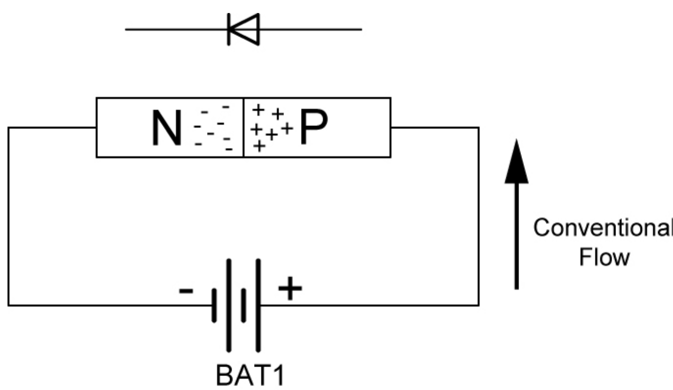
Cornerstone Electronics Technology and Robotics I Week 16
Diodes and Transistor Switches

- Administration:
  - Prayer
  - Turn in quiz
- Review:
  - Design and wire a voltage divider that divides your +9 V voltage source into thirds and where the current through all three resistors is approximately 3 mA.
- Electricity and Electronics, **Section 17.2,** Semiconductor Diodes:
  - A diode is a device designed to permit electron flow in one direction and to block flow in the other direction.
  - Structure: A semiconductor diode is made of N-type and P-type semiconductors that are fused together. The N-type material has a surplus of electrons (thus the negative charge), and the P-type material is deficient in electrons (thus the positive charge).

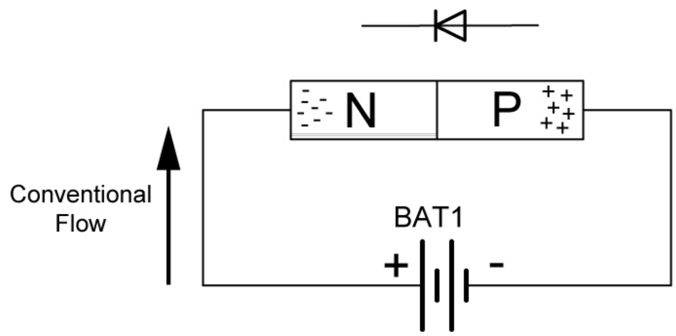
  - Semiconductor Diode Symbol: The cathode contains the N-type material and the anode contains the P-type material.

  - Forward Biased: Once a small potential (approximately 0.6 V) is applied to the diode, current will flow through the diode. This drawing is for illustration purposes only; a load must be in the circuit for a forward biased diode otherwise it may be considered a short circuit. Remember that the direction of electron flow is opposite that of conventional flow.



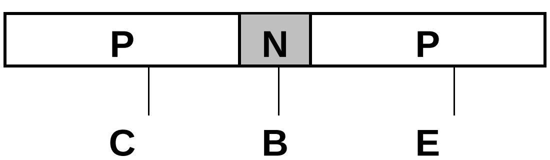
Forward Biased Diode

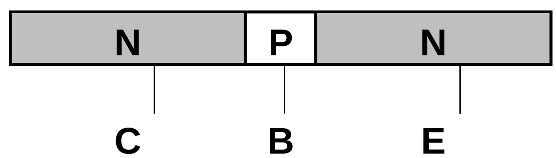
- Reversed Biased: Current will not flow through the diode until it is raised to the breakdown voltage.



Reversed Biased Diode

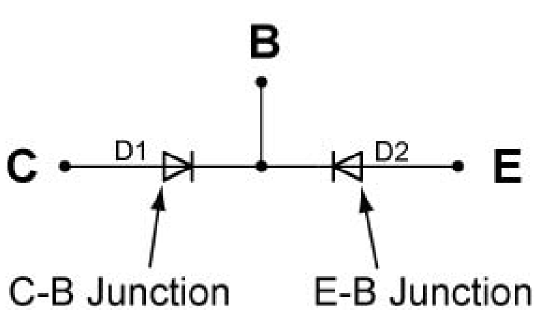
- Robot Building for Beginners, **Chapter 16,** Transistor Switches:
    - Perform Diodes and Transistor Switches Lab 1- LM393N Current Limitations.
    - Lab 1 revealed the current capability limitations of the LM393 comparator. Because most chips use their output pins only to send signals to other circuit devices, this problem has been solved. This lesson will employ a bipolar transistor as the solution for this problem.
    - Bipolar Transistors, PNP and NPN:
        - Transistors are made of N-type and P-type semiconductor materials like diodes, but they have three leads.
        - Basic structure of PNP and NPN transistor:



