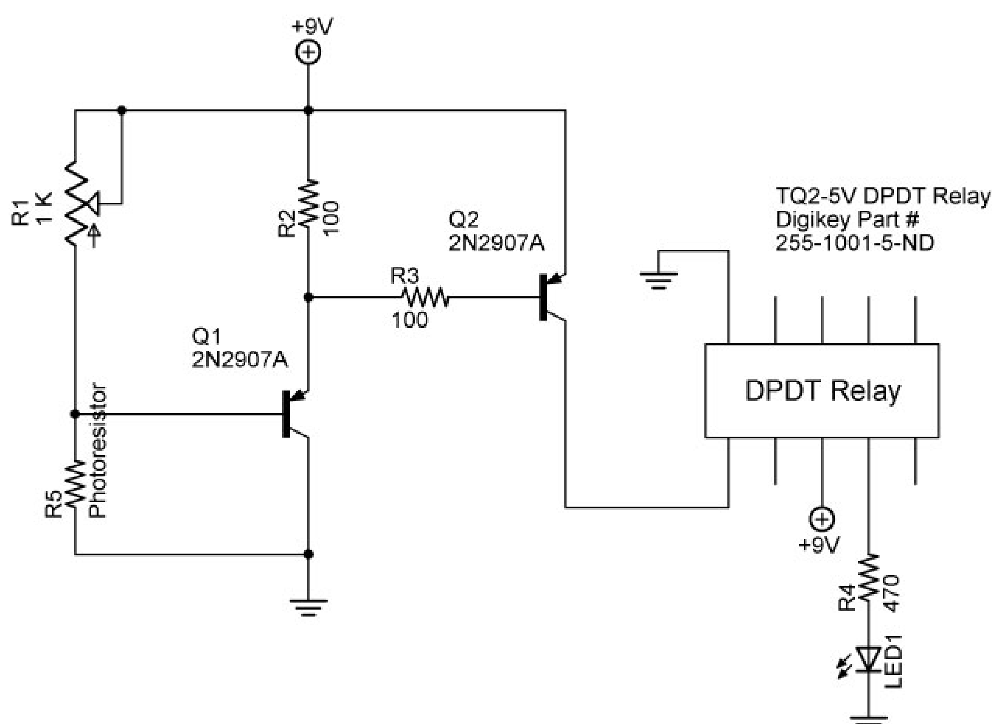
- **Notes:**
    - This power supply circuit could be used in the audio amplifier circuit in LAB 4.

Electronics Technology and Robotics I Week 11
Other Sources and Photoresistors Lab 1 – Photoresistors

- **Purpose:** The purpose of this lab is to acquaint the student with:
  - Photoresistor and how their resistance varies at different light levels and
  - A practical application for a photoresistor

- **Apparatus and Materials:**
  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – Digital Multimeter
  - 3 – Cds photocells
  - 1 – 1 K Tripot
  - 2 – 100 Ohm Resistors
  - 1 – 470 Ohm Resistor
  - 2 – 2N2907A PNP Transistors
  - 1 – LED
  - 1 – DPDT Relay (Digikey # 255-1001-5-ND)

- **Procedure:**
  - Using the DMM, measure and record the maximum and minimum resistances for 3 photoresistors.
  - Wire the following photoresistor control circuit using a photoresistor as the sensor:



- Using a photoresistor, design a light controlled circuit to vary the brightness of an LED. Wire the circuit on your breadboard and draw the schematic in the results. Remember, 9 volts applied directly to an LED will burn it out.

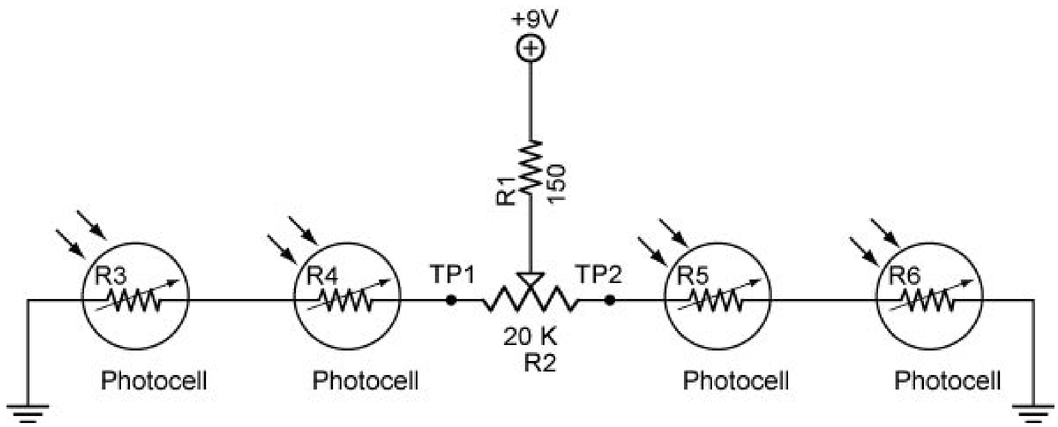
- **Results:**
  - Cds Photocell Resistances:

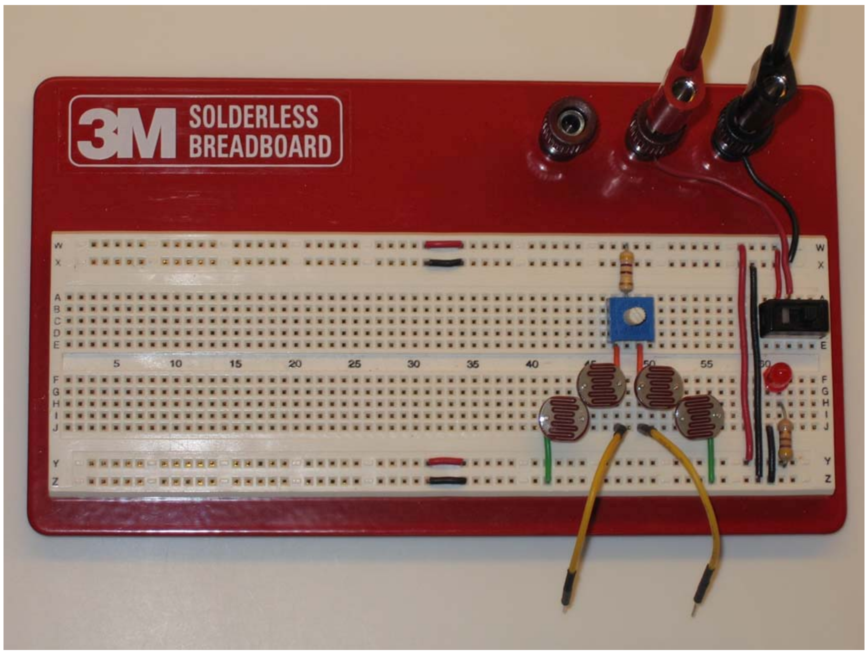
Cds Photocell	Minimum Resistance	Maximum Resistance
1		
2		
3		

  - Schematic of Variable Brightness LED Circuit:

Electronics Technology and Robotics I Week 11
Other Sources and Photoresistors Lab 2 – Balanced Brightness Circuit

- **Purpose:** The purpose of this lab is to acquaint the student with
- **Apparatus and Materials:**
    - 1 – Solderless Breadboard with 9 V Power Supply
    - 1 – Digital Multimeter
- **Procedure:**
    - Photoresistors are aligned in pairs so it can detect a wider area than a single photoresistor.
    - Build the following balanced brightness-sensing circuit that will be used as the sensing circuit for Sandwich, the line following robot.





Balanced Brightness Circuit Schematic and Layout

- Measure the voltages at Test Points 1 and 2.
- Using ambient lighting, adjust R_2 to equalize the voltages at Test Points 1 and 2.
- Now take a flashlight and shine it over each pair of photocells and measure the voltage differential between Test Points 1 and 2. Shield the other pair of photocells from the flashlight.
- The variation of the voltage at the test points will be critical for Sandwich to follow a line.

- **Results:**

Condition	Voltage at Test Point 1	Voltage at Test Point 2	Difference
Equal lighting on photocells			
Bright light on R_3 and R_4			
Bright light on R_5 and R_6			

- **Conclusions:**
  - What is the purpose of the 470 ohm resistor?

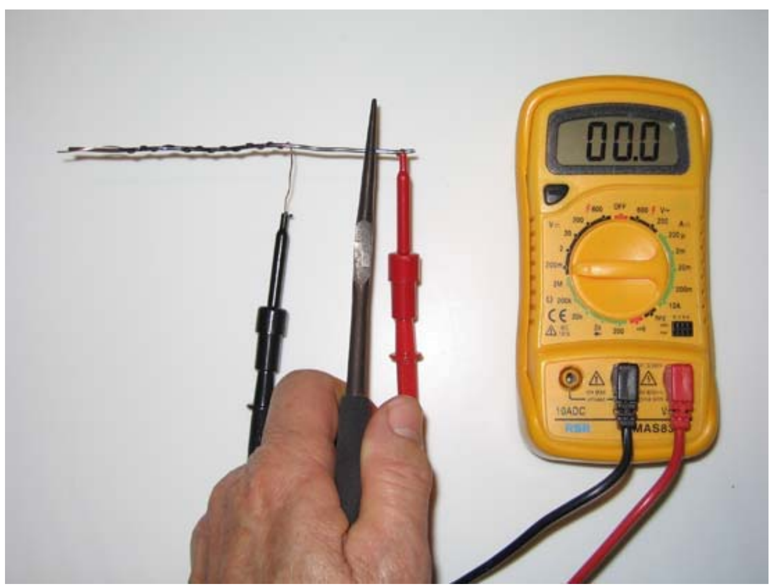
Electronics Technology and Robotics I Week 11
Other Sources and Photoresistors Lab 3 – Thermocouples

- **Purpose:** The purpose of this lab is to acquaint the student with the basic construction of a thermocouple.

- **Apparatus and Materials:**

  - 1 – Digital Multimeter
  - 1 – Piece of Copper Wire
  - 1 – Piece of Steel Wire
  - 1 – Pair of Pliers
  - 1 – Match or Gas Lighter

- **Procedure:**
  - Twist the copper and steel wires together.
  - Connect the multimeter leads to the two twisted wires. Hold the steel wire as shown to protect the positive multimeter lead.
  - Measure and record the voltage before heat is applied.
  - Apply the flame to the far end of the twisted wires to protect the negative multimeter lead. Record the voltage output of this thermocouple as heat is applied and after cool down.



- **Results:**

Condition	Voltage
Before Heat	
Heat Applied	
After Cool Down	

Electronics Technology and Robotics I Week 12
Series Circuits Lab 1 – Series Resistors

- **Purpose:** The purpose of this lab is to verify, by experiment, the formula for total resistance for resistors in series.
- **Apparatus and Materials:**
    - 1 – Solderless Breadboard with 9 V Supply
    - 1 – Digital Multimeter
    - 1 – 220 Ohm Resistor
    - 1 – 330 Ohm Resistor
    - 1 – 470 Ohm Resistor
    - 1 – 1 K Ohm Resistor
    - 1 – 2.2 K Ohm Resistor
- **Procedure:**
    - Total Resistance of Series Resistors Using Ohm Meter:
        - Wire the series resistor network in Figure 1.
        - Measure the resistance of each resistor and record.
        - Add the individual resistances to determine the total resistance of the network.
        - Check the formula $R_T = R_1 + R_2 + R_3 + R_4 + R_5$.
        - Now measure the total resistance of the resistor network and record.

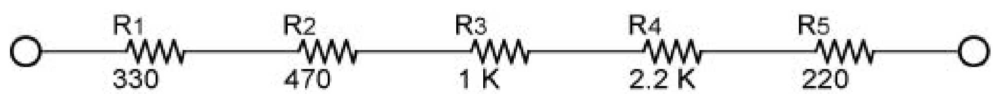


Figure 1

- Total Resistance of Series Resistors Using Ohm's Law:
    - Connect a 9 V battery to the resistor network as shown in Figure 2.

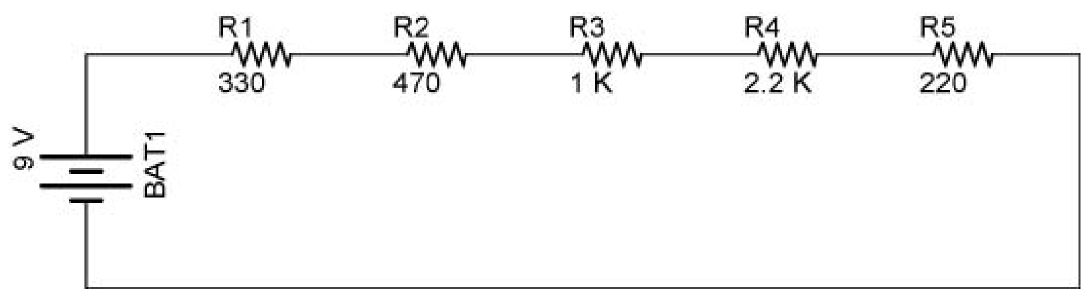


Figure 2

- Measure the source voltage V_T and the current I_T through the series resistor network.
- Knowing V_T and I_T, calculate the total resistance R_T using Ohm's Law.

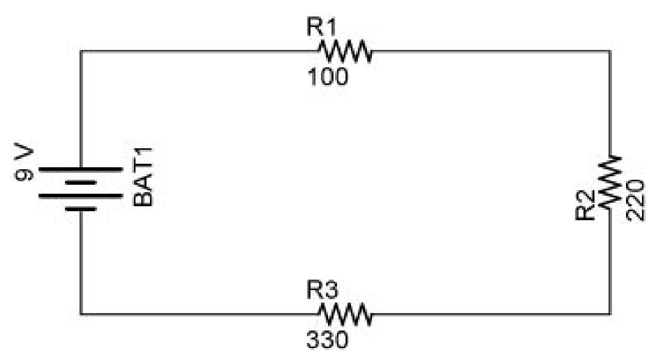
- **Results:**

Resistor	Resistors Nominal Value (Ω)	Resistors Measured Value (Ω)	Total Resistance Measured	Total Resistance Ohm's Law
R1	R1 = 220 Ω			
R2	R2 = 330 Ω			
R3	R3 = 470 Ω			
R4	R4 = 1K Ω			
R5	R5 = 2.2K Ω	______		
	R_T = 4,220	R_T =	R_T =	R_T =

- **Conclusions:**
  - Do the four values of R_T equal one another? Explain any discrepancies.
  - If a 1 M Ohm resistor is in series with a 100 Ohm resistor, which resistor affects the total resistance more?

Electronics Technology and Robotics I Week 12
Series Circuits Lab 2 – Kirchhoff's Voltage Law

- **Purpose:** The purpose of this lab is to experimentally verify Kirchhoff's Voltage Law for a series resistor circuit.
- **Apparatus and Materials:**
  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – Digital Multimeter
  - 1 – 100 Ohm Resistor
  - 1 – 220 Ohm Resistor
  - 1 – 330 Ohm Resistor
- **Procedure:**
  - Wire the following series circuit and measure the voltage drop across each resistor.
  - Compare the sum of the voltage drops with the voltage source:



- **Results:**

	Voltage
V_1	
V_2	
V_3	______
$V_1 + V_2 + V_3$	
V_{SOURCE}	

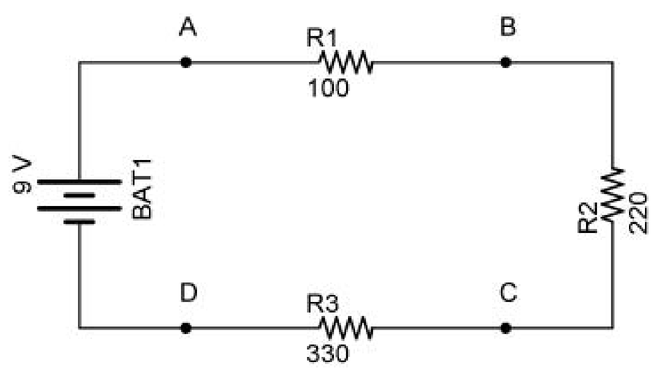
- **Conclusions:**
  - Does $V_{SOURCE} = V_1+V_2+V_3$?
  - Or put another way, does $V_{SOURCE} - V_1 - V_2 - V_3 = 0$? Explain any discrepancies.

Electronics Technology and Robotics I Week 12
Series Circuits Lab 3 – Current in Series Circuits

- **Purpose:** The purpose of this lab is to verify, by experiment, the formula for total current for resistors in series.

- **Apparatus and Materials:**
    - 1 – Solderless Breadboard with 9 V Power Supply
    - 1 – Digital Multimeter
    - 1 – 100 Ohm Resistor
    - 1 – 220 Ohm Resistor
    - 1 – 330 Ohm Resistor

- **Procedure:**
    - Using the same circuit from Lab 2, measure and record the current at each Point A - D.



- **Results:**

	Current (mA)
I_A	
I_B	
I_C	
I_D	

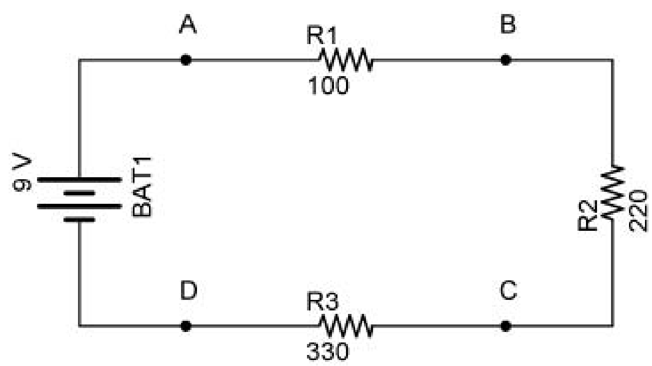
- **Conclusions:**
    - How do the 4 current readings relate to one another?

Electronics Technology and Robotics I Week 12
Series Circuits Lab 4 – Power in Series Circuits

- **Purpose:** The purpose of this lab is to verify, by experiment, that the total power consumed in series circuit is equal to the sum of the power consumed by each resistor.

- **Apparatus and Materials:**
    - 1 – Solderless Breadboard with 9 V Power Supply
    - 1 – Digital Multimeter
    - 1 – 100 Ohm Resistor
    - 1 – 220 Ohm Resistor
    - 1 – 330 Ohm Resistor

- **Procedure:**
    - Calculate the power for each resistor and then the total power consumed for the following circuit:



- **Results:**

Resistor	Voltage (V)	Current (A)	Power (W)
R1 = 100 Ω	V1 =	I1 =	P1 =
R2 = 220 Ω	V2 =	I2 =	P2 =
R3 = 330 Ω	V3 =	I3 =	P3 =
			$P_1 + P_2 + P_{3} =$
	$V_{T} =$	$I_{T} =$	$P_{T} =$

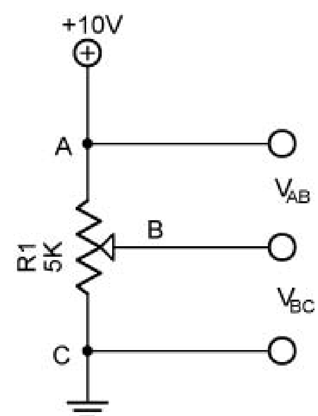
- **Conclusions:**

Electronics Technology and Robotics I Week 12
Series Circuits Lab 5 – Voltage Dividers

- **Purpose:** The purpose of this lab is to verify, by experiment, that t

- **Apparatus and Materials:**
    - 1 – Solderless Breadboard with 10 V Power Supply
    - 2 – Digital Multimeters
    - 1 – 5 K Ohm Potentiometer
    - Several 1 K Ohm Resistors

- **Procedure:**
    - Using 1 k resistors, design and build a voltage divider on your breadboard that will divide your source voltage (10 V) into 10 V, 7.5 V, 5 V, and 2.5 V. Calculate the voltage with respect to ground at each resistor connection. Then measure and record the voltage with respect to ground at each resistor connection.
    - Potentiometers can be used as voltage dividers. Wire the circuit below then measure and record the voltmeter readings V_{AB} and V_{BC} as you adjust the potentiometer. Take 3 readings.



- **Results:**
    - Voltage Divider with 1 K Resistors:

Point	Calculated Voltage	Measured Voltage
A		
B		
C		
D		

- Potentiometer as a Voltage Divider:

	Reading 1	Reading 2	Reading 3
V_{AB}			
V_{BC}	______	______	______
Total			

- **Conclusions:**
  - In the voltage divider using 1 K resistors, explain any discrepancies between the calculated and measured voltages.
  - In the potentiometer experiment, are the sums of V_{AB} + V_{BC} nearly consistent?
  - Do the sums of V_{AB} + V_{BC} nearly equal the source voltage (10 V). Explain any discrepancies.

