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Date: November 25, 2019
Professor Steven Gillette

Abstract
In this lab, I created 4 circuits to observe current, voltage, and switching behaviors of NPN and PNP transistors as a simulation of microprocessor control for a simulated work load including direct transistor switching and switching to a relay. Additionally, learned the concepts as to why a switching relay must have a flyback, or clamping diode installed in parallel with a coil relay.

Learning Objectives

- Use a transistor to interface a (simulated) microprocessor output and a load
- Build and test an "active high" transistor switch circuit
- Build and test an "active low" transistor switch circuit

Notes:

1. Took all voltage measurements relative to ground (unless otherwise stated)
2. Recorded relevant measurements and calculation results in data tables
3. Recorded all measured values on the circuit schematics
4. Used all available precision in calculations, rounded off answers to 3 significant figures

Materials

Quantity	Description
1	12V lamp
1	2N3904 or 2N2896 transistor
1	2N4403 transistor
1	1N4148 diode
1	12V relay
1	Base resistor (TBD)
1	Global Specialties trainer
1	Digital multimeter (DMM)

Procedure – Setup

1. Used an ohmmeter to measure the 12V lamp's cold resistance. Used Ohm's Law to ***calculated and record*** the expected operating current at room temperature.

   R = $\boxed{59.1\Omega}$ $I = \frac{E}{R} = \frac{12V}{59.1\Omega} = .203A = 203mA$

2. Built circuit 1. ***Measured and recorded*** the actual operating current at working temperature. Use this I_{load} value for the transistor interface design steps below.

   I = $\boxed{23.48mA}$ $R = \frac{E}{I} = \frac{12V}{23.48mA} = 511\Omega$ Resistance increased at operating current!

3. ***Measured and recorded*** the voltage outputs of the GS Trainer SW1 in the on and off positions. This switch simulates the voltage and current outputs for a typical microcontroller. Used the on value as V_{in} for the design calculations below. Ensured that the switch bank voltage selection was set to 5V to ensure that the switch was receiving 5V rather than the +12V source voltage.

   E = $\boxed{5.05V}$

Procedure – Lamp Driver Design & Test

4. Using Circuit 2 as a template, designed a lamp driver circuit that will operate with the SW1 input. Assume a transistor beta of 100.

   a. ***Calculated and recorded*** the desired base current using the Base Current Formula.

$$I_B = \frac{I_{load}}{\beta_{dc}} \frac{23.48mA}{100} = 235\mu A$$

   b. ***Calculated and recorded*** the base resistor value using the Base Resistor formula.

$$R_{base} = \frac{V_{in} - V_{BE}}{2 * \ I_{base}} = \frac{5.05V - 0.6V}{2 * 234\mu A} = \frac{4.45V}{4.696\mu A} = 9.51k\Omega$$

5. Built Circuit 2 **using a resistor nearest to** R_{base} value calculated above. 9.5kΩ

6. ***Measured and recorded*** V_{BE}, V_{LOAD}, V_{CE}, for both HIGH and LOW inputs from SW1.

	HIGH	**LOW**
V_{IN}	+5V	0V
V_{BE}	793mV	-22mV
V_{LOAD}	11.8V	0V
V_{CE}	169mV	0V

7. ***Demonstrated*** the circuit performance to the instructor or lab assistant for ***signature***. (See Attachment A – Signature and Lab Notes)

Procedure – Relay Driver Design & Test

8. ***Measured and recorded*** the resistance of the relay coil. ***Calculated and recorded*** the expected Circuit 3 current using Ohm's Law.

   R = $\boxed{362\Omega}$ $\quad I = \frac{E}{R} = \frac{12.03V}{362\Omega} = .33A = 33mA$

9. Using Circuit 3 as a template, designed a relay driver circuit that will operate with the SW1 input, assuming a transistor beta of 100.

a. ***Calculated and recorded*** the desired base current using the Base Current Formula.

$$I_B = \frac{I_{load}}{\beta_{dc}} \frac{33mA}{100} = 330\mu A$$

b. ***Calculated and recorded*** the base resistor value using the Base Resistor formula.

$$R_{base} = \frac{V_{in} - V_{BE}}{2 * \ I_{base}} = \frac{5.05V - 0.6V}{2 * 330\mu A} = \frac{4.45V}{660\mu A} = 6.74k\Omega$$

10. Built Circuit 3 **using a resistor nearest to** R_{base} value calculated above, 6.8kΩ.

11. ***Measured and recorded*** V_{BE}, V_{LOAD}, V_{CE}, for both HIGH and LOW inputs from SW1.

	HIGH	**LOW**
V_{IN}	+5V	0V
V_{BE}	800mV	-2.5mV
V_{LOAD}	11.8V	1.7V
V_{CE}	500µV	0.1V

12. ***Demonstrated*** the circuit performance to the instructor or lab assistant for ***signature***. (See Attachment A – Signature and Lab Notes)

Procedure – PNP Lamp Driver

13. Built Circuit 4. Connected the input first to +12, then to 0V (ground). Note; this circuit is "active low," meaning the input is driven low to turn on the transistor.

14. ***Measured and recorded*** V_{BE}, V_{LOAD}, V_{CE}, for both HIGH and LOW inputs from SW1. (12V & 0V)

	HIGH	**LOW**
V_{IN}	+12V	0V
V_{BE}	9.13V	-0.4mV
V_{LOAD}	2.18V	11.83V
V_{CE}	9.78V	111mV

15. ***Demonstrated*** the circuit performance to the instructor or lab assistant for signature. (See Attachment A – Signature and Lab Notes)

Formulas

Base Current

$$I_B = \frac{I_{load}}{\beta_{dc}}$$

Where;
I_B = base current
β_{dc} = transistor beta (gain)
I_{load} = operating current

Base Resistor

$$R_{base} = \frac{V_{in} - V_{BE}}{2 \times I_{base}}$$

Where;
R_{base} = base resistor (ohms)
2 = safety factor (current is limited by the load)
V_{in} = S1 high output voltage
V_{BE} = base emitter barrier potential
I_{base} = desired base current

Results Data

Lamp Driver Setup

Lamp Resistance (Ω)	Source Voltage	Expected Current (mA) I = E / R	Measured Current (mA)	GS Trainer SW1 Voltages	
				HI	LO
59.1Ω	12V	$I = \frac{12V}{59.1\Omega}$	203mA	5.05V	0V

Lamp Driver Design

Desired Base Current		
I_{LOAD}	b_{DC}	$I_B = I_{LOAD} / b_{DC}$
23.48mA	100	234µA

Base Resistor			
V_{IN} (SW1 HI)	V_{BE}	I_{BASE}	$R_{base} = \frac{V_{in} - V_{BE}}{2 \times I_{base}}$
5.05V	0.6V	234µA	9.5kΩ

Lamp Driver Test

	HIGH	LOW
V_{IN}	+5V	0V
V_{BE}	793mV	-22mV
V_{LOAD}	11.8V	0V
V_{CE}	169mV	0V

Results Data

Relay Driver Design

Coil Resistance (Ω)	Source Voltage	Expected Current (mA) I = E / R	GS Trainer SW1 Voltages	
			HI	LO
362Ω	12V	33mA	5.05V	0V

Desired Base Current		
I_{LOAD}	b_{DC}	$I_B = I_{LOAD} / b_{DC}$
33mA	100	330µA

Base Resistor			
V_{IN} (SW1 HI)	V_{BE}	I_{BASE}	$R_{base} = \frac{V_{in} - V_{BE}}{2 \times I_{base}}$
5.05V	0.6V	330µA	6.74kΩ

Relay Driver Test

	HIGH	LOW
V_{IN}	+5V	0V
V_{BE}	800mV	-2.5mV
V_{LOAD}	11.77V	1.7V
V_{CE}	500µV	0.1mV

PNP Lamp Driver Test

	HIGH	LOW
V_{IN}	+12V	0V
V_{BE}	9.13V	-0.4mV
V_{LOAD}	2.18V	11.83V
V_{CE}	9.78V	111mV

Critical Thinking

1. For circuit 1, why was the measured lamp current different than the calculated lamp current?

Resistance is affected by the heat of the filament. The resistance through the lamp was observed to increase.

2. Discuss the advantages of transistors over electromechanical contacts.

Transistors area significantly faster in operation and last longer between than mechanical switch contacts found in electromechanical relays. Additionally, transistors use significantly less current and take up less space than relays. Lastly, all these factors drive price down. Transistors cost less than relays.

3. Explain the reason for the protection diode in Circuit 3.

When a relay coil circuit is de-energized, the energy stored in the magnetic field of the coil tends to flow in the reverse direction. A protection diode will assist in preventing the current from flowing back into the circuit during the de-energizing phase of the inductor coil.

4. What did you learn with this lab?

This lab was an opportunity to observe the switching capabilities of the transistor simulating microprocessor control in both active high and active low configurations. It was also an opportunity to explore that resistance in incandescent lamps increases as a result of the heat generated from the filament and how flyback diodes can help protect a transistor circuit. Lastly, while we could not measure the speed of effect of switching on the lamp versus switching the relay, the experiment allowed for exploration of switching solid state and mechanical loads.

Appendix A – Signature and Lab Notes

SIERRA COLLEGE	MECH 10 - Lab 21 Transistor Drivers	Mechatronics Real Skills Real Jobs
Name Cayce Beaner		11/21/19

Learning Objectives

- Use a transistor to interface a (simulated) microprocessor output and a load
- Build and test an "active high" transistor switch circuit
- Build and test an "active low" transistor switch circuit

Notes:

1. Take all voltage measurements relative to ground (unless otherwise stated)
2. Record relevant measurements and calculation results in data tables
3. Record all measured values on the circuit schematics
4. Use all available precision in calculations, round off answers to 3 significant figures

Materials

Quantity	Description
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1	2N4403 transistor
1	1N4148 diode
1	12V relay
1	Base resistor (TBD)
1	Global Specialties trainer
1	Digital multimeter (DMM)

Procedure – Setup

1. Use an ohmmeter to measure the 12V lamp's cold resistance. Use Ohm's Law to ***calculate and record*** the expected operating current at room temperature. $I = \frac{E}{R} = \frac{12V}{59.1\Omega} = \boxed{203mA}$
2. Build circuit 1. ***Measure and record*** the actual operating current at working temperature. Use this I_{load} value for the transistor interface design steps below. 23.43mA ? $R = \frac{12V}{23.43mA}$ Resistance up when hot 511Ω
3. ***Measure and record*** the voltage outputs of the GS Trainer PB1 in the on and off positions. This switch simulates the voltage and current outputs for a typical microcontroller. Use the on value as V_{in} for the design calculations below. 5.05V √ Troubleshoot the trainer if the PB1 voltage outputs are not +5V HI, 0.0V LO.

5V

Used the +5V setting not +V or 12V setting

Procedure – Lamp Driver Design & Test

4. Using Circuit 2 as a template, design a lamp driver circuit that will operate with the PB1 input. Assume a transistor beta of 100.
   a. ***Calculate and record*** the desired base current using the Base Current Formula. Show your work. $\frac{23.43mA}{100} = 234\mu A$
   b. ***Calculate and record*** the base resistor value using the Base Resistor formula. Show your work. $R_b = \frac{5.05V - 0.6V}{2 \times 234\mu A} = \frac{4.45}{4.696\mu A} = 9.51 K\Omega$

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9.51 kΩ

~~5.~~ Build Circuit 2 using the R_{base} value calculated above.

~~6.~~ ***Measure and record*** V_{BE}, V_{LOAD}, V_{CE}, for both HIGH and LOW inputs from PB1.

SDJ ~~7.~~ ***Demonstrate*** the circuit performance to the instructor or lab assistant for ***signature***.

Procedure – Relay Driver Design & Test

~~8.~~ ***Measure and record*** the resistance of the relay coil. ***Calculate and record*** the expected Circuit 3 current using Ohm's Law. 367Ω

~~9.~~ Using Circuit 3 as a template, design a relay driver circuit that will operate with the PB1 input. Assume a transistor beta of 100.

~~a.~~ ***Calculate and record*** the desired base current using the Base Current Formula. Show your work. $\frac{33mA}{100} = 330\mu A$

b. ***Calculate and record*** the base resistor value using the Base Resistor formula. Show your work. $\frac{5.05-.6}{2 \times 330\mu A} = 6.742k\Omega$

~~10.~~ Build Circuit 3 using the R_{base} value calculated above.

~~11.~~ ***Measure and record*** V_{BE}, V_{LOAD}, V_{CE}, for both HIGH and LOW inputs from PB1.

SDJ ~~12.~~ ***Demonstrate*** the circuit performance to the instructor or lab assistant for ***signature***.

Procedure – PNP Lamp Driver

~~13.~~ Build Circuit 4. Connect the input first to +12, then to 0V (ground). Note; this circuit is "active low," meaning the input is driven low to turn on the transistor.

~~14.~~ ***Measure and record*** V_{BE}, V_{LOAD}, V_{CE}, for both HIGH and LOW inputs from PB1. (12V & 0V)

SDJ ~~15.~~ ***Demonstrate*** the circuit performance to the instructor or lab assistant for signature.