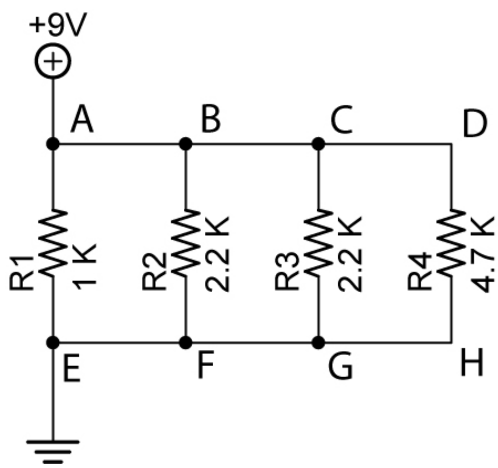
Electronics Technology and Robotics I Week 13
Parallel Circuits Lab 1 – Voltage Drop in a Parallel Circuit

- **Purpose:** The purpose of this lab is to experimentally verify that the voltage drops across parallel resistors are equal.

- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – Digital Multimeter
  - 1 – 1 K Ohm Resistor
  - 2 – 2.2 K Ohm Resistors
  - 1 – 4.7 K Ohm Resistor

- **Procedure:**
  - Wire the following circuit
  - Measure and record V_{AE}, V_{BF}, V_{CG}, and V_{DH}.



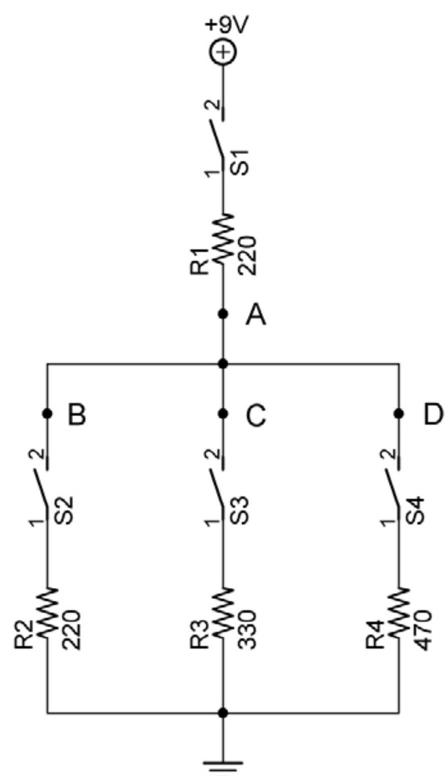
- **Results:**

Points	Voltage Drop
A - E	
B - F	
C - G	
D - H	

- **Conclusions:**
  - How do the voltage drops V_{AE}, V_{BF}, V_{CG}, and V_{DH} relate to each other?

Electronics Technology and Robotics I Week 13
Parallel Circuits Lab 2 – Kirchhoff's Current Law

- **Purpose:** The purpose of this lab is to experimentally verify Kirchhoff's Current Law.
- **Apparatus and Materials:**
  - 1 – Solderless Breadboard with 9 V Power Supply
  - 4 – Digital Multimeters
  - 4 - Switches
  - 2 – 220 Ohm Resistors
  - 1 – 330 Ohm Resistor
  - 1 – 470 Ohm Resistor
- **Procedure:**
  - In the following circuit, simultaneously measure the current at points A, B, C, and D. With all switches closed, see if $I_A = I_B + I_C + I_D$. Record the results. Measure and record the currents of the other combinations in the table using open and closed switches.
  - Verify Kirchhoff's Current Law for each case.



Note how the current through R_1 changes as resistors R_2, R_3, and R_4 are added or removed from the circuit.

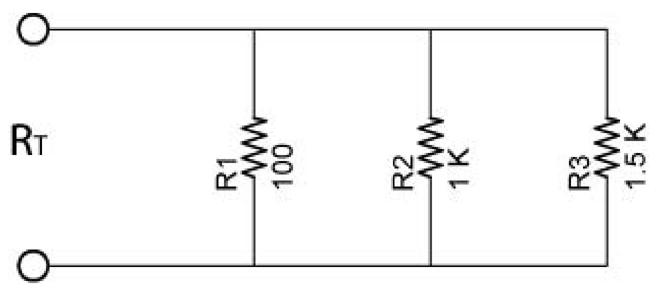
- **Results:**

Current In	Currents Out			Total of Currents Out
I_A (mA)	I_B (mA)	I_C (mA)	I_D (mA)	Total (mA)
				$I_B + I_C + I_D =$
				$I_B + I_C =$
				$I_B + I_D =$
				$I_C + I_D =$
				$I_B =$
				$I_C =$
				$I_D =$

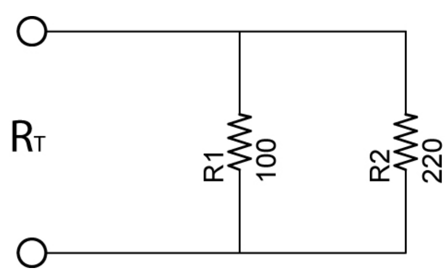
- **Conclusions:**
  - Does the experiment verify Kirchhoff's Current Law? Explain.

Electronics Technology and Robotics I Week 13
Parallel Circuits Lab 3 – Total Resistance in a Parallel Circuit

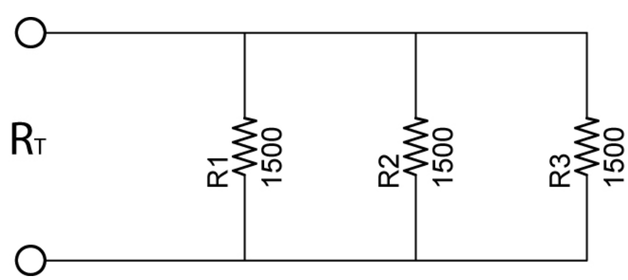
- **Purpose:** The purpose of this lab is to experimentally verify the reciprocal rule for total resistance of a parallel circuit.
- **Apparatus and Materials:**
  - 1 – Solderless Breadboard
  - 1 – Digital Multimeter
  - 1 – 100 Ohm Resistors
  - 1 – 220 Ohm Resistors
  - 3 – 1500 Ohm Resistor
- **Procedure:**
  - Resistors in Parallel:
    - Wire the following circuit below then calculate and measure/record R_T.



  - Two Parallel Resistors:
    - Wire the following circuit below then calculate and measure/record R_T.



  - Equal Resistors:
    - Wire the following circuit below then calculate and measure/record R_T.



- **Results:**
  - Resistors in Parallel:

R_T Calculated	R_T Measured

  - Two Parallel Resistors:

R_T Calculated	R_T Measured

  - Equal Resistors:

R_T Calculated	R_T Measured

- **Conclusions:** In each case, evaluate how well the R_T calculated matched the R_T measured. Explain any discrepancies.

  - Resistors in Parallel:

$$1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \ldots\ldots\ldots.. + 1/R_N$$

  - Two Parallel Resistors:

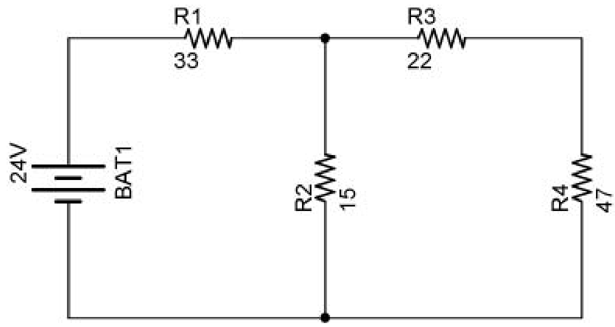
$$R_T = R_1R_2/R_1+R_2$$

  - Equal Resistors:

$$R_T = R/N$$

Electronics Technology and Robotics I Week 14
Combination Circuits Lab 1 – Problem 1

- Example Problem 1:
  - Solve for all of the unknowns in the following circuit. Fill in each unknown in the table below the circuit.



	Resistance	Voltage	Current	Power
R1	R1 = 33 Ω			
R2	R2 = 15 Ω			
R3	R3 = 22 Ω			
R4	R4 = 47 Ω			
Total		V_T = 24 V		

- Remember, to solve **series circuit** problems, you can use any or all of the following equations:

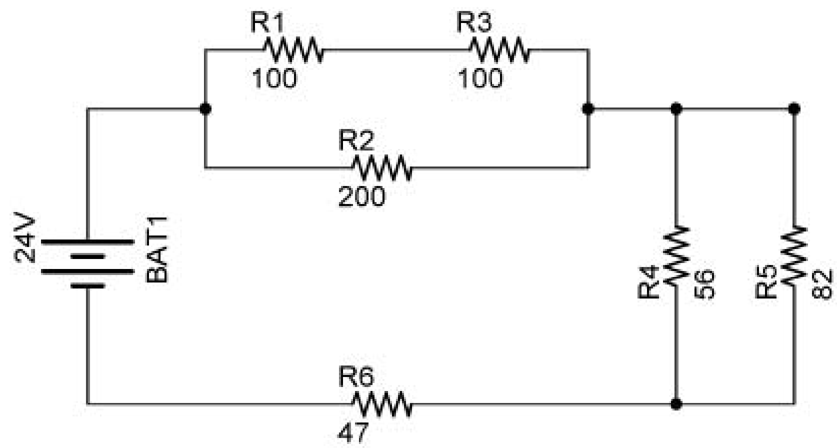
$$R_T = R_1 + R_2 + R_3 + \ldots + R_N$$
$$V_T = V_1 + V_2 + V_3 + \ldots + V_N$$
$$I_T = I_1 = I_2 = I_3 = \ldots I_N$$
$$V = I \times R$$

- Remember, to solve **parallel circuit** problems, you can use any or all of the following equations:

$$1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \ldots\ldots\ldots\ldots + 1/R_N$$
$$V_T = V_1 = V_2 = V_3 = \ldots\ldots V_N$$
$$I_T = I_1 + I_2 + I_3 + \ldots + I_N$$
$$V = I \times R$$

Electronics Technology and Robotics I Week 14
Combination Circuits Lab 1 – Problem 2

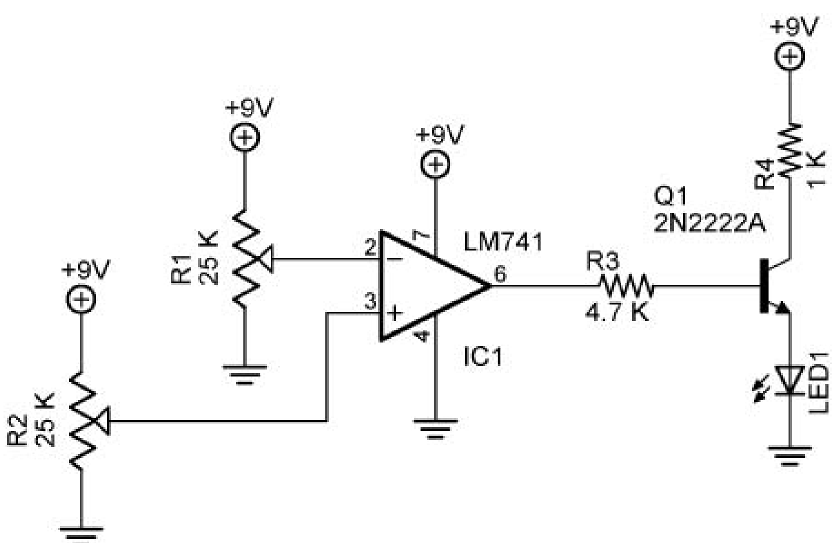
- Example Problem 2:
  - Solve for all of the unknowns in the following circuit. Fill in each unknown in the table below the circuit.



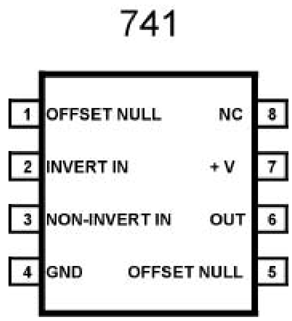
	Resistance	Voltage	Current	Power
R1	R1 = 100 Ω			
R2	R2 = 200 Ω			
R3	R3 = 100 Ω			
R4	R4 = 56 Ω			
R5	R4 = 82 Ω			
R6	R4 = 47 Ω			
Total		V_T = 24 V		

Electronics Technology and Robotics I Week 15
Voltage Comparators Lab 1 – 741 Comparator

- **Purpose:** The purpose of this lab is to test the 741 IC as a comparator.
- **Apparatus and Materials:**
  - 1 – Solderless Breadboard with 9 V Power Supply
  - 3 – Digital Multimeters
  - 1 – 741 Op Amp
  - 2 – 25 K Potentiometers
  - 1 – 4.7 K Ohm Resistor
  - 1 – 1 K Ohm Resistor
  - 1 – 2N2222A NPN Transistor
  - 1 – LED
- **Procedure:**
  - Build Circuit 1 and use three multimeters to measure V_{REF}, V_{IN}, and V_{OUT}.
  - Non-inverting Operation:
    - In the first test, let pin 2 be the reference voltage (V_{REF}). Adjust R_1 to set pin 2 to about 4.5 V.
    - Adjust R_2 so the voltage input (V_{IN}) into pin 3 varies from 0 to 9V. If V_{IN} is less than V_{REF} is the LED on or off? Measure V_{OUT}. If V_{IN} is more than V_{REF} is the LED on or off? Measure V_{OUT}. Record your results.
    - At what voltage does the LED change state? Record your results.
  - Inverting Operation:
    - In the second test, let pin 3 be the reference voltage (V_{REF}). Adjust R_2 to set pin 3 to approximately 4.5 V.
    - Adjust R_1 so the voltage input (V_{IN}) into pin 2 varies from 0 to 9V. Make the same observations and measurements as in the first test.



Circuit 1



741 Pin Layout or Pinout

Results:

- o Test 1:
  - Pin 2 reference voltage (V_{REF}): __________V
  - Pin 3 (V_{IN}) less than V_{REF}: LED on or off V_{OUT} = __________ V
  - Pin 3 (V_{IN}) more than V_{REF}: LED on or off V_{OUT} = __________ V
  - V_{IN} where the LED changes state? __________V
- o Test 2:
  - Pin 3 reference voltage (V_{REF}): __________V
  - Pin 2 (V_{IN}) less than V_{REF}: LED on or off V_{OUT} = __________ V
  - Pin 2 (V_{IN}) more than V_{REF}: LED on or off V_{OUT} = __________ V
  - V_{IN} where the LED changes state? __________V

- **Conclusions:**
  - o How do the results from Test 1 differ from the results of Test 2?

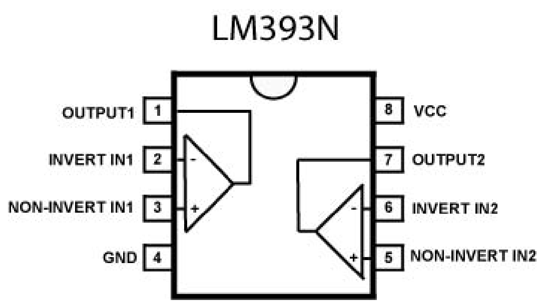
Electronics Technology and Robotics I Week 15
Voltage Comparators Lab 2 – LM393N Comparator

- **Purpose:** The purpose of this lab is to acquaint the student with the LM393N comparator and its inverting and non-inverting modes.

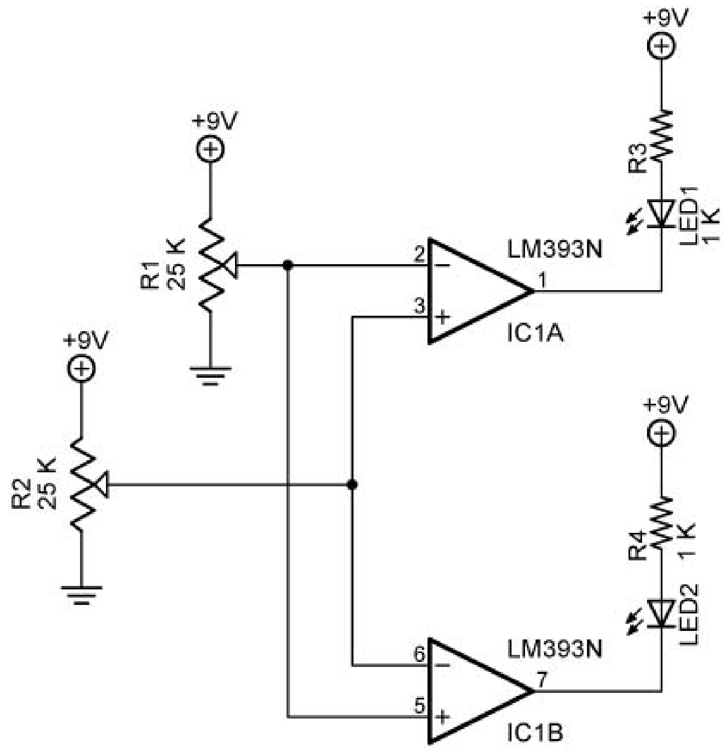
- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9 V Power Supply
  - 2 – Digital Multimeters
  - 1 – LM393N Comparator
  - 2 – 25 K Potentiometers
  - 2 – 1 K Resistors
  - 2 – LEDs

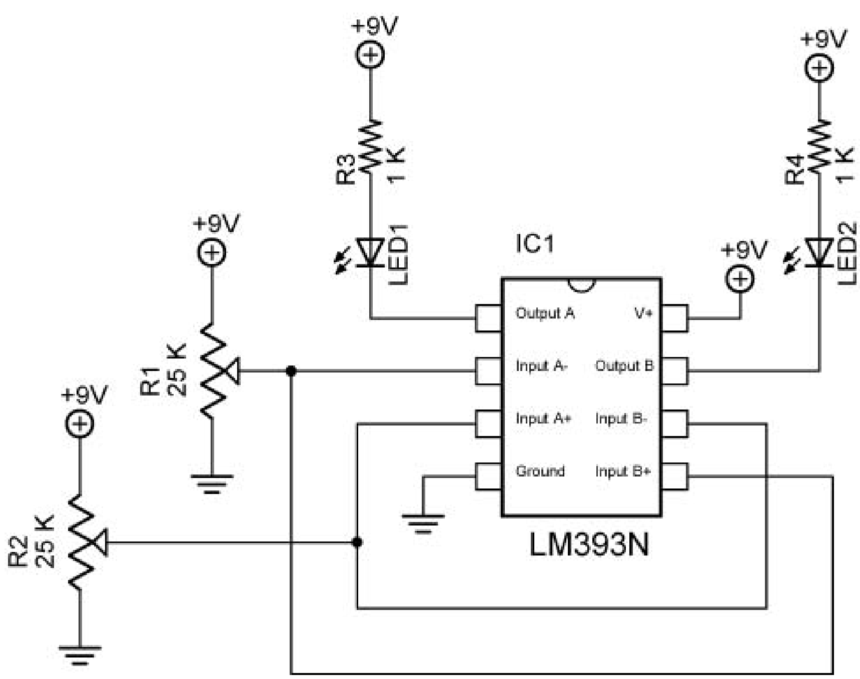
- **Procedure:**
  - Build Circuit 2. Wiring Diagram 1 may assist in the assembly of the circuit.
  - In this test, let pins 2 and 5 be the reference voltage (V_{REF}). Adjust R_1 to set pins 2 and 5 to about 4.5 V.
  - Adjust R_2 so that the voltage input (V_{IN}) into pins 3 and 6 varies from 0 to 9V. If V_{IN} is less than V_{REF} are the LEDs on or off? If V_{IN} is more than V_{REF} are the LEDs on or off? Record your results.
  - At what voltage does the LED change state? Record your results.
  - LM393N Pin Layout:



  - Always use the IC extractor when removing ICs.



Circuit 2



Wiring Diagram 1

- **Results:**
  - Pins 2 and 5 reference voltage (V_{REF}): __________V
  - Pins 3 and 6 (V_{IN}) less than V_{REF}: LED1 on or off   LED2 on or off
  - Pins 3 and 6 (V_{IN}) more than V_{REF}: LED1 on or off   LED2 on or off
  - V_{IN} where the LED changes state? __________V
- **Conclusions:**
  - If Pin 2 of IC1A is set for non-inverting mode, what mode is IC1B in?

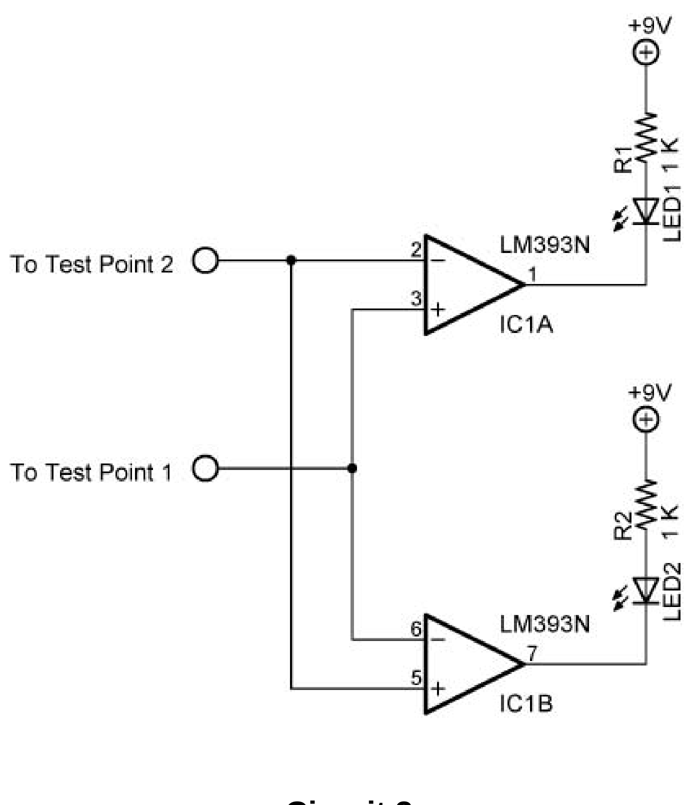
Electronics Technology and Robotics I Week 15
Voltage Comparators Lab 3 – Brightness Comparison Circuit

- **Purpose:** The purpose of this lab is to acquaint the student with the LM393N comparator and its inverting and non-inverting modes.

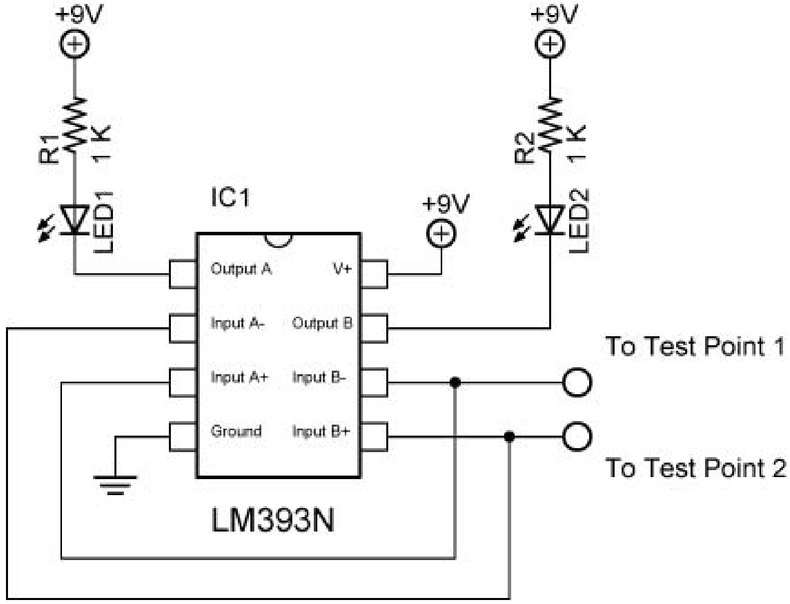
- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – LM393N Comparator
  - 2 – 25 K Potentiometers
  - 2 – 1 K Resistors
  - 2 – 470 Resistors
  - 2 – LEDs (Regular)
  - 2 – LEDs (Bright White)

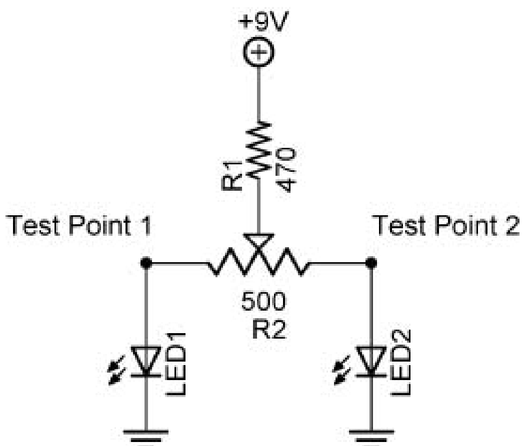
- **Procedure:**
  - Build Circuit 3. Wiring Diagram 2 is available to assist in the assembly of the circuit.
  - The test points 1 and 2 are connected to the brightness circuit from Week 8. Refer to Circuit 4 for connections.
  - Move your hand over the photoresistors in the brightness circuit and observe the LED output of the LM393N IC.



Circuit 3

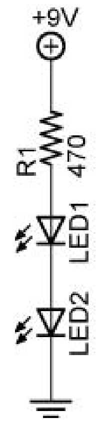


Wiring Diagram 2



Circuit 4 (from Week 8)

- The Headlight Circuit:
  - Wire the schematic Circuit 5 using the bright white LEDs.



Circuit 5

- **Conclusions:**
  - Sandwich will compare the voltages at Test Points 1 and 2 when following a black electrical tape line. Which side of the Sandwich will the motors 1 and 2 be connected to the have it follow the line?

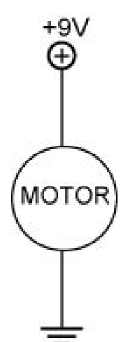
Electronics Technology and Robotics I Week 16
Diodes and Transistor Switches Lab 1 – LM393N Current Limitations

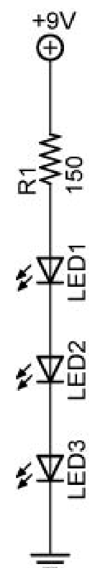
- **Purpose:** The purpose of this lab is to acquaint the student with the current limitations of the LM393 voltage comparator.

- **Apparatus and Materials:**

    - 1 – Solderless Breadboard with 9 V Power Supply
    - 1 – Digital Multimeter
    - 1 – Gearhead Motor, HNGH12-1324Y-R
    - 1 – 150 Ohm Resistor
    - 3 – Yellow LEDs
    - 3 – Green LEDs

- **Procedure:**
    - Sandwich current requirements:
        - Measure and record the maximum current used by the gearhead motor in Sandwich. Use a DMM that saves the maximum current value. See schematic below.
        - Measure and record the current to power three series yellow and then three green LED's.
        - Total the maximum currents of the components.





    - Review the attached data sheet for the LM393 comparator. Note the typical Output Sink Current value. Record and determine the difference.

- **Results:**

Part	Maximum Current (mA)
2 Gearhead Motors	
3 Yellow LEDs	
3 Green LEDs	+ ________________
Total Current Required by Sandwich	
Typical Output Sink Current of LM393	- ________________
Difference	

- **Conclusions:**
    - Does the LM393 provide sufficient current output to handle the load requirements of Sandwich?

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 Vdc, $T_{low} \le T_A \le T_{high}$,* unless otherwise noted.)

Characteristic	Symbol	LM393A Min	LM393A Typ	LM393A Max	Unit
Output Leakage Current	I_{OL}				µA
V_{in-} = 0 V, $V_{in+} \ge$ 1.0 Vdc, V_O = 5.0 Vdc, T_A= 25°C		–	0.1	–	
V_{in-} = 0 V, $V_{in+} \ge$ 1.0 Vdc, V_O = 30 Vdc, $T_{low} \le T_A \le T_{high}$		–	–	1.0	
Supply Current	I_{CC}				mA
$R_L = \infty$ Both Comparators, T_A = 25°C		–	0.4	1.0	
$R_L = \infty$ Both Comparators, V_{CC} = 30 V		–	1.0	2.5	

ELECTRICAL CHARACTERISTICS (V_{CC} = 5.0 Vdc, $T_{low} \le T_A \le T_{high}$, unless otherwise noted.)

Characteristic	Symbol	LM392, LM393 Min	LM392, LM393 Typ	LM392, LM393 Max	LM2903, LM2903V Min	LM2903, LM2903V Typ	LM2903, LM2903V Max	Unit
Input Offset Voltage (Note 2)	V_{IO}							mV
T_A = 25°C		–	±1.0	±5.0	–	±2.0	±7.0	
$T_{low} \le T_A \le T_{high}$		–	–	9.0	–	9.0	15	
Input Offset Current	I_{IO}							nA
T_A = 25°C		–	±5.0	±50	–	±5.0	±50	
$T_{low} \le T_A \le T_{high}$		–	–	±150	–	±50	±200	
Input Bias Current (Note 3)	I_{IB}							nA
T_A = 25°C		–	25	250	–	25	250	
$T_{low} \le T_A \le T_{high}$		–	–	400	–	200	500	
Input Common Mode Voltage Range (Note 3)	V_{ICR}							V
T_A = 25°C		0	–	V_{CC} –1.5	0	–	V_{CC} –1.5	
$T_{low} \le T_A \le T_{high}$		0	–	V_{CC} –2.0	0	–	V_{CC} –2.0	
Voltage Gain $R_L \ge$ 15 kΩ, V_{CC} = 15 Vdc, T_A = 25°C	A_{VOL}	50	200	–	25	200	–	V/mV
Large Signal Response Time V_{in} = TTL Logic Swing, V_{ref} = 1.4 Vdc V_{RL} = 5.0 Vdc, R_L = 5.1 kΩ, T_A = 25°C	–	–	300	–	–	300	–	ns
Response Time (Note 5) V_{RL} = 5.0 Vdc, R_L = 5.1 kΩ, T_A = 25°C	t_{TLH}	–	1.3	–	–	1.5	–	µs
Input Differential Voltage (Note 6) All $V_{in} \ge$ Gnd or V– Supply (if used)	V_{ID}	–	–	V_{CC}	–	–	V_{CC}	V
Output Sink Current $V_{in} \ge$ 1.0 Vdc, V_{in+} = 0 Vdc, $V_O \le$ 1.5 Vdc T_A = 25°C	I_{Sink}	**6.0**	**16**	–	6.0	16	–	**mA**
Output Saturation Voltage	V_{OL}							mV
$V_{in} \ge$ 1.0 Vdc, V_{in+} = 0, $I_{Sink} \le$ 4.0 mA, T_A = 25°C		–	150	400	–	–	400	
$T_{low} \le T_A \le T_{high}$		–	–	700	–	200	700	
Output Leakage Current	I_{OL}							nA
V_{in-} = 0 V, $V_{in+} \ge$ 1.0 Vdc, V_O = 5.0 Vdc, T_A = 25°C		–	0.1	–	–	0.1	–	
V_{in-} = 0 V, $V_{in+} \ge$ 1.0 Vdc, V_O = 30 Vdc, $T_{low} \le T_A \le T_{high}$		–	–	1000	–	–	1000	
Supply Current	I_{CC}							mA
$R_L = \infty$ Both Comparators, T_A = 25°C		–	0.4	1.0	–	0.4	1.0	
$R_L = \infty$ Both Comparators, V_{CC} = 30 V		–	–	2.5	–	–	2.5	

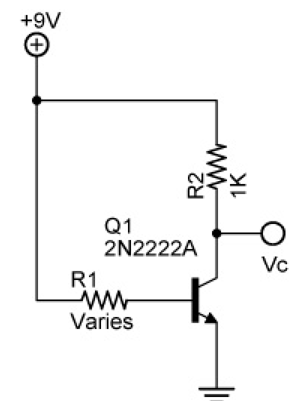
*T_{low} = 0°C, T_{high} = +70°C for LM393/393A
LM293 T_{low} = –25°C, T_{high} = +85°C
LM2903 T_{low} = –40°C, T_{high} = +105°C
LM2903V T_{low} = –40°C, T_{high} = +125°C

NOTES: 2. At output switch point, $V_O \simeq$ 1.4 Vdc, R_S = 0 Ω with V_{CC} from 5.0 Vdc to 30 Vdc, and over the full input common mode range (0 V to V_{CC} = –1.5 V).
3. Due to the PNP transistor inputs, bias current will flow out of the inputs. This current is essentially constant, independent of the output state, there fore, no loading changes will exist on the input lines.
5. Response time is specified with a 100 mV step and 5.0 mV of overdrive. With larger magnitudes of overdrive faster response times are obtainable.
6. The comparator will exhibit proper output state if one of the inputs becomes greater than V_{CC}, the other input must remain within the common mode range. The low input state must not be less than –0.3 V of ground or minus supply.

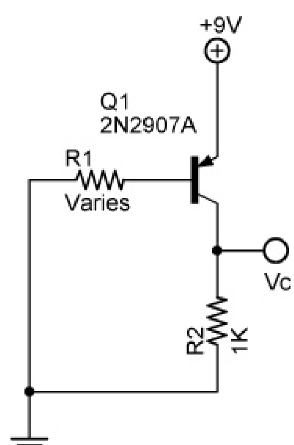
Electronics Technology and Robotics I Week 16

Diodes and Transistor Switches Lab 2 – Testing 2N2222A NPN and 2N2907A PNP Transistors

- **Purpose:** The purpose of this lab is to measure important variables for the operation of a 2N2222A NPN and 2N2907A PNP transistors.
- **Apparatus and Materials:**
  - 1 – Solderless Breadboard with 9 V Power Supply
  - 3 – Digital Multimeters
  - 1 – 2N2222A NPN Transistor
  - 1 – 10M, 1M, 820K, 680K, 560K, 470K, 390K, 330K, 270K, 220K, 180K, 150K, 120K, 100K, 47K, 33K, 10K, 3.3K, and 1K Resistors
- **Procedure:**
  - Build the 2N2222A NPN transistor test circuit below.
  - Insert the 10M resistor for R1 (the base resistor).
  - Measure the current into the transistor's base and collector and also measure the voltage at the collector with respect to ground. Record your results.
  - Substitute all of the other resistors for R1 and repeat the current and voltage measurements. Record your results.
  - Calculate and record the β for each trial resistor.



  - Repeat the above procedure for the 2N2907A PNP transistor.



- **Results:**
  - o 2N2222A NPN Transistor:

R_1	I_B	I_C	V_C	β
(Ω)	(mA)	(mA)	(V)	
10M				
1M				
820K				
680K				
560K				
470K				
390K				
330K				
270K				
220K				
180K				
150K				
120K				
100K				
47K				
33K				
10K				
3.3K				
1.0K				

- 2N2907A PNP Transistor:

R_1 (Ω)	I_B (mA)	I_C (mA)	V_C (V)	β
10M				
1M				
820K				
680K				
560K				
470K				
390K				
330K				
270K				
220K				
180K				
150K				
120K				
100K				
47K				
33K				
10K				
3.3K				
1.0K				

- **Conclusion:**
  - Does a very small current to the base control a larger current that flows through the collector/emitter leads?
  - What range of values does the amplification □ remain relatively constant?
  - At what value of resistor do you think the transistor acts as a switch?

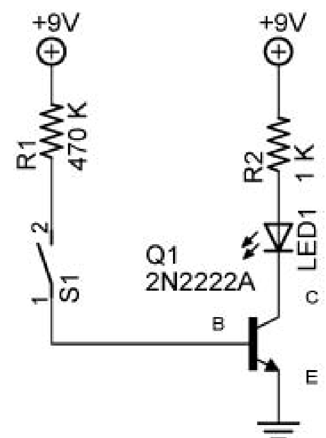
Electronics Technology and Robotics I Week 16
Diodes and Transistor Switches Lab 3 – NPN and PNP Transistor Load Placement

- **Purpose:** The purpose of this lab is to demonstrate placement of the load in a NPN and PNP transistor switch.

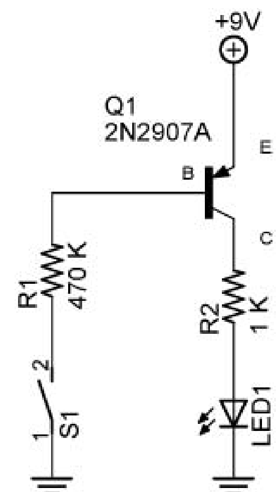
- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with 9 V Power Supply
  - 2 – Digital Multimeters
  - 1 – 2N2907A PNP Transistor
  - 1 – 2N2222A NPN Transistor
  - 1 – SPST Switch
  - 1 – 470 K Resistor
  - 1 – 1 K Resistor
  - 1 – LED

- **Procedure:**
  - Build these NPN and PNP transistor test circuits. Note the placement of the loads (the resistor R2 and the LED).



NPN Transistor Switch



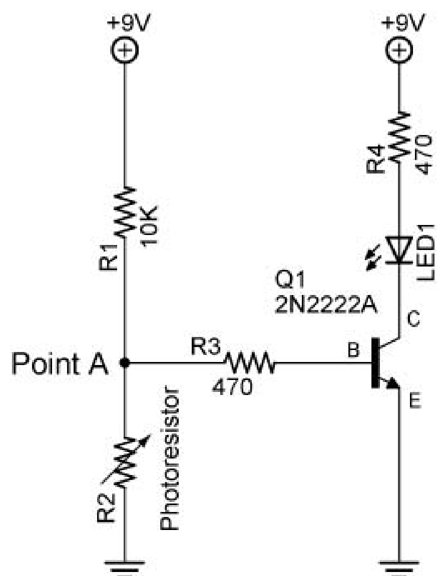
PNP Transistor Switch

Electronics Technology and Robotics I Week 16
Diodes and Transistor Switches Lab 4 – NPN Switch Circuit Application

- **Purpose:** The purpose of this lab is to demonstrate a practical use of a transistor switch.

- **Apparatus and Materials:**
    - 1 – Solderless Breadboard with 9 V Power Supply
    - 1 – Digital Multimeter
    - 1 – 2N2222A NPN Transistor
    - 1 – 10 K Resistor
    - 1 – Photoresistor
    - 2 – 470 Ohm Resistor
    - 1 – LED

- **Procedure:**
    - Wire the following circuit on a breadboard.
    - Vary the amount of light entering the photoresistor using a flashlight.
    - Measure and record the highest and lowest voltage readings at Point A, V_A, with respect to ground.
    - Also measure and record the voltage at Point A when the LED just lights.

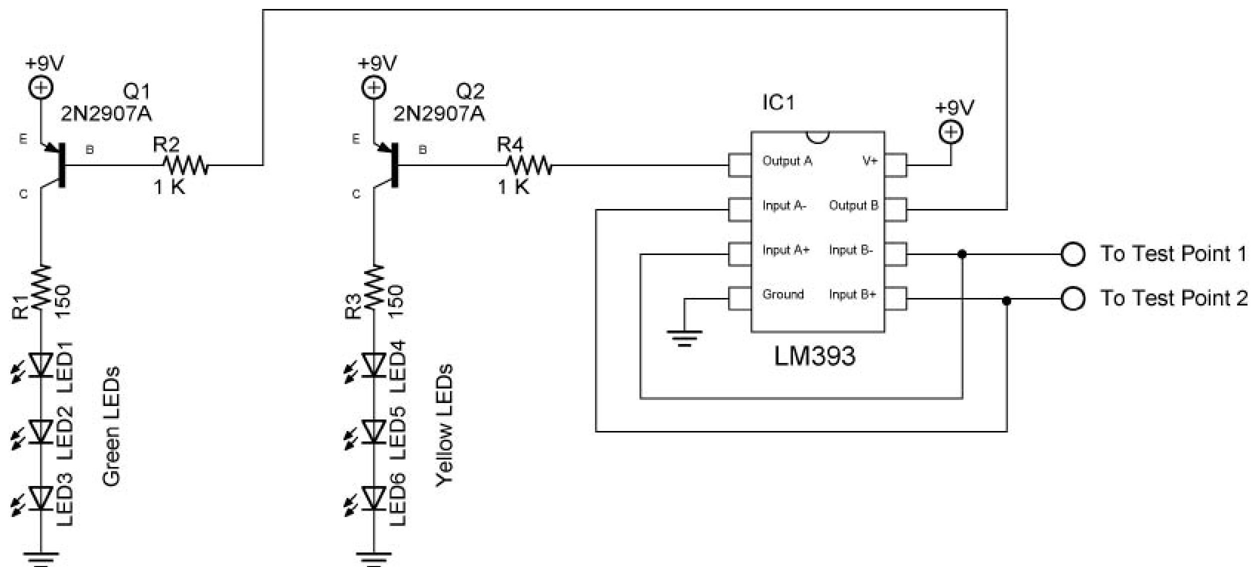


- **Results:**

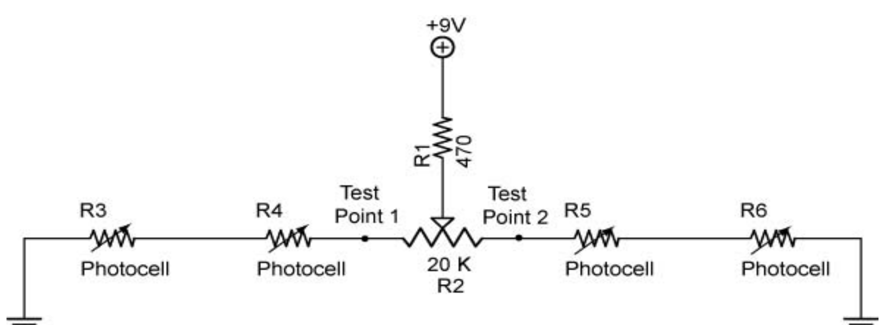
Event at Point A	Voltage (V)
Lowest Reading	
Highest Reading	
LED Just Lights	

Electronics Technology and Robotics I Week 16
Diodes and Transistor Switches Lab 5 – Brightness Comparator

- **Purpose:** The purpose of this lab is to set up the switching circuit for the line following robot Sandwich.
- **Apparatus and Materials:**
    - 1 – Solderless Breadboard with 9 V Power Supply
    - 1 – Digital Multimeter
    - 1 – LM393N Voltage Comparator
    - 2 – 2N2907A PNP Transistors
    - 2 – 150 Ohm Resistors
    - 2 – 1 K Resistors
    - 3 – Green LEDs
    - 3 – Yellow LEDs
- **Procedure:**
    - Wire the brightness comparator transistor circuit:



    - Test Points 1&2 are located in the Brightness Balancing circuit (Week 11): http://www.cornerstonerobotics.org/curriculum/lessons_year1/ER%20Week11,%20Other%20Sources,%20Photoresistor.pdf



Electronics Technology and Robotics I Week 17
Magnetism LAB 1 – Floating Compass Pin

- **Purpose:** The purpose of this lab is to have the student build a simple compass.