Formulas

Base Current

$$I_B = \frac{I_{load}}{\beta_{dc}}$$

Where;
I_B = base current
β_{dc} = transistor beta (gain)
I_{load} = operating current

Base Resistor

$$R_{base} = \frac{V_{in} - V_{BE}}{2 \times I_{base}}$$

Where;
R_{base} = base resistor (ohms)
2 = safety factor (current is limited by the load)
V_{in} = S1 high output voltage
V_{BE} = base emitter barrier potential
I_{base} = desired base current

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Results Data

Lamp Driver Setup

Lamp Resistance (Ω)	Source Voltage	Expected Current (mA) I = E / R	Measured Current (mA)	~~PB1~~ SW1 GS Trainer Voltages	
				HI	LO
59.1Ω	12V	$I = \frac{12V}{59.1\Omega}$	203mA	5.05V	0V

Lamp Driver Design

Desired Base Current		
I_{LOAD}	β_{DC}	$I_B = I_{LOAD} / \beta_{DC}$
23.48mA	100	234μA

Base Resistor			
V_{IN} (PB1 HI)	V_{BE}	I_{BASE}	$R_{base} = \frac{V_{in} - V_{BE}}{2 \times I_{base}}$
5.05V	0.6V	234μA	9.51kΩ

Using 9.5kΩ

Lamp Driver Test

	HIGH	LOW
V_{IN}	+5V	0V
V_{BE}	793mV	- 22mV
V_{LOAD}	11.8V	0V
V_{CE}	169mV	0V

Results Data

Relay Driver Design

Coil Resistance (Ω)	Source Voltage	Expected Current (mA) I = E / R	sw1 GS Trainer ~~PB1~~ Voltages	
			HI	LO
362Ω	12.03V 12V	33mA	5.05	0V

Desired Base Current		
I_{LOAD}	β_{DC}	$I_B = I_{LOAD} / \beta_{DC}$
33mA	100	330μA

Base Resistor			
V_{IN} (sw1 ~~PB1~~ HI)	V_{BE}	I_{BASE}	$R_{base} = \dfrac{V_{in} - V_{BE}}{2 \times I_{base}}$
5.05V	0.6V	330μA	6.74kΩ