- **Apparatus and Materials:**

    - 1 – Straight Pin
    - 1 – Dish of Water
    - 1 – Permanent Magnet
    - Paper Towels

- **Procedure:**
    - Snip off the head of a straight pin using wire cutters.
    - Drop the pin into a dish of water. Hold it horizontally at its middle between two fingers, just above the water, then let go. Make sure the pin is floating. Observe the pin's alignment. Rotate the pin while still in the water by using a pencil and observe the pin's alignment. Make sure that the magnet is not in close proximity to the dish of water. Record the results.
    - Magnetize the pin by placing it on the permanent magnet.
    - Once again, drop the pin into the dish of water. Observe the pin's alignment. Rotate the pin by using a pencil and observe the pin's alignment. Record the results.

- **Results:**
    - Alignment of unmagnetized pin:

    - Alignment of magnetized pin:

- **Conclusions:**
    - What conclusion can be made about the earth and magnetism?

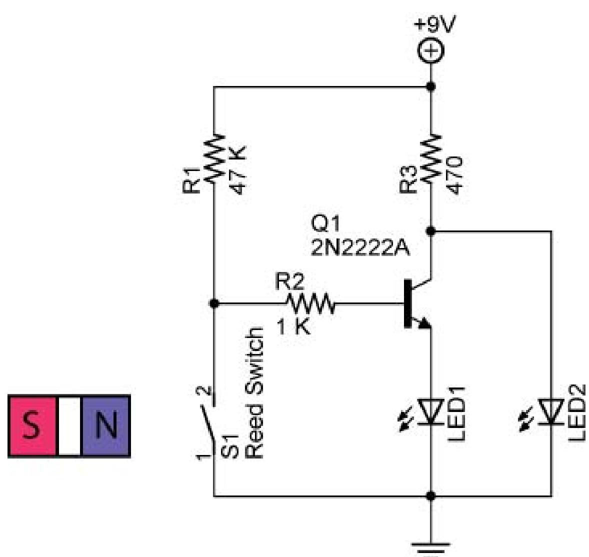
Electronics Technology and Robotics I Week 17
Magnetism LAB 2 – Reed Switch and Reed Relay

- **Purpose:** The purpose of this lab is to acquaint the student with a magnetic sensor switch and a reed relay.

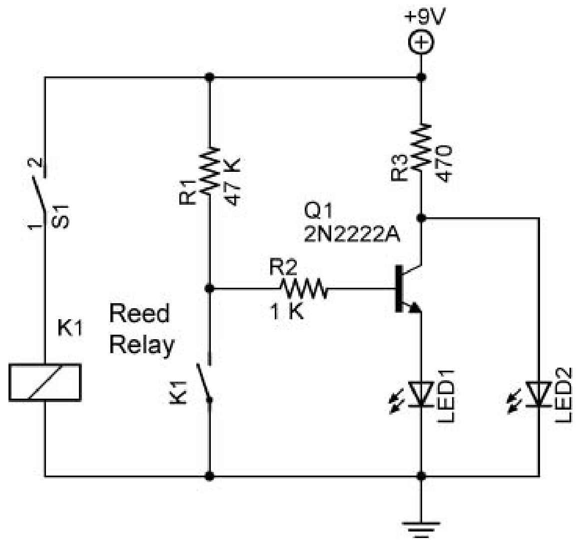
- **Apparatus and Materials:**

  - 1 – Breadboard with a +9 V Power Supply
  - 1 – Bar Magnet
  - 1 – Reed Switch
  - 1 – Reed Relay (Radio Shack #275-233) See: http://www.radioshack.com/product/index.jsp?productId=2062479&cp=
  - 1 – 47 Ohm Resistor
  - 1 – 470 Ohm Resistor
  - 1 – 1 K Resistor
  - 1 – 2N222A NPN Transistor
  - 2 - LEDs

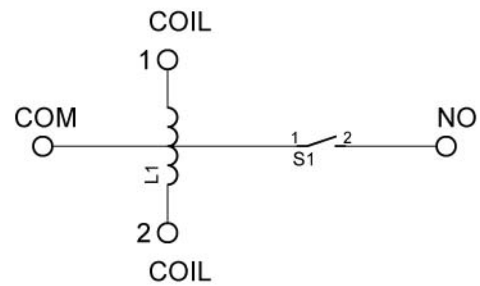
- **Procedure:**
  - Magnetic switches: A reed switch is a magnetic switch that will open or close depending upon the strength of the magnetic field acting upon it.
  - Wire the following circuit then use a magnet to activate the switch:
  - Replace the switch with a reed relay as shown in the reed relay circuit. The reed relay wiring diagram shows the connections.
  - Use the switch S1 to activate the reed relay.



Reed Switch Circuit



Reed Relay Circuit



Reed Relay (K1) Wiring Diagram

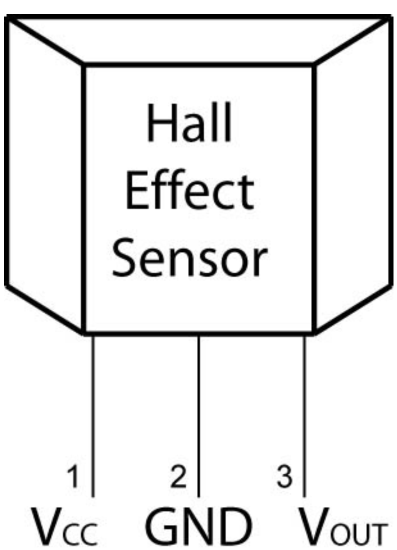
- **Conclusions:**
    - How is the magnetic force generated to close the switch in the reed relay K1?

Electronics Technology and Robotics I Week 17
Magnetism LAB 3 – Digital Hall-Effect Sensor

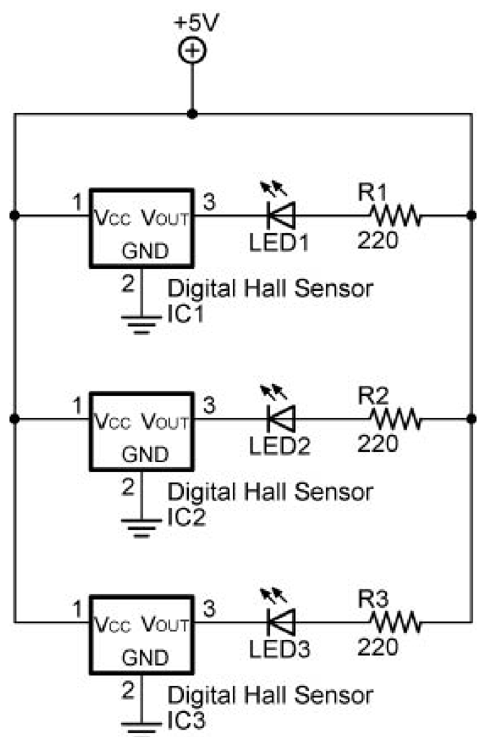
- **Purpose:** The purpose of this lab is to acquaint the student with a digital Hall-Effect sensor.

- **Apparatus and Materials:**
    - 1 – Breadboard with a +5 V Power Supply
    - 3 – Hall-Effect Digital Sensors (#402 LESSEMF.com, http://www.lessemf.com/dcgauss.html)
    - 3 – 220 Ohm Resistors
    - 3 - LEDs

- **Procedure:**
    - Wire the Hall-Effect bargraph circuit below. Use a magnet to approach the Hall-Effect switch sensors from one side then the other side.
    - Leave enough room between the sensors and the LEDs to insert the magnet. See photos of spacing below.

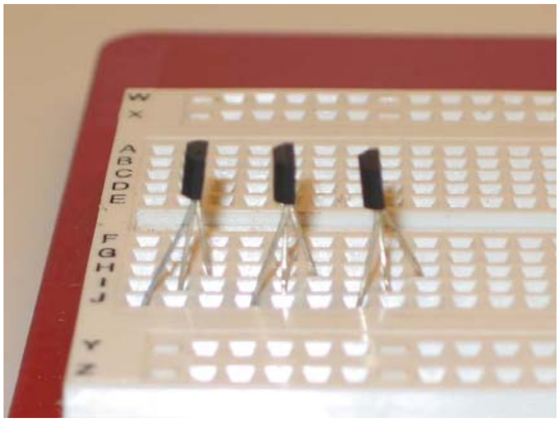


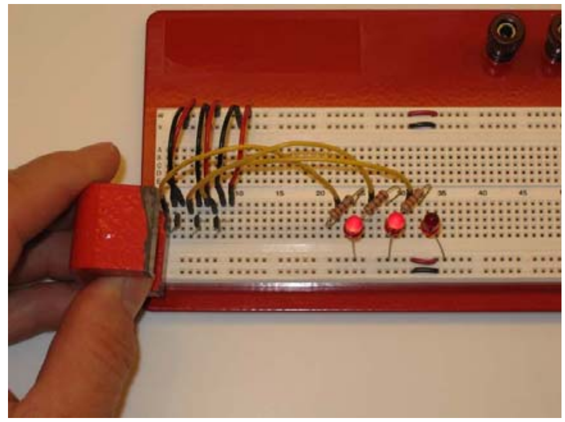
Sensor Pin Layout



Hall Effect Bargraph Circuit

From *Electronic Sensor Circuits & Projects*
By Forrest M. Mims





Sensor Pin Insertion into Breadboard

Final Hall Effect Circuit

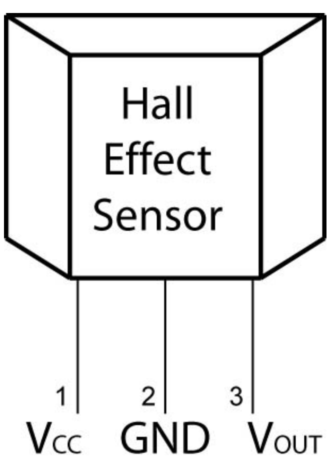
Electronics Technology and Robotics I Week 17
Magnetism LAB 4 – Linear Hall-Effect Sensor

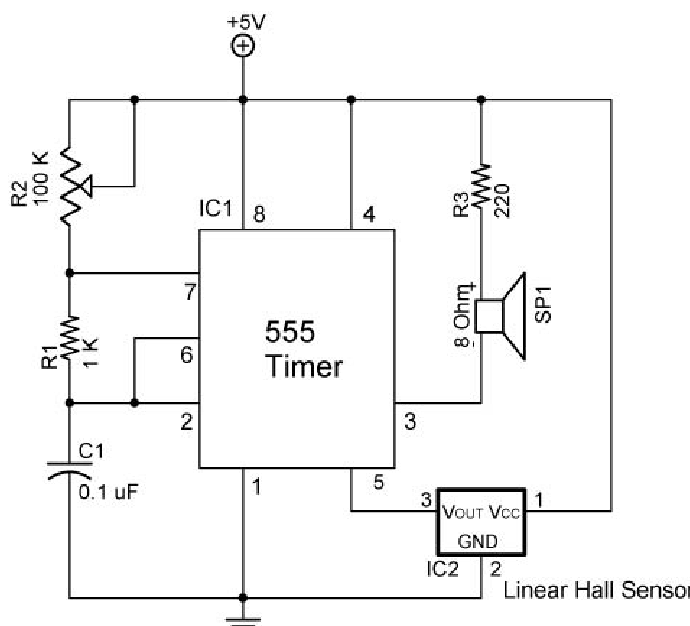
- **Purpose:** The purpose of this lab is to acquaint the student with a linear Hall-Effect sensor.

- **Apparatus and Materials:**

    - 1 – Breadboard with a +5 V Power Supply
    - 1 – Linear Hall-Effect Sensor (#400 LESSEMF.com, http://www.lessemf.com/dcgauss.html)
    - 1 – 555 Timer IC
    - 1 – 1K Resistor
    - 1 – 100K Potentiometer
    - 1 – 220 Ohm Resistor
    - 1 – 1K Resistor
    - 1 – 8 Ohm Speaker

- **Procedure:**
    - Wire the Hall Effect tone generator below. Use a magnet to change the output of the linear Hall Effect sensor.





Sensor Pin Layout **Magnetic Tone Generator**

From *Electronic Sensor Circuits & Projects*
By Forrest M. Mims

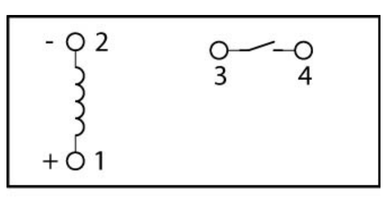
Electronics Technology and Robotics I Week 18
Electrical Relay LAB 1 – Voltage Separation

- **Purpose:** The purpose of this lab is to demonstrate that the voltage source which controls a relay coil can be separate from the voltage source that controls the secondary circuit.

- **Apparatus and Materials:**

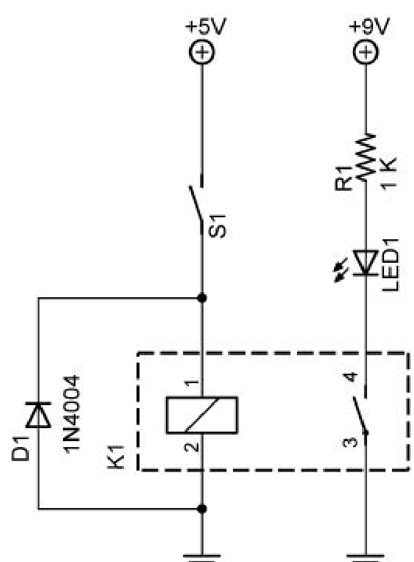
    - 1 – Breadboard with a +5 V and +9 V Power Supplies
    - 1 – 1N4004 Diode
    - 1 – SPST Relay (Digikey # Z945-ND) http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail?name=Z945-ND
    - 1 – SPST Switch
    - 1 – 1K Resistor
    - 1 – LED

- **Procedure:**
    - Build Relay Circuit 1 on your breadboard. The circuit uses a voltage source of +5 V to energize the relay coil and a separate a voltage source of +9 V to power the LED circuit.
    - Notice that the two circuits in Relay Circuit 1 are not connected electrically. Their interaction is by the coil generating a magnetic field which closes the contacts (switch) in the relay.



K1 (Z945-ND Bottom View)

SPST Relay Wiring Diagram



Relay Circuit 1

- **Results:**

Position of Switch	LED Response
S1 Open	
S1 Closed	

- **Conclusions:**
  - The data sheet for the relay states, “When mounting two or more relays side by side, provide a minimum space of 3 mm between relays.” Why?

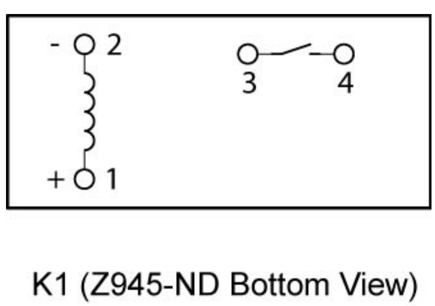
Electronics Technology and Robotics I Week 18
Electrical Relay LAB 2 – Relay Application 1

- **Purpose:** The purpose of this lab is to demonstrate an application of a relay.

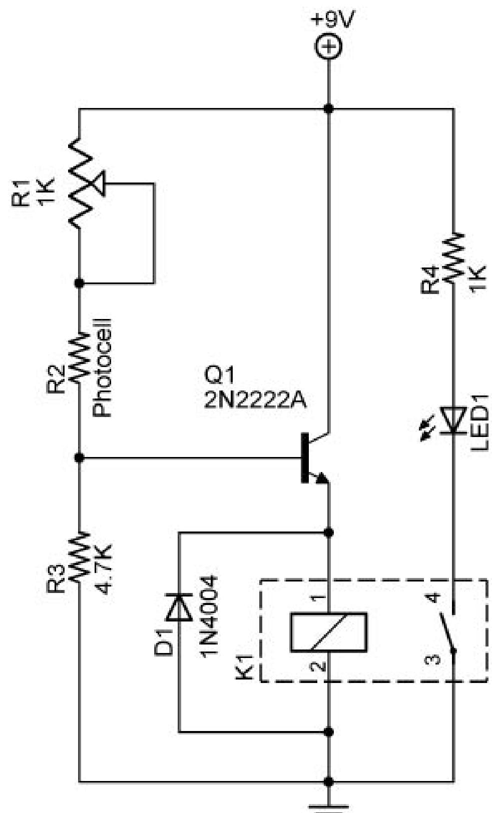
- **Apparatus and Materials:**

  - 1 – Breadboard with a +9 V Power Supply
  - 1 – 1 K Tripot
  - 1 – Photoresistor
  - 1 – 4.7 K Resistor
  - 1 – 1 K Resistor
  - 1 – 2N2222A NPN Transistor
  - 1 – 1N4004 Diode
  - 1 – SPST Relay (Digikey # Z945-ND) http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail?name=Z945-ND

- **Procedure:**
  - Wire the following light activated relay circuit:



SPST Relay Wiring Diagram



Light Activated Relay Circuit

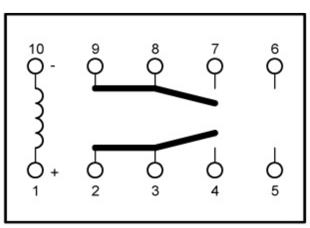
Electronics Technology and Robotics I Week 18
Electrical Relay LAB 3 – Relay as a Buzzer (Oscillator)

- **Purpose:** The purpose of this lab is to demonstrate that a relay can act as a buzzer (oscillator). Also the student must design and build a relay circuit.

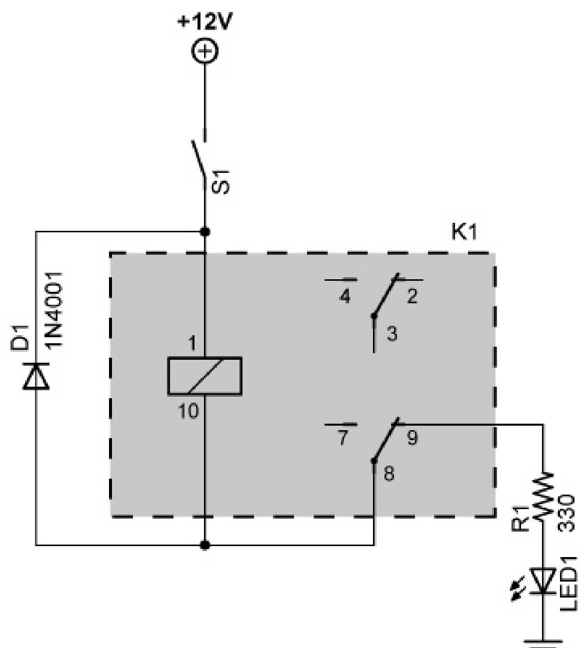
- **Apparatus and Materials:**

    - 1 – Breadboard with +12 V Power Supply
    - 1 – SPST Switch
    - 1 – 1N4001 Diode
    - 1 – 470 μF Capacitor
    - 1 – DPDT Relay (Digikey # 255-1002-5-ND) http://search.digikey.com/scripts/DkSearch/dksus.dll?vendor=0&keywords=255-1002-5-nd

- **Procedure:**
    - Wire a DPDT relay to become a buzzer using the following circuit. **Note** that Pin 1 on the relay coil is the positive connection. Also note that Pin 10 is not connected directly to ground but to Pin 8. **Close the switch for only a short period of time since the buzzing action will create excessive wear on the relay contacts.** Complete the explanation in the conclusions.

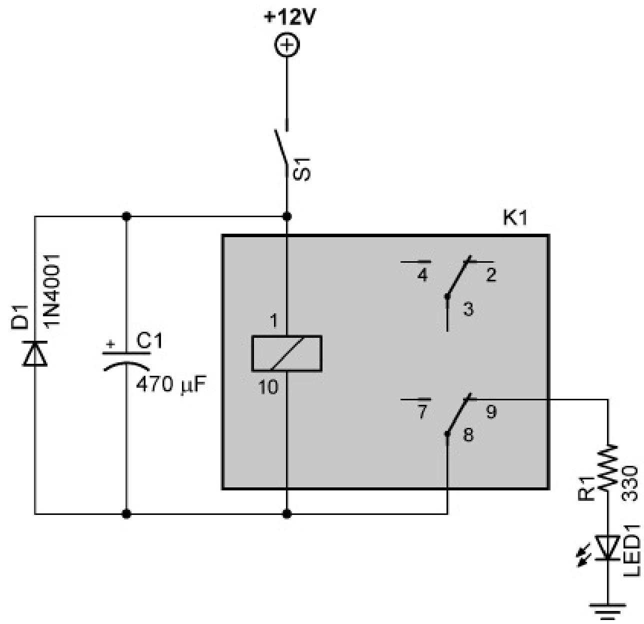


255-1002-5-ND Top View **(12V)**



DPDT Relay Wiring Diagram **Relay Buzzer Circuit**

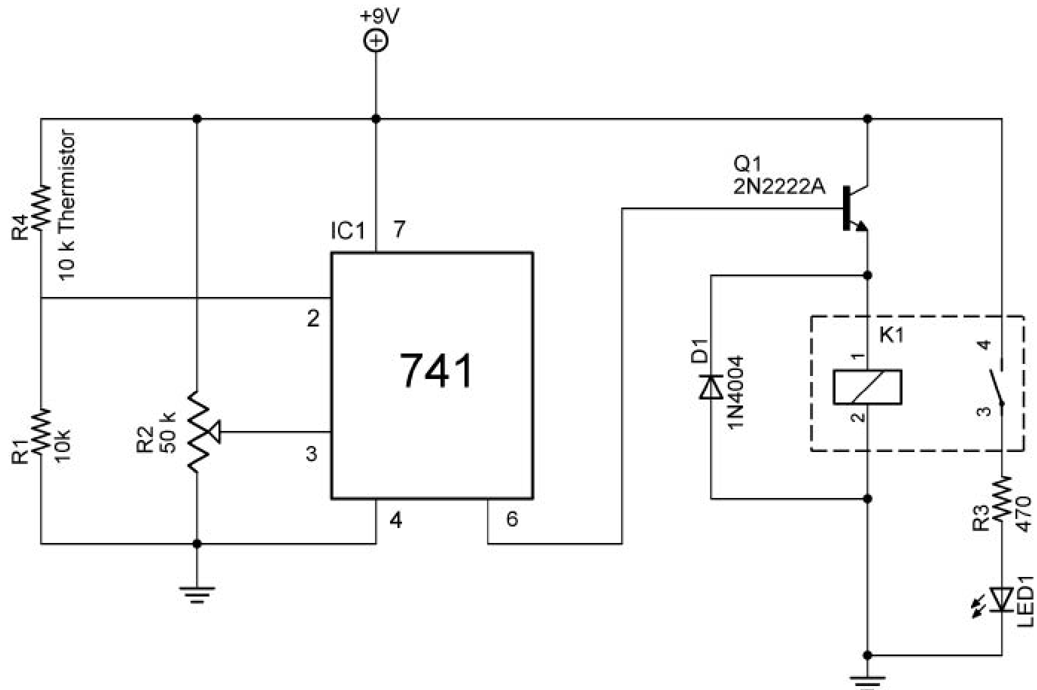
- Now add a capacitor to the circuit as shown in the following schematic.



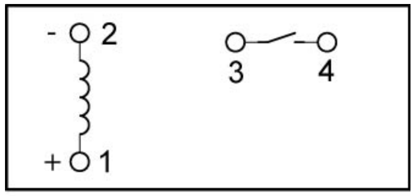
- **Conclusions:**
  - Explain the electrical process that makes the relay turns on and off creating the sound of a buzzer.

Electronics Technology and Robotics I Week 18
Electrical Relay LAB 4 – Relay Application 2

- **Purpose:** The purpose of this lab is to demonstrate another application of a relay.
- **Apparatus and Materials:**
    - 1 – Breadboard with a +9 V Power Supply
    - 1 – 741 Op Amp
    - 1 – 10 K Thermistor
    - 1 – 10 K Resistor
    - 1 – 50 K Tripot
    - 1 – 470 K Resistor
    - 1 - LED
    - 1 – 2N2222A NPN Transistor
    - 1 – 1N4004 Diode
    - 1 – SPST Relay (Digikey # Z945-ND) http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail?name=Z945-ND
- **Procedure:**
    - Build the temperature activated relay below:



Temperature Activated Relay Circuit



K1 (Z945-ND Bottom View)

Electronics Technology and Robotics I Week 19
Soldering Tutorial LAB 1 – Tinning a Wire

- **Purpose:** The purpose of this lab is to tin the end of a stranded wire.

- **Apparatus and Materials:**

    - 1 – Soldering Iron and Holder with Moistened Sponge
    - 1 – 0.022 Resin-Core Solder
    - 1 – 0.50 Resin-Core Solder
    - 1 – Wire Cutting Pliers
    - 1 – Wire Strippers
    - 1 – Helping Hands
    - 2 – 5 cm #22 Gauge Stranded Wires

- **Procedure:**
    - Follow all safety precautions.
    - Turn on the soldering iron.
    - Moistened the sponge with distilled water.
    - Cut a two pieces of stranded wire about 5 cm long.
    - Stripe 1 cm of insulation from all ends of the wires.
    - Place the ends of one wire into the helping hands. The bare wire should be free of the alligator clip.
    - Clean the soldering iron tip off on the sponge.
    - Hold the soldering iron against the bare wire.
    - Apply a small amount of fresh 0.022 solder between the soldering iron tip and the bare wire to help conduct heat to the wire faster.
    - As the wire heats, apply more solder to the wire away from the tip of the soldering iron.
    - The solder should be heated by the wire so it will flow into the stranded wire.
    - After the bare portion of the wire is soldered, continue to hold the soldering iron against the wire for about a half of a second then pull away.
    - Inspect the tinned wire for:
        - Shiny surface
        - Wire strands – they should be visible
        - Excess insulation damage
    - Tin the other end of the wire of the wire.
    - Tin both ends of the other wire.
    - Tinning the tool tip: Just after turning the soldering iron off, apply a generous amount of 0.050 solder to your soldering iron tip.

Electronics Technology and Robotics I Week 19
Soldering Tutorial LAB 2 – Soldering Lug-Type Terminal Strips

- **Purpose:** The purpose of this lab is to solder stranded wires to a lug-type terminal strip.

- **Apparatus and Materials:**

    - 1 – Soldering Iron and Holder with Moistened Sponge
    - 1 – 0.022 Resin-Core Solder
    - 1 – 0.50 Resin-Core Solder
    - 1 – Wire Cutting Pliers
    - 1 – Wire Strippers
    - 1 – Helping Hands
    - 2 – 5 cm #22 Gauge Stranded Wires
    - 1 – Lug-Type Terminal Strip

- **Procedure:**
    - Follow all safety precautions.
    - Turn on the soldering iron.
    - Moistened the sponge with distilled water.
    - Clean the component leads and lugs with rubbing alcohol.
    - Tin the end of a wire.
    - Attach the wire to the lug of the terminal strip.
        - Insert the end of the tinned wire through the lug allowing the insulation to be about 1 mm above the lug.
        - Crimp the wire around the lug using the pliers.
        - Cut the end of the wire off even with the top of the lug.
    - Clean the soldering iron tip off on the sponge.
    - Hold the soldering iron against the lug and the wire.
    - Apply a small amount of fresh 0.022 solder between the soldering iron tip and the lug to help conduct heat to the connection faster.
    - As the lug and wire heat, apply more solder directly to the connection but not to the soldering tip.
    - The solder should be heated by the lug so it will flow into the connection.
    - Make sure that the entire eyelet of the lug is filled with solder to keep the connection from failure long term.
    - Don't move the wire or the connection for a few seconds to allow the solder to cool.
    - Practice with other wires and lugs.
    - Tinning the tool tip: Just after turning the soldering iron off, apply a generous amount of 0.050 solder to your soldering iron tip.

Electronics Technology and Robotics I Week 19
Soldering Tutorial LAB 3 – Soldering Components to a PC Board

- **Purpose:** The purpose of this lab is to solder components to a PC board.
- **Apparatus and Materials:**
    - 1 – Soldering Iron and Holder with Moistened Sponge
    - 1 – 0.022 Resin-Core Solder
    - 1 – 0.50 Resin-Core Solder
    - 1 – Wire Cutting Pliers
    - 1 – Wire Strippers
    - 1 – Helping Hands
    - 2 – 5 cm #22 Gauge Stranded Wires
    - 2 – 5 cm #22 Gauge Solid Wires
    - 5 – Resistors
    - 1 – PC Board
- **Procedure:**
    - Follow all safety precautions.
    - Turn on the soldering iron.
    - Moistened the sponge with distilled water.
    - Clean the component leads with rubbing alcohol and the PC board with steel wool.
    - If needed, tin the component leads.
    - Insert the component leads through the holes of the PC board.
    - To hold the component in place while you are soldering, you may want to bend the leads on the bottom of the board at about a 45 degree angle.
    - Place the PC board into the helping hands.
    - Bring the soldering iron tip so that it rests against both the component lead and the board.
    - Apply a small amount of fresh 0.022 solder between the soldering iron tip and the component lead and solder pad to help conduct heat to the connection faster.
    - Allow the component lead and solder pad to heat up for about one second.
    - Feed the 0.022 solder to the component lead and solder pad, but not the tip of the iron.
    - Once the surface of the pad is completely coated, stop adding solder and remove the soldering iron. The soldered connection should look like a miniature Hershey kiss, not a rounded ball.
    - Don't move the wire or the connection for a few seconds to allow the solder to cool.
    - If the connection looks like a rounded ball, remove the solder by following the instructions in Lab 4 and resolder.
    - Cutoff the excess wire on the leads.
    - Inspect the PC board for:
        - Cold solder joints
        - Solder bridging across the conductive pathways, or traces.

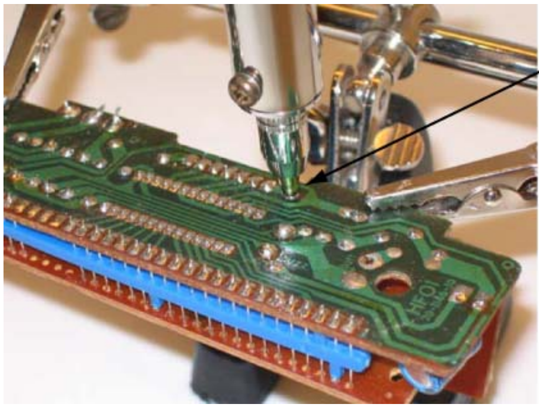
Electronics Technology and Robotics I Week 19
Soldering Tutorial LAB 4 – Desoldering Components on a PC Board

- **Purpose:** The purpose of this lab is to remove solder from a soldered connection on a PC board.

- **Apparatus and Materials:**

  - 1 – Soldering Iron and Holder with Moistened Sponge
  - 1 – Electric Desoldering Tool (Electronix Express # 060848) http://www.elexp.com/sdr_0848.htm
  - 1 – 0.022 Resin-Core Solder
  - 1 – 0.50 Resin-Core Solder
  - 1 – Helping Hands
  - 1 – PC Board from Lab 3

- **Procedure:**
  - Follow all safety precautions.
  - Plug in the electric desoldering tool.
  - Place the PC board from Lab 3 into the helping hands.
  - Insert the tip of the desoldering tool over the lead to be desoldered.

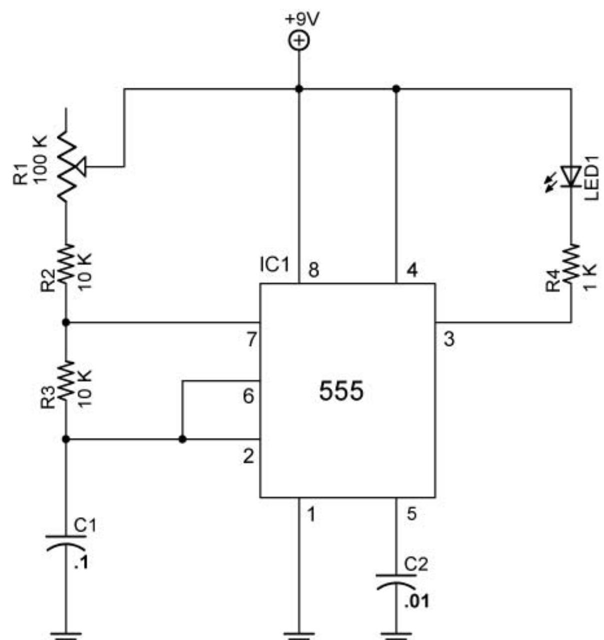


Insert the electric desoldering tool directly over the lead.

  - Heat the lead and release the pump.
  - Resolder the lead.
  - Tinning the tool tip: Just after turning the soldering iron off, apply a generous amount of 0.050 solder to your soldering iron tip.

Electronics Technology and Robotics I Week 20
DC and AC Lab 1 – PWM Used to Control an LED

- **Purpose:** The purpose of this lab is to demonstrate a practical application of PWM (Pulse-Width-Modulation).
- **Apparatus and Materials:**
  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – Digital Multimeter
  - 1 – 100 K Tripot
  - 2 – 10 K Resistors
  - 1 – 1 K Resistor
  - 1 – 0.1 μF Capacitor
  - 1 – 0.01 μF Capacitor
  - 1 – 555 Timer IC
- **Procedure:**
  - Build the 555 circuit that uses PWM to control the brightness of an LED.



555 PWM Brightness Circuit

From *123 Robotic Experiments for the Evil Genius*
(Powered by an active low on pin 3)

- **Results:**

	Voltage Pin 3 to GND	LED Brightness
Minimum Voltage		
Maximum Voltage		

- **Conclusions:**
  - Why does the LED brightness increase as the voltage at pin 3 decreases?

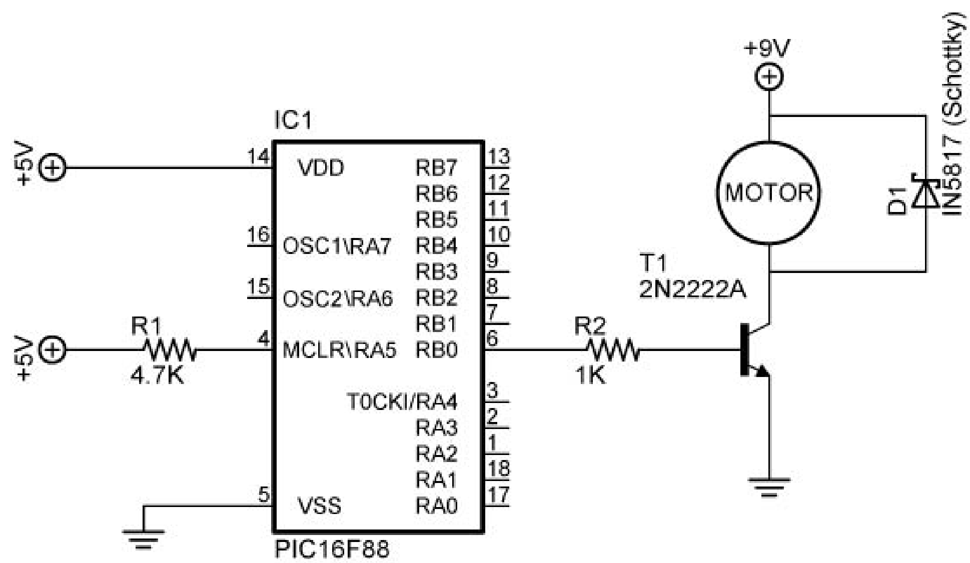
Electronics Technology and Robotics I Week 20
DC and AC Lab 2 – PWM Used to Control a Motor

- **Purpose:** The purpose of this lab is to demonstrate how PWM is used to control the speed of a motor.

- **Apparatus and Materials:**

  - 1 – Solderless Breadboard with + 9V and +5V Power Supplies
  - 1 – Oscilloscope
  - 1 – PIC16F88 Microcontroller
  - 1 – 1 K Resistors
  - 1 – 4.7 K Resistor
  - 1 – 2N2222A NPN Transistor
  - 1 – 1N5817 Schottky Diode
  - 1 – DC Motor

- **Procedure:**
  - Wire the circuit pwm1 below.
  - The PIC is programmed in PicBasic Pro. The program is online at: http://cornerstonerobotics.org/code/pwm1.pdf



pwm1

  - Place an oscilloscope probe on the output pin RB0 and observe the relationship between the waveform and the action of the motor.

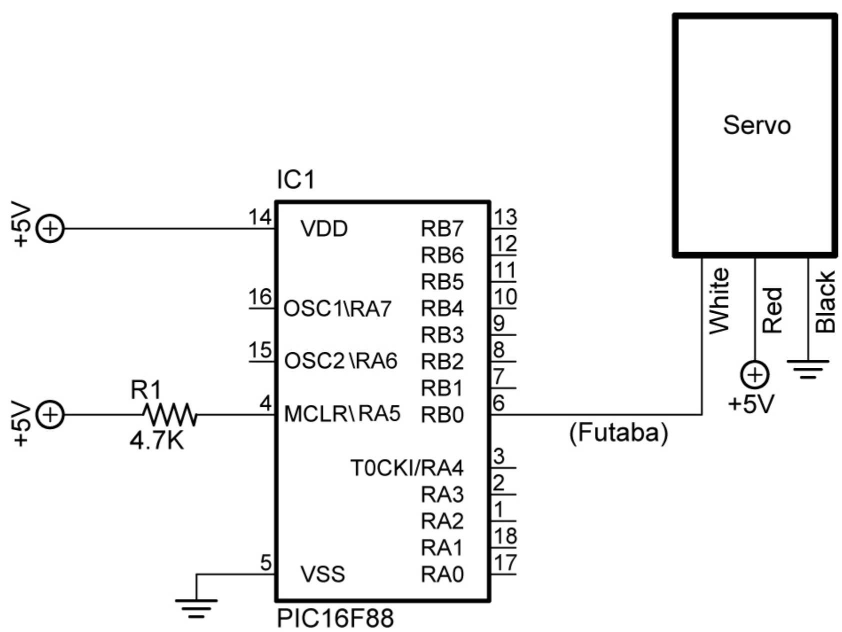
Electronics Technology and Robotics I Week 20
DC and AC Lab 3 – Servo Pulses

- **Purpose:** The purpose of this lab is to demonstrate the pulse waveforms that control hobby servos.

- **Apparatus and Materials:**

    - 1 – Solderless Breadboard with +5V Power Supply
    - 1 – Oscilloscope
    - 1 – PIC16F88 Microcontroller
    - 1 – 4.7 K Resistor
    - 1 – Hobby Servo

- **Procedure:**
    - Wire the circuit servo1, servo2, servo3 below.
    - **Note: The servo must have a separate +5V power supply from the PIC microcontroller.**
    - The PIC is programmed in PicBasic Pro. The program is online at: http://cornerstonerobotics.org/code/servo3.pdf



servo1, servo2, and servo3

- Place an oscilloscope probe on the output pin RB0 and observe the relationship between the waveform and the action of the servo motor.

Electronics Technology and Robotics I Week 20
Oscilloscope Lab 1 – Initial Startup Procedure

- **Purpose:** The purpose of this exercise is to perform the startup procedure for an oscilloscope.

- **Apparatus and Materials:**

    - 1 – Oscilloscope

- **Procedure:**
    - Set the basic controls as follows: These settings prepare the scope for a single-trace display of a zero-volt base line, centered vertically and horizontally. At this point, no signal is applied.
        - **Vertical Mode Control** (O13): CH1 (See the next page for the location of the controls on the oscilloscope.)
        - **CH 1 Input Coupling Switch** (O9): GND
        - **CH 1 Vertical Position Control** (O5): centered.
        - **Horizontal Position Control** (O8): centered.
        - **Trigger Coupling Switch** (O6): AUTO
        - **Intensity Control** (O3): minimum intensity.
        - **Time/Div Control** (O14): 0.5 ms/Div
    - Plug in the oscilloscope and turn the **Power Switch** (O1) on. Allow the unit a few seconds to warm up.
    - Slowly bring the **Intensity Control** (O3) up. You should see a horizontal trace near the center of the screen.
    - Adjust the trace sharpness with the **Focus Control** (O4), and adjust the trace tilt with the **Trace Rotation Control** (O2).
    - Follow the same process for a single trace on channel 2. Start by setting the **Vertical Mode Control** (O13) to CH2.