Using 6.8kΩ

Relay Driver Test

	HIGH	LOW
V_{IN}	+5V	0V
V_{BE}	800mV	-2.5mV
V_{LOAD}	11.77V	-1.7V
V_{CE}	500μV	0.1mV

PNP Lamp Driver Test

	HIGH	LOW
V_{IN}	+12V	0V
V_{BE}	9.13V	-0.4mV
V_{LOAD}	2.18V	11.83V
V_{CE}	9.78V	111mV

Critical Thinking

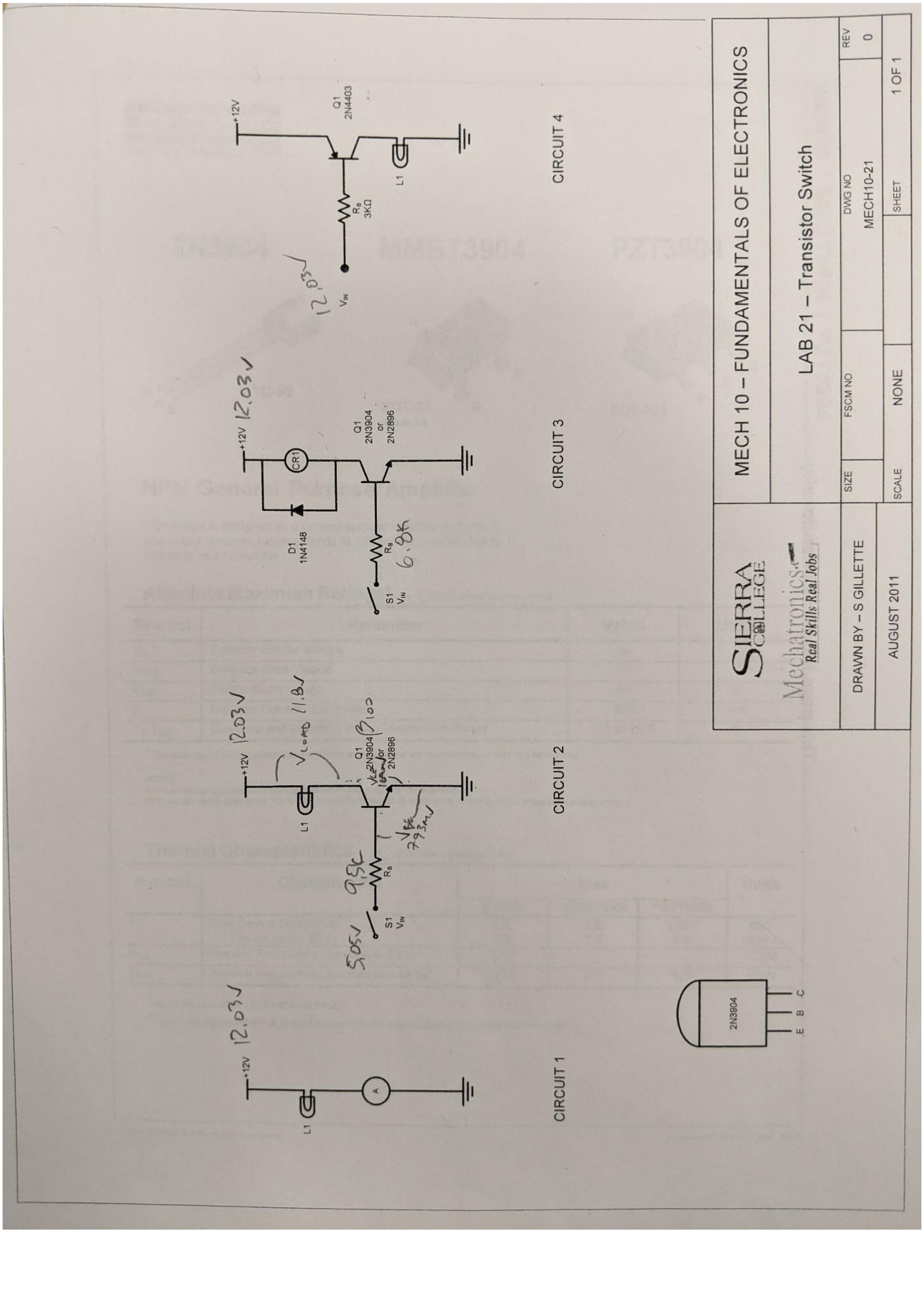
1. For circuit 1, why was the measured lamp current different than the calculated lamp current? resistance is affected by heat of filament
2. Discuss the advantages of transistors over electromechanical contacts. fast, life.
3. Explain the reason for the protection diode in Circuit 3. protect from rev current when switched off
4. What did you learn with this lab?

Grading Criteria

		Points Possible	Points Earned
Documentation	Abstract, introduction, experiment, data results, conclusions, attachments, clarity, spelling, grammar	**10**	
Setup	Currents calculated, measured, and recorded.	**5**	
Lamp Driver	Base current and resistor calculated; Circuit values measured and recorded; circuit demonstrated & signed off	**10**	
Relay Driver	Base current and resistor calculated; Circuit values measured and recorded; circuit demonstrated & signed off	**10**	
PNP Lamp Driver	Circuit values measured and recorded; circuit demonstrated & signed off	**10**	
Critical thinking	Questions answered completely & accurately. State conclusions drawn and lessons learned from the lab	**10**	
On-time submittal	Lab report is submitted in accordance with the assignment due date as posted on Canvas	**5**	
	Total	**60**	

Lab Report Format

Abstract - a summary and high-level overview of the lab and its results
Introduction - State the objectives of the laboratory and list the equipment required
Experiment - Describe the procedure used to carry out the lab
Results Data - list all data taken in table or graphical format
Critical Thinking - State the conclusions drawn and lessons learned from the laboratory activities. Answer any questions found within the lab procedure.
Attachments – grading criteria, verification signatures, circuit diagrams, lab procedures & notes



MECH 10 – FUNDAMENTALS OF ELECTRONICS
LAB 21 – Transistor Switch
SIERRA COLLEGE
Mechatronics
Real Skills Real Jobs
DRAWN BY – S GILLETTE
AUGUST 2011
SIZE
FSCM NO
DWG NO
MECH10-21
REV
0
SCALE
NONE
SHEET
1 OF 1
CIRCUIT 1
CIRCUIT 2
CIRCUIT 3
CIRCUIT 4
+12V
L1
Q1
2N3904
or
2N2896
D1
1N4148
CR1
S1
VIN
RB
3KΩ
2N4403
2N3904
E B C
12.03V
5.05V
9.5K
6.8K
11.8V

Grading Criteria

		Points Possible	Points Earned
Documentation	Abstract, introduction, experiment, data results, conclusions, attachments, clarity, spelling, grammar	**10**	
Setup	Currents calculated, measured, and recorded.	**5**	
Lamp Driver	Base current and resistor calculated; Circuit values measured and recorded; circuit demonstrated & signed off	**10**	
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