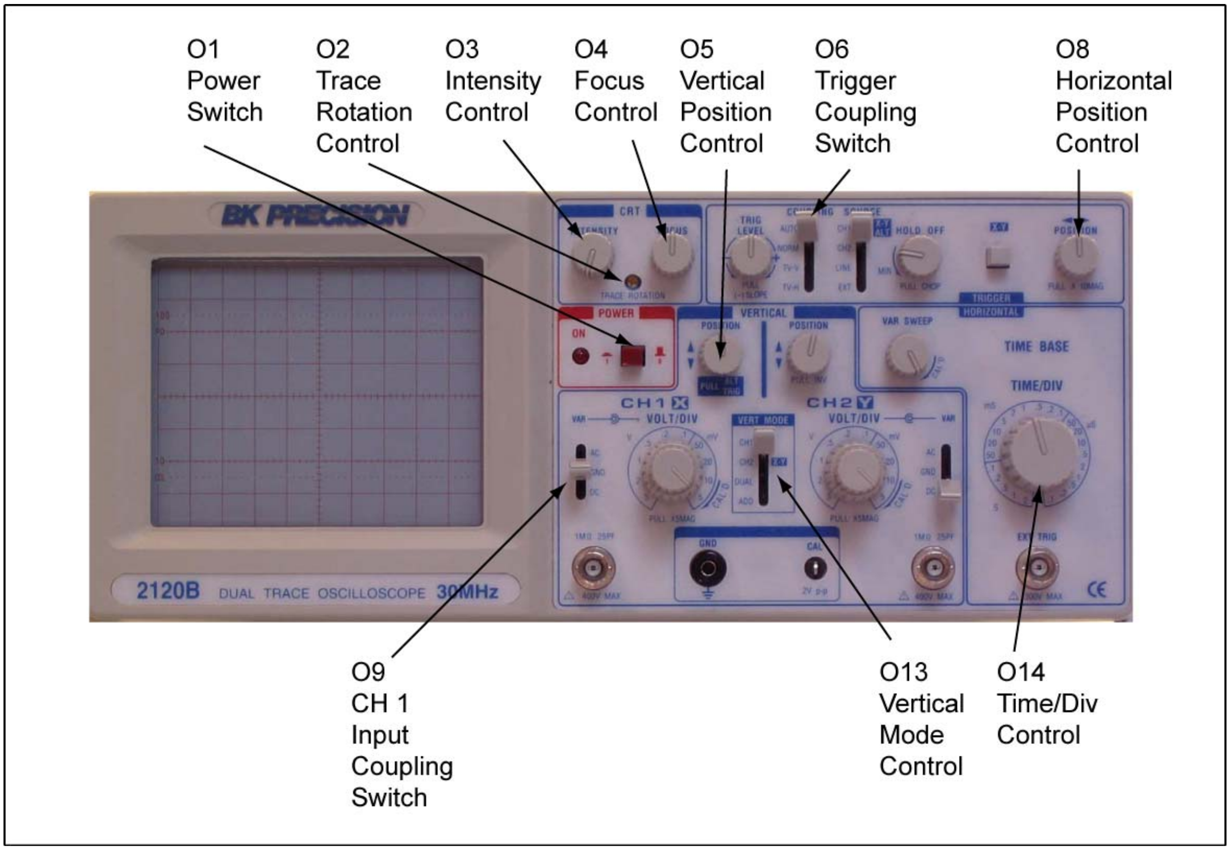


Figure 20 - 2 BK Precision 2120B Controls for Lab 1

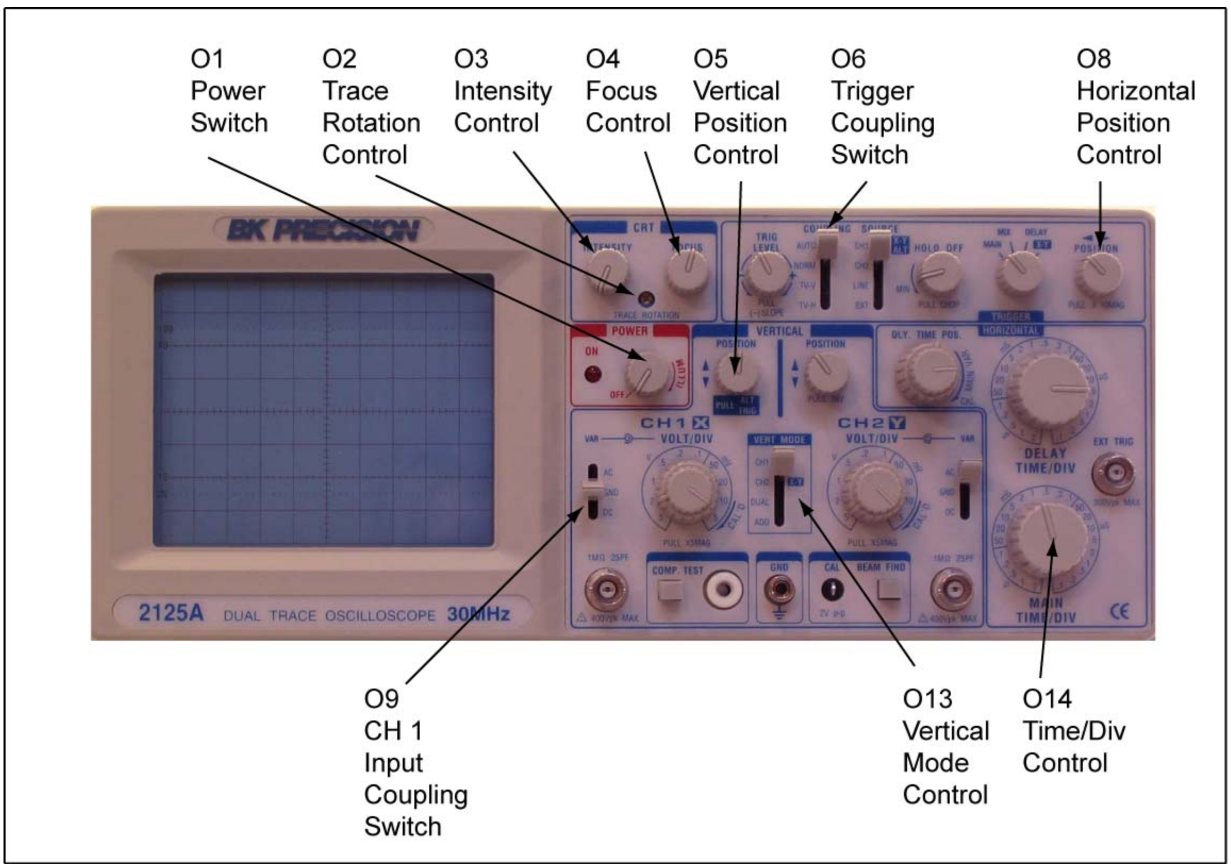


Figure 20 - 3 BK Precision 2125A Controls for Lab 1

Electronics Technology and Robotics I Week 20
Oscilloscope Lab 2 – Display a Signal

- **Purpose:** The purpose of this exercise is to display a signal on an oscilloscope.

- **Apparatus and Materials:**

  - 1 – Oscilloscope
  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – 25 K Tripot
  - 2 – 1 K Resistors
  - 1 – 220 Ohm Resistor
  - 1 – 2.2 μF Capacitor
  - 1 – 2N2222A NPN Transistor
  - 1 – 555 Timer IC
  - 1 – LED

- **Procedure:**
  - Wire the 555 timer LED flasher circuit below.
  - Connect the scope probe to the **CH 1 Input Jack** (O10). (See the next page for the location of the controls on the oscilloscope.)
  - Adjust the **CH 1 Variable Attenuator** (O11) to the full clockwise position. This assures that the screen's vertical divisions for the voltage scale are in calibrated.
  - Set the **CH 1 Volts/Div Control** (O12) to 5.
  - **CH 1 Input Coupling Switch** (O9): DC

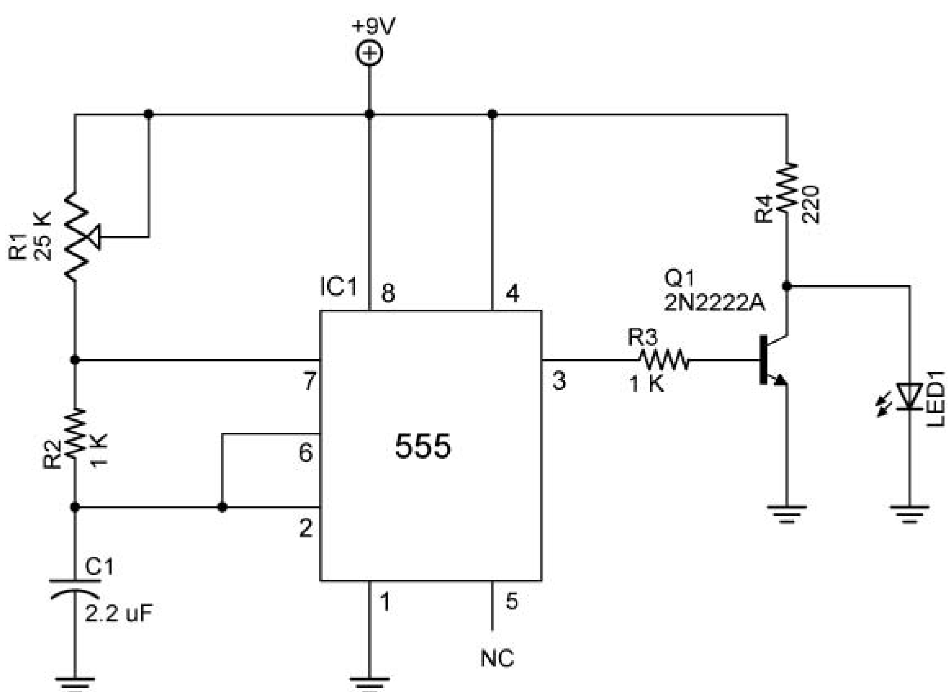


Figure 20 - 4 LED Flasher

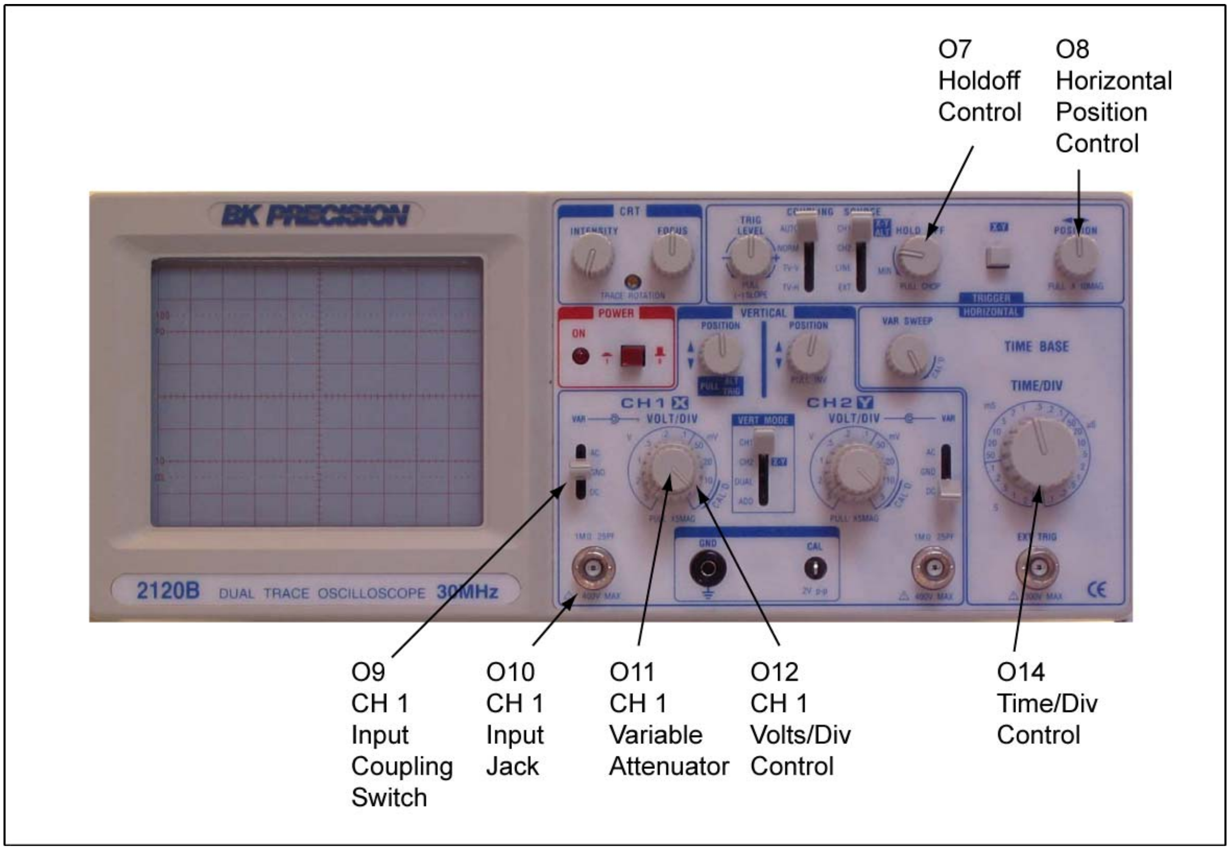


Figure 20 - 5   BK Precision 2120B Controls for Lab 2

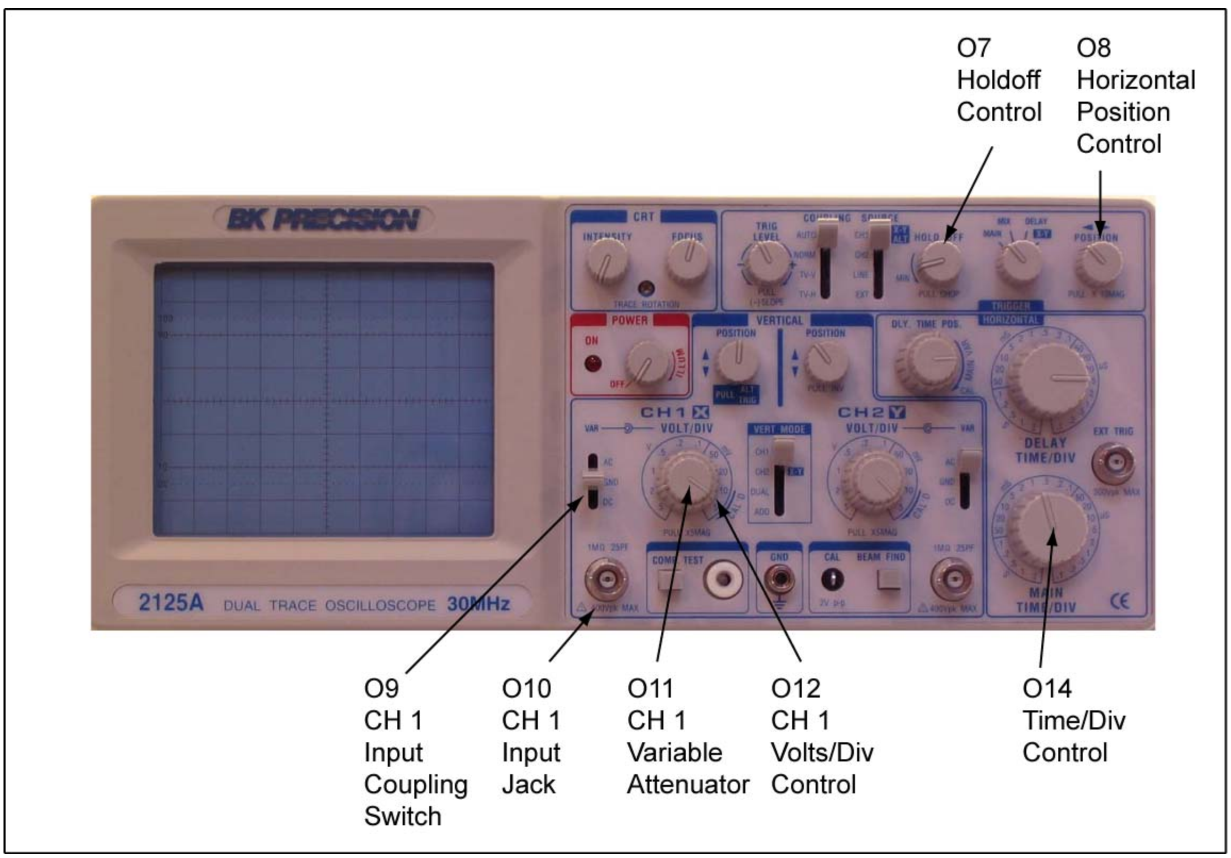


Figure 20 - 6   BK Precision 2125A Controls for Lab 2

- Now connect the probe's ground clip to the circuit ground.
- Set the probe slide switch to x1.

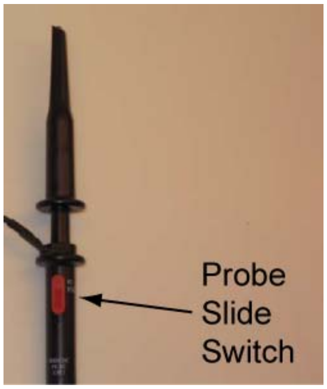


Figure 20 – 7 Oscilloscope Probe

- Display the wave form across the LED by connecting the probe tip to anode of the LED. Adjust the **Holdoff Control** (O7) to help stabilize the waveform.
- Adjust R1 and observe the changes in the waveform.
- Voltage Level of Pulse:
  - Set the **CH 1 Volt/Div Control** (O12) to 1. This means each vertical division on the screen is equal to 1 volt.
  - Calculating the voltage from an oscilloscope:

    Voltage = Number of Divisions Tall x Volts/Div Setting

For example in Figure 20 – 8, if the Volt/Div Control is set for 2 volts:

Voltage = Number of Divisions Tall x Volts/Div Setting
Voltage = 3.2 Divisions Tall x 2 Volts
Voltage = 6.4 V

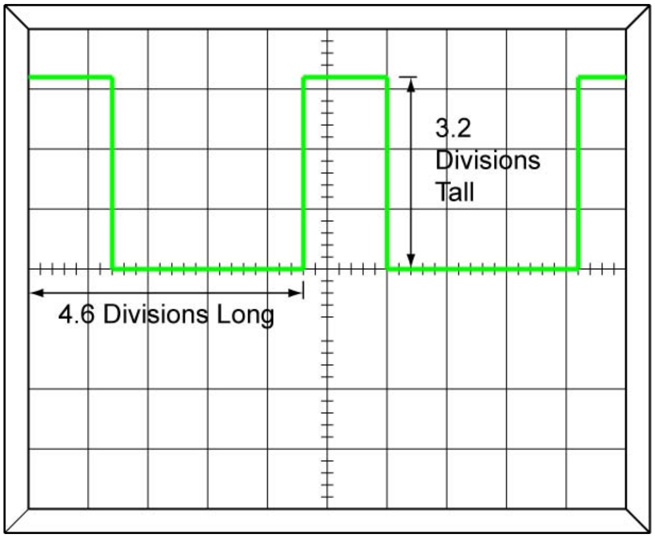


Figure 20 – 8 Calculating Voltages

- Measure and record the voltage at the anode of the LED.

- Timing of Pulses:
  - Set the **Time/Div Control** (O14) to 5 ms.
  - Measure and record the length of time of the positive pulse. To assist with this measurement, you may want to move the leading edge of the pulse to a division line using the **Horizontal Position Control** (O8).
  - Vary R1 and note the changes in the waveform.
  - Now set R1 to have the longest off time between pulses. You may have to change the **Time/Div Control** (O14) to display two pulses on the screen.
  - Measure and record the maximum time off between pulses.
  - Now set R1 to have the shortest off time between pulses. R1 is set to just before the pulse waveform breaks down. Change the **Time/Div Control** (O14) to achieve greater precision.
  - Measure and record the minimum time off between pulses.
- Period T of a Waveform:
  - Calculating the period from an oscilloscope:

T (Period of Waveform) = Number of Divisions Long x Time/Div Setting

For example in Figure 20 – 9, if the Time/Div Control is set for 0.5 ms:

T = Number of Divisions Long x Time/Div Setting
T = 4.6 Divisions Long x 0.5 ms
T = 2.3 ms

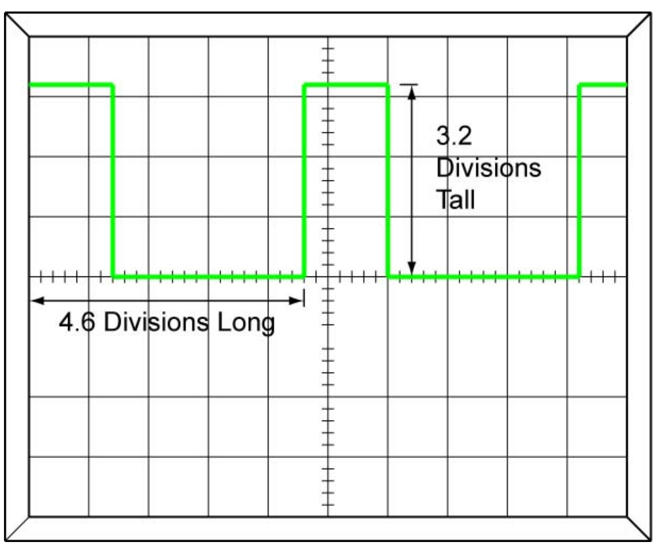


Figure 20 – 9 Calculating the Period

- Set the period (T) of the waveform to 20 ms. Since

  T = Number of Divisions Long x Time/Div Setting,
  Number of Divisions Long = T / Time/Div Setting

Let Time/Div Setting = 5 ms and T = 20 ms,

  Number of Divisions Long = 20 ms / 5 ms
  Number of Divisions Long = 4 Divisions Long

- Have the instructor verify your setting.
- Calculate and record the frequency of this waveform. F = 1/T

- Now adjust R1 to the point when the blinking effect appears to become a constant light.
- Measure the period T of this waveform.
- Calculate and record the frequency.

- **Results:**

Voltage at anode of LED	V
Length of time of the positive pulse	ms
Does the pulse width change by varying R1?	Yes / No
Maximum time off between pulses	ms
Minimum time off between pulses	ms
Frequency of waveform w/ period = 20 ms	Hz
Frequency when blinking stops	Hz

- **Conclusions:**
  - From the results of the last frequency calculation, why do you think 60 Hz is used to power generation?

Electronics Technology and Robotics I Week 21
Oscilloscope/Function Generator Lab 1 – Basic Operation of a Function Generator

- **Purpose:** The purpose of this lab is having the student learn the basic controls of a function generator.

- **Apparatus and Materials:**
    - 1 – Oscilloscope
    - 1 – Function Generator
    - 1 – BNC Male to BNC Male Cable

- **Procedure:**
    - Select the type of waveform by rotating the **Function Switch** (FG2). See the Figure 21 – 1 for the function generator control locations.
    - Select the frequency range by rotating the **Frequency Range Selector Switch** (FG).
    - Connect the function generator **Main Output** (FG6) to the **CH1 Input Jack** (O10) on the oscilloscope. See the Figures 21 – 2 and 21 - 3 for the oscilloscope control locations.
    - Set the oscilloscope **Vertical Mode Control** (O13) to CH 1.
    - Set the **CH 1 Input Coupling Switch** (O9) to AC.
    - Adjust the oscilloscope **CH 1 Variable Attenuator** (O11) to the full clockwise position.
    - Set the oscilloscope **CH 1 Volts/Div Control** (O12) to 5.
    - Set the oscilloscope **CH 1 Input Coupling Switch** (O9) to AC.
    - Turn on both the oscilloscope **Power Switch** (O1) and the function generator **Power Switch** (FG4).
    - Select different types of waveforms by rotating the function generator **Function Switch** (FG2).
    - Adjust the amplitude of the waveform by rotating the function generator **Amplitude Control** (FG3)
    - Adjust the frequency by changing the function generator **Frequency Control** (FG5) and **Frequency Range Selector Switch** (FG1).

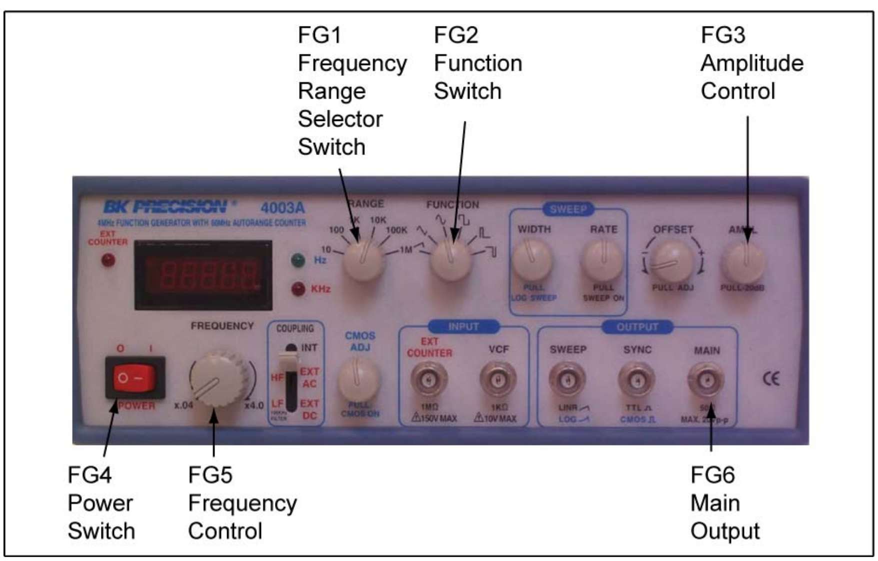


Figure 21 – 1 BK Precision 4003A Function Generator Controls for Lab 1

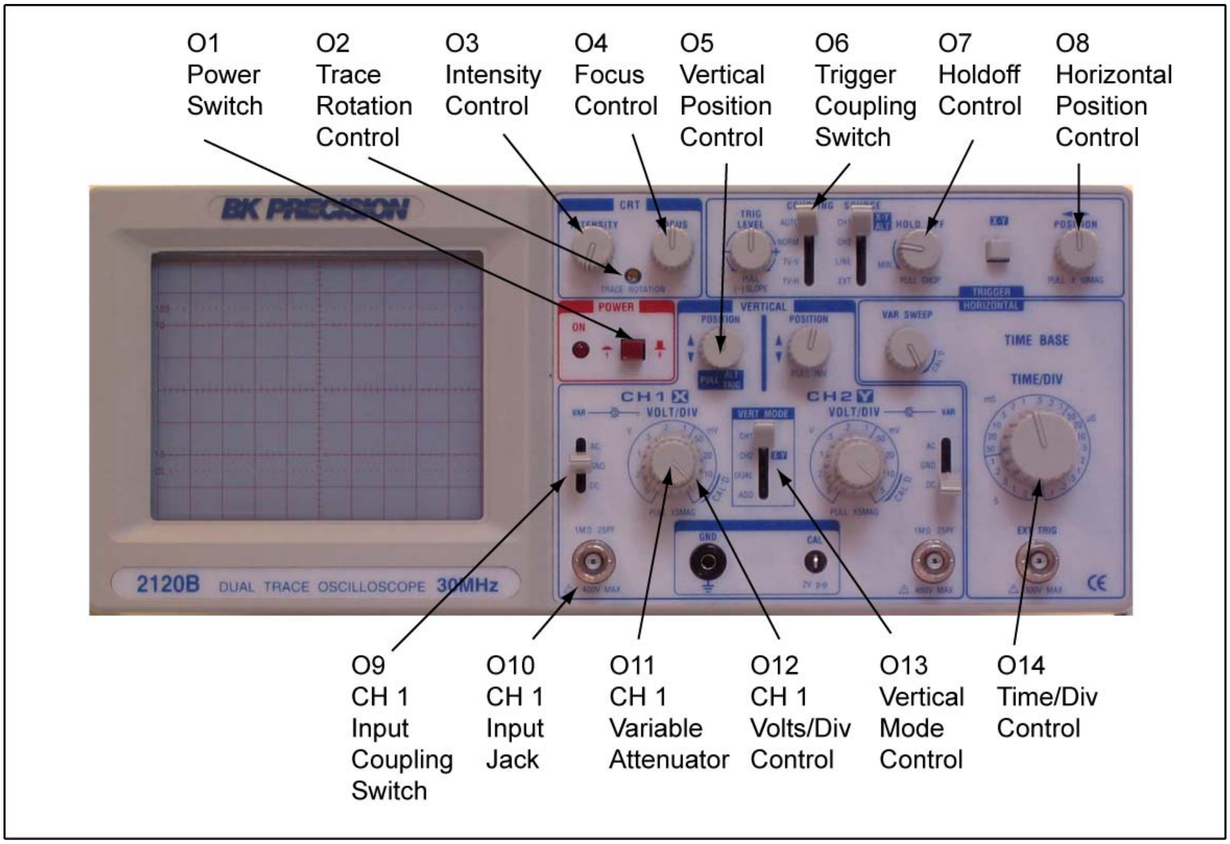


Figure 21 – 2 BK Precision 2120B Oscilloscope Controls for Lab 1

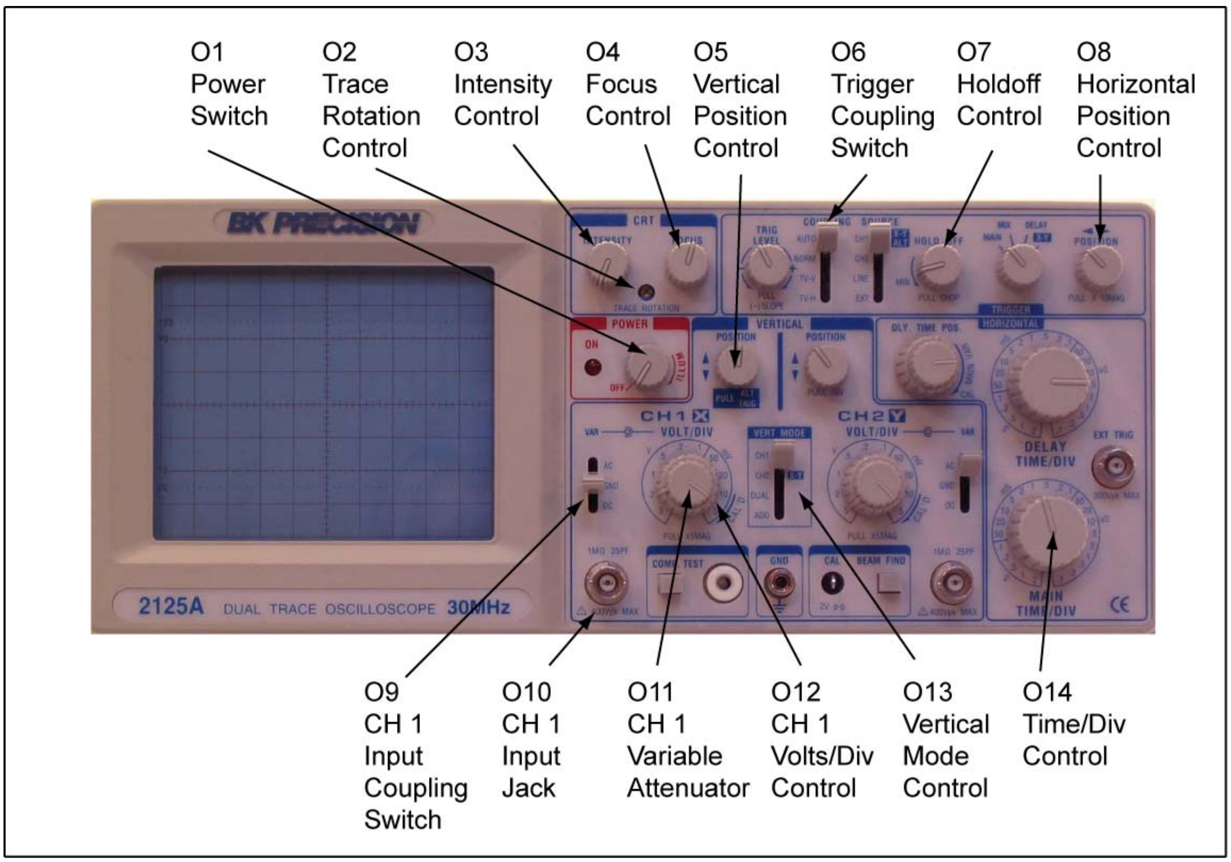


Figure 21 – 3 BK Precision 2125A Oscilloscope Controls for Lab 1

Electronics Technology and Robotics I Week 21
Oscilloscope Lab 2 – Displaying a DC Voltage and Dual Display

- **Purpose:** The purpose of this lab is to display a dc voltage and a dual voltage trace on an oscilloscope.

- **Apparatus and Materials:**

    - 1 – Oscilloscope
    - 1 – Function Generator
    - 1 – BNC Male to BNC Male Cable
    - 1 – 9 V Battery

- **Procedure:**
    - Leave the function generator **Main Output** connected to the **CH1 Input Jack** on the oscilloscope.
    - Set the **Vertical Mode Control** to Dual.
    - Connect a scope probe to the **CH 2 Input Jack**. The Channel 2 controls are identical to the Channel 1 controls except they are to the right of the **Vertical Mode Control**.
    - Adjust the **CH 2 Variable Attenuator** to the full clockwise position.
    - Set the **CH 2 Volts/Div Control** to 5.
    - Set the **CH 2 Input Coupling Switch** to DC.
    - Connect the probe's ground clip to the (–) terminal of the battery.
    - Set the probe slide switch to x1.
    - Connect the probe tip to the (+) terminal of the battery.
    - Turn on both the oscilloscope **Power Switch** and the function generator **Power Switch**.
    - Adjust the **CH 1 Vertical Position Control** and the **CH 2 Vertical Position Control** such that the ac signal is above the dc signal.

Electronics Technology and Robotics I Week 21
Oscilloscope Lab 3 – Other Dual Displays

- **Purpose:** The purpose of this lab is to display circuit inputs and outputs as a dual voltage trace on an oscilloscope.

- **Apparatus and Materials:**
  - 1 – Oscilloscope
  - 1 – Function Generator
  - 1 – BNC Male to BNC Male Cable
  - 1 – 9 V Battery

- **Procedure:**
  - **Inverter Circuit:**
    - Wire the 74LS04 below. Use a function generator set at a 1 KHz square wave as the input signal. Connect one of the six inverter inputs, e.g. A1, to the **CH 1 Input Jack** on the oscilloscope and one of the inverter outputs, e.g. Y1, to the **CH 2 Input Jack**.
    - Connect the input from the inverter circuit to channel 1 and the output from the inverter to channel 2.

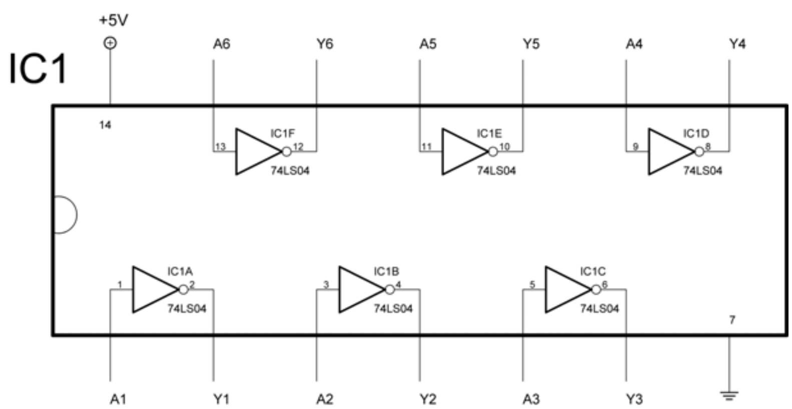


Figure 21 – 4 74LS04 Hex Inverter

$Y = \overline{A}$	
Input A	**Output Y**
L	H
H	L

H = High Logic Level (+5 V)
L = Low Logic Level (0 V)

Figure 21 – 5 Inverter Truth

- **Binary Count Circuit:**
  - Wire the following dual J-K flip-flop circuit.
  - Use a function generator set at a 1 KHz square wave as the clock input.
  - Connect Q1 to **CH 1 Input Jack** and Q2 to **CH 2 Input Jack** on the oscilloscope.

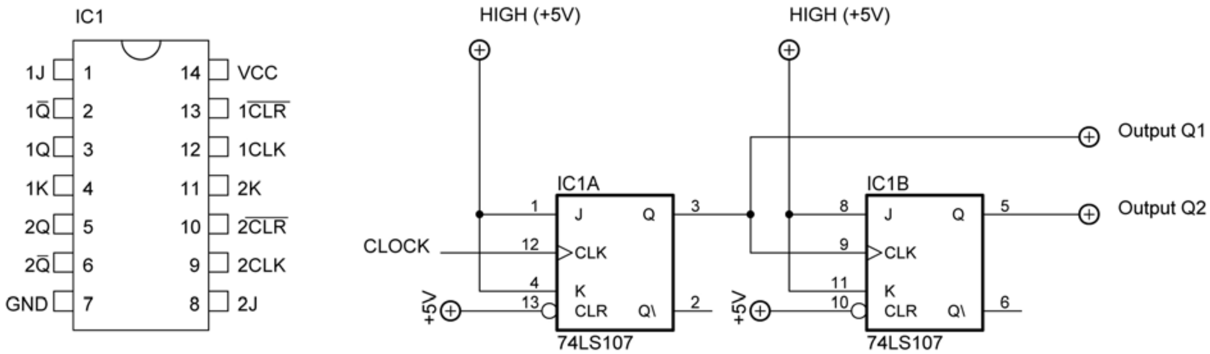


Figure 21 – 6 74LS107 Flip-Flop Pin Layout and Binary Counting Circuit

Decimal	Binary
0	00
1	01
2	10
3	11

Figure 21 – 7 Counting to 3 in Binary

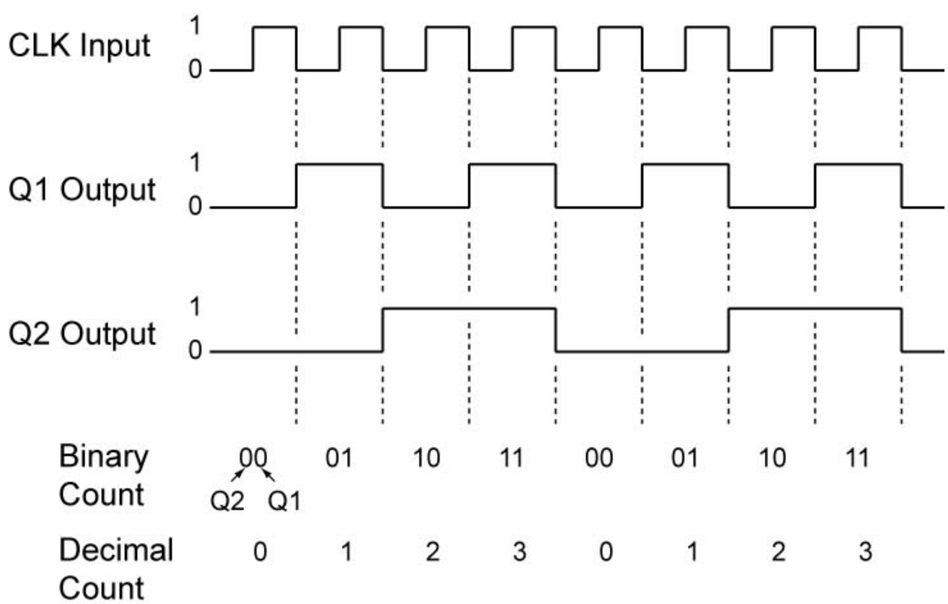


Figure 21 – 8 Q1 and Q2 Outputs

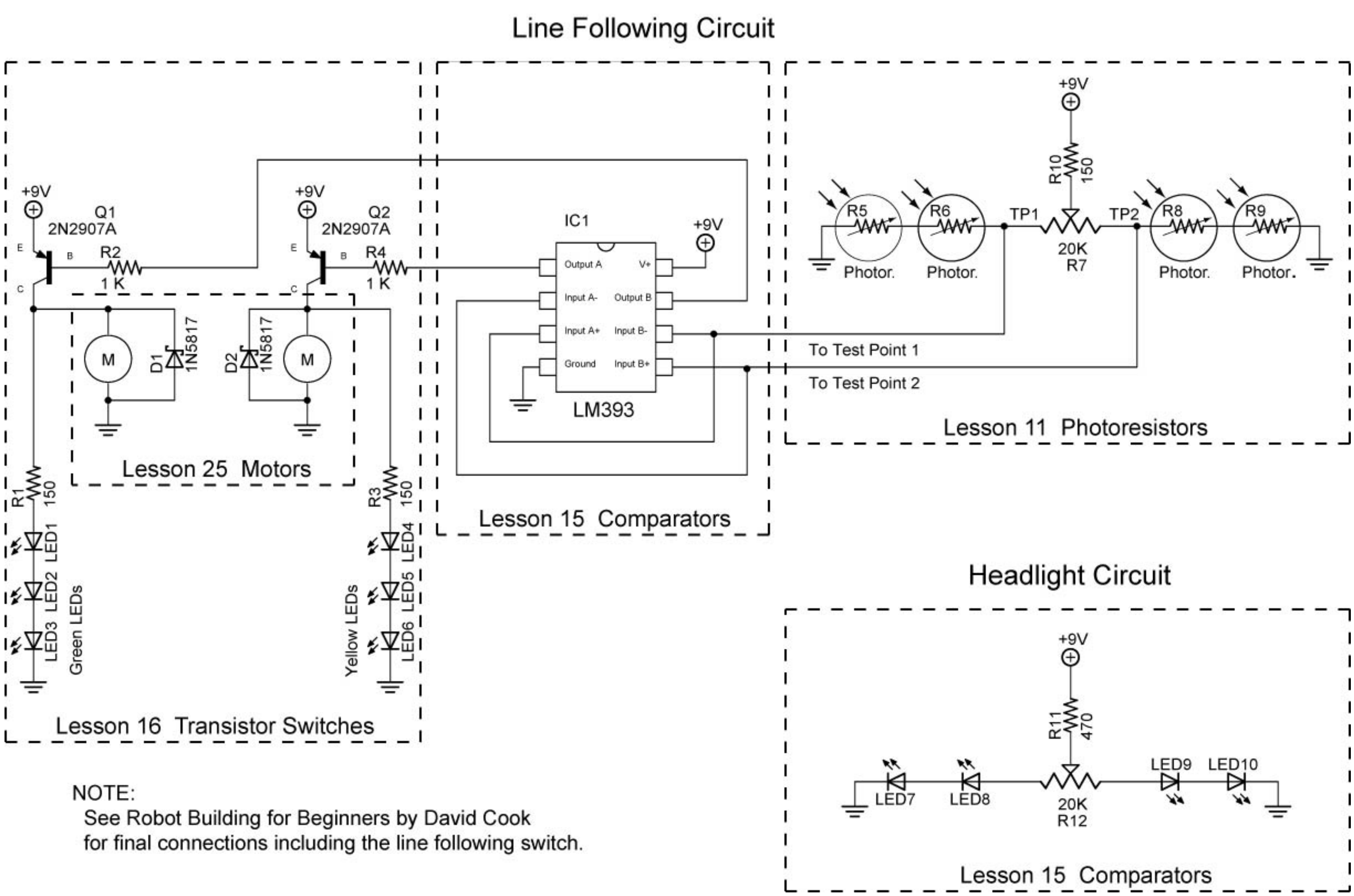
Electronics Technology and Robotics I Week 22
Sandwich PCB Lab 1 – Soldering Parts to PCB

- **Purpose:** The purpose of this lab is to solder the Sandwich parts to the Printed Circuit Board (PCB).

- **Apparatus and Materials:**

  - 1 – Soldering Iron and Accessories
  - Sandwich Parts including PCB

- **Procedure:**
  - Solder Sandwich Printed Circuit Board:
    - Follow steps on printout from http://www.robotroom.com/SandwichPCB.html
    - Wire motors, see page 389 Robot Building for Beginners
    - Wire the battery snap and the power switch in the same manner as the motors in the Sandwich Circuit Review:



Electronics Technology and Robotics I Week 24
Molex Connectors Lab 1 – Adding Molex Connectors

- **Purpose:** The purpose of this lab is to connect the Moles connectors and troubleshoot the Sandwich PCB.

- **Apparatus and Materials:**

  - Molex Connectors
  - Sandwich Parts including PCB

- **Procedure:**
  - Check for unsoldered and unconnected leads.
  - Make sure the red wire of the battery goes to the positive pin on the Molex power switch connector. The other pin of the Molex power switch connector should be wired to the positive voltage bus.
  - Connect all motors, switches and battery snap (without the battery).
  - Measure the power off and power on resistance:
    - Put multimeter on battery snaps with the battery not connected. Turn on and off the power switch. The off position should read infinite and the on position should read between 5,000 and 50,000 ohms.
    - Cover the photoresistors with your hand; the resistance of the circuit should be quite high.
    - Expose the photoresistors to light; the resistance should be low.
  - Power up the circuit board.
  - Check performance and troubleshoot.

Cornerstone Electronics Technology and Robotics Week 26
Sandwich Body Construction

- Wire Sandwich switch per page 410 in Robot Building for Beginners.
- Robot Building for Beginners, **Chapter 24, Body Building**
  - Position breadboard on the bottom of the container and against the front. Mark four screw holes.
  - Drill 7/64" holes for circuit board mounting. Assumes that you use #4 screws to mount circuit board.
  - Layout the center points for the motor mounting on grid paper, see page 450 in the Cook book. Transfer points to removable labels and draw 7.6 mm circle using the circle template. Apply label to each side of the container, 4.5 cm from the rear of the container. Measure up 4 mm from lip to bottom of 7.6 cm circle. See book for positioning. Poke holes in container using scribe.
  - Drill 7/64" holes in all centers of motor mount layout.
  - Using a grinding stone on the Dremel, grind out the motor shaft holes on each side of the container. Check motor alignment and screw holes. The raised section of the motor should stick out of the container.
  - Cut off the lid of the M & M candy tube. Measure 10.8 cm and cut off the bottom of the tube. Drill approximately a 1 cm hole at the mid-point of the tube,
  - Sand the ends of the tube to deburr.
  - Wrap approximately 120 cm of masking tape around one of the motors and approximately 60 cm of tape around the other motor. Test fit into M & M tube.
  - Pilot 7/64" hole for both switches and the battery holder. Grind out the switch holes to proper size.
  - Install power switch, line-following switch, and battery holder.
  - Install motors.
  - Install circuit board using #4-40 x 1 ½" s/s screws and 1" nylon spacers.
  - Attach switches, motors, and battery to the circuit board using the Molex connectors.
  - Attach and tighten the circuit board to the body. The board may have to be drilled out if #6 screws are used for mounting.
  - Drill 9/64" holes for tripots.
  - Cut elongated hole over photocells. Use razor knife.
  - Run Sandwich over dark of white line.

Electronics and Robotics I Week 29
Capacitance Lab 1 – Storing and Releasing Charge

- **Purpose:** The purpose of this lab is to verify that a capacitor stores electrical energy when a voltage is applied and that when the voltage source is removed, the capacitor returns its stored electrical energy to the circuit.

- **Apparatus and Materials:**
  - 1 – Digital Multimeter
  - 1 – 3 Volt Battery Power Supply
  - 1 – 2.5 Volt Lamp
  - 1 – Lamp Holder
  - 1 – 30,000 μF Capacitor (http://www.skycraftsurplus.com/index.asp?PAGEACTION=CONTACTUS)
  - 1 – 140,000 μF Capacitor (http://www.skycraftsurplus.com/index.asp?PAGEACTION=CONTACTUS)
  - 1 – 1,000,000 μF or 1F Capacitor (http://sciencekit.com/one-farad-capacitor/p/IG0024229/)
  - Alligator Clips

- **Procedure:**
  - Take an alligator clip and short the terminals of each capacitor.
  - Measure and record the voltage across each shorted capacitor.
  - Charge each capacitor with the 3 volt battery supply.
  - Measure and record the voltage across each charged capacitor.
  - Connect the 2.5 v lamp to each of the capacitors and remain connected until the lamp dims. Measure and record the time the lamp is lit.
  - Measure and record the voltage across each discharged capacitor.

- **Results:**

Capacitor Condition	30,000 uF Capacitor	140,000 uF Capacitor	1 F Capacitor
Voltage after Shorted	V	V	V
Voltage after Charged	V	V	V
Voltage after Discharge	V	V	V
Time for Discharge	S	S	S

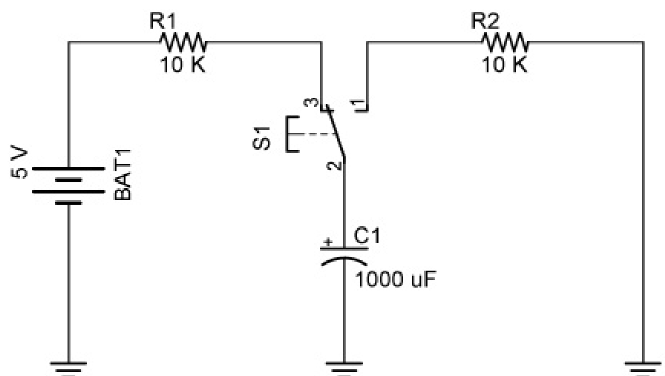
- **Conclusions:**
  - Which capacitor takes longer to discharge? Explain why.

- **Charging/Discharging a Capacitor Applet:** http://micro.magnet.fsu.edu/electromag/java/capacitor/index.html

Electronics and Robotics I Week 29

Capacitance Lab 2 – Charging and Discharging a Capacitor through a Resistor

- **Purpose:** The purpose of this lab is to verify the formula for the time constant, τ.
- **Apparatus and Materials:**
  - 1 – Breadboard with a 5 VDC Power Source
  - 2 – Digital Multimeters
  - 1 – Oscilloscope
  - 1 – Stop Watch
  - 2 – 10 K Resistors
  - 2 – 22 K Resistors
  - 1 – SPDT Switch
  - 1 – 1000 μF Capacitor
- **Procedure:**
  - Build the following circuit and place a voltmeter across the capacitor C1 and an ammeter between S1 and C1.
  - Qualitative Results:
    - Slide the switch toward the battery to charge the capacitor through resistor R1, and then slide the switch to the other position to discharge the capacitor through resistor R2.
    - Observe the voltage across and the current through the capacitor while switching back and forth. Record your observations.



$\tau = R\,C$

$\tau = 10.0 \times 10^{3}$ ohms $\times\ 1.0 \times 10^{-3}$ farads

$\tau = 10$ sec

Figure 30-12 Charging and Discharging a Capacitor through a Series Resistor

- Quantitative Results:
  - Measure and record the voltage across the power source.
  - Calculate and record 63.2% of the source voltage.
  - Measure and record the time in seconds it takes the capacitor to charge to 63.2 % of the source voltage (the definition of the time constant, τ).
  - Charge the capacitor until it is fully charged to the source voltage.
  - Subtract 63.2% of the source voltage from the value of the source voltage and record the result.
  - Measure and record the time in seconds it takes the capacitor to lose 63.2 % of its full charge (the definition of the time constant, τ).
- Replace the 2 – 10 K resistors with the 2 – 22 K resistors and repeat the Quantitative Results procedure used for the 10 K resistors.

- **Results:**
  - Qualitative Results:
    - When charging the capacitor, how does the voltage increase across the capacitor change with time?
    - When charging the capacitor, how does the current decrease through the capacitor change with time?
    - When discharging the capacitor, how does the voltage decrease across the capacitor change with time?
    - When discharging the capacitor, how does the current decrease through the capacitor change with time?
  - Quantitative Results:

Measurement	10 K Circuit	22 K Circuit
Power Source Voltage	V	V
63.2% of Power Source Voltage	V	V
Calculated Time to Charge 63.2% of Power Source Voltage	sec	sec
Measured Time to Charge 63.2% of Power Source Voltage	sec	sec
Power Source Voltage - 63.2% of Power Source Voltage	V	V
Calculated Time to Loose 63.2% of the Full Charge	sec	sec
Measured Time to Loose 63.2% of the Full Charge	sec	sec

- **Conclusions:**
  - Compare the calculated and measured times for the capacitor to charge to 63.2% of the power source (the time constant, □). If the two values are not equal, explain the discrepancy.
  - Compare the calculated and measured times for the capacitor to discharge to 63.2% of the power source (the time constant, □). If the two values are not equal, explain the discrepancy.

Electronics and Robotics I Week 29
Capacitance Lab 3 – Application of an RC Circuit

- **Purpose:** The purpose of this lab is to demonstrate an application of a capacitor in a 555 timer circuit.

- **Apparatus and Materials:**

  - 1 – Breadboard with a 5 VDC Power Source
  - 1 – Oscilloscope
  - 1 – 555 Timer IC
  - 2 – 47 K Resistors
  - 1 – 470 Ohm Resistor
  - 1 – 47 μF Capacitor
  - 1 - LED

- **Procedure:**
  - Wire the circuit in Figure 30 – 13.
    - Using an oscilloscope, observe the waveform across the capacitor on Channel 1 of the oscilloscope and compare it with the waveform on the output pin 3 on Channel 2.
    - Replace C1 with a 10 uF capacitor. Note the difference in waveform.

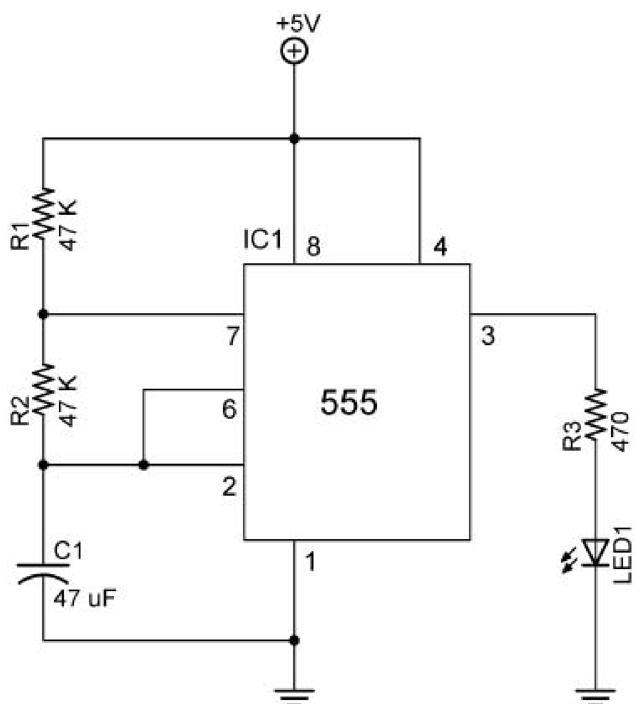


Figure 30 – 13 Basic Astable Circuit

- When charging C1, the current must pass through R1, R2, and C1. See Figure 30 – 14.
- When discharging, the current passes through only R2 and C1.
- With C1 = 10 μF, calculate and record the time constants for the charge and discharge cycles.

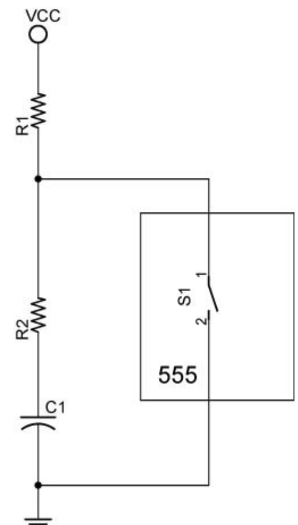


Figure 30 – 14, Simplified Diagram of C1 Charging through R1 & R2

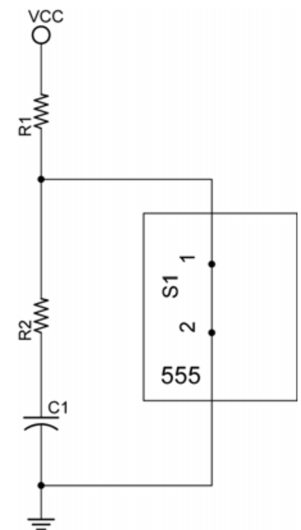
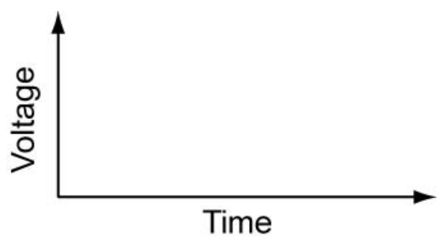
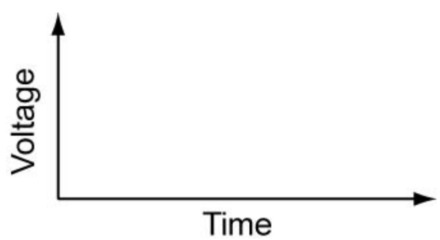


Figure 30 – 15, Simplified Diagram of C1 Discharging through R2

- **Results:**
  - Sketch the waveform across the capacitor.



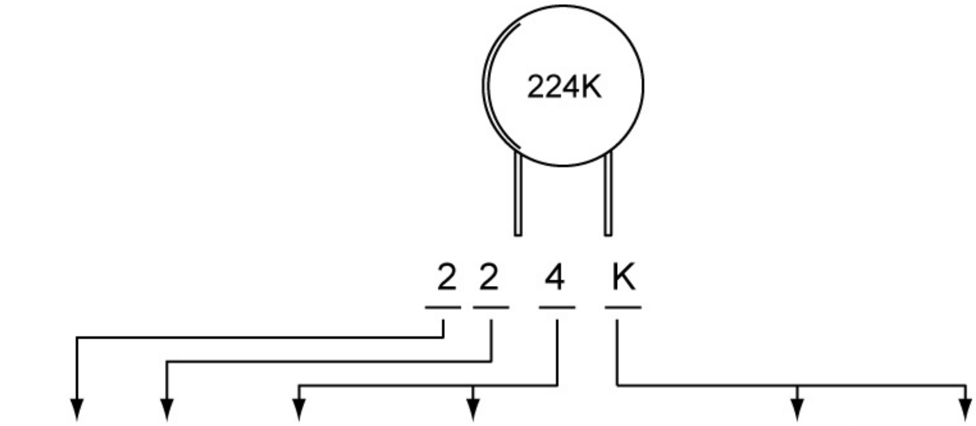
  - Sketch the waveform at the output pin 3.



- **Conclusions:**
  - Why does it take more time for the LED to light the first time than for the rest of the cycles?
  - Is the time the LED is on equal to the time it is off? Why or why not?

Capacitor Codes
Cornerstone Electronics Technology and Robotics I

Ceramic Disk Capacitor Value and Tolerance Codes:



First and Second Digits of Capacitance	Numerical Code	Multiply By (Additional # of Zeros)
22	0	10^0= 1 (0)
22	1	10^1= 10 (1)
22	2	10^2= 100 (2)
22	3	10^3= 1,000 (3)
22	4	10^4= 10,000 (4)
22	5	10^5= 100,000 (5)

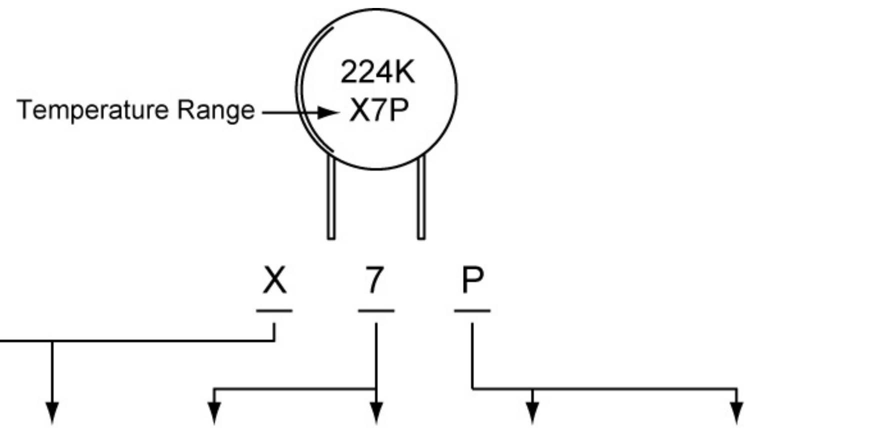
Letter Symbol	Tolerance
J	+/- 5%
K	+/- 10%
M	+/- 20%
P	+100%,-0%
Z	-20%,+80%

Example 224K: 22 x 10^4 pF = 220,000 pF = 220 nF = 0.22 μF +/- 10%.

Ceramic Disk Capacitor Temperature Code: See Page 2

Film Capacitor Value Code: See Page 3

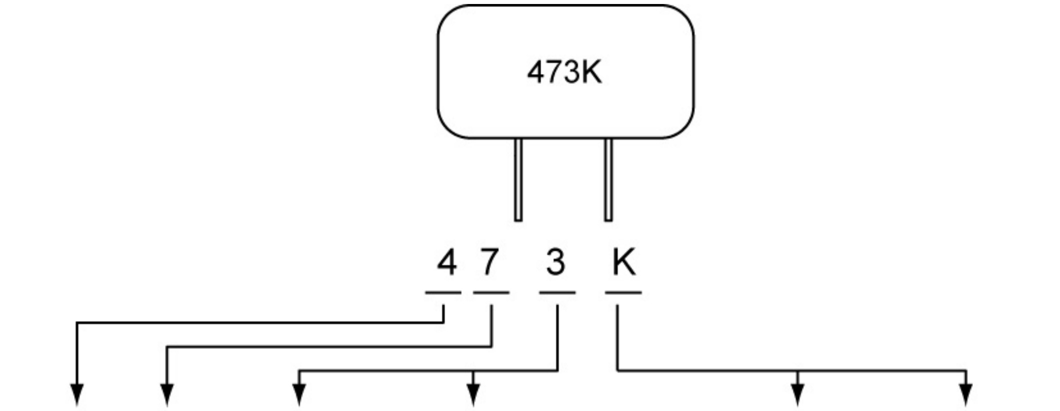
Ceramic Disk Capacitor Temperature Code:



Lettter Symbol	Low Temperature	Numerical Code	High Temperature	Lettter Symbol	Maximum Capacitance Change over Temperature Range
Z	+10^{0}C	2	+45^{0}C	A	+/- 1.0%
Y	-30^{0}C	4	+65^{0}C	B	+/- 1.5%
X	-55^{0}C	5	+85^{0}C	C	+/- 1.1%
-	-	6	+105^{0}C	D	+/- 3.3%
-	-	7	+125^{0}C	E	+/- 4.7%
-	-	-	-	F	+/- 7.5%
-	-	-	-	P	+/- 10.0%
-	-	-	-	R	+/- 15.0%
-	-	-	-	S	+/- 22.0%
-	-	-	-	T	+ 22%, - 33%
-	-	-	-	U	+ 22%, - 56%
-	-	-	-	V	+ 22%, - 82%

Example X7P: The letter X designates a low temperature of -55^{0} C. The digit 7 designates a high temperature of +125^{0} C. The letter P specifies that the capacitance will vary +/- 10% over the temperature range of -55^{0} C to +125^{0} C.

Film Capacitor Value and Tolerance Codes:



First and Second Digits of Capacitance	Numerical Code	Multiply By (Additional # of Zeros)
47	0	10^0= 1 (0)
47	1	10^1= 10 (1)
47	2	10^2= 100 (2)
47	3	10^3= 1,000 (3)
47	4	10^4= 10,000 (4)
47	5	10^5= 100,000 (5)

Letter Symbol	Tolerance
B	+/- 0.1 pF
C	+/- 0.25 pF
D	+/- 0.5 pF
F	+/- 1 pF
G	+/- 2.0 pF
H	+/- 3%
J	+/- 5%
K	+/- 10%
M	+/- 20%

Example 473K: 47 x 10^3 pF = 47,000 pF = 47 nF = 0.047 μF +/- 10%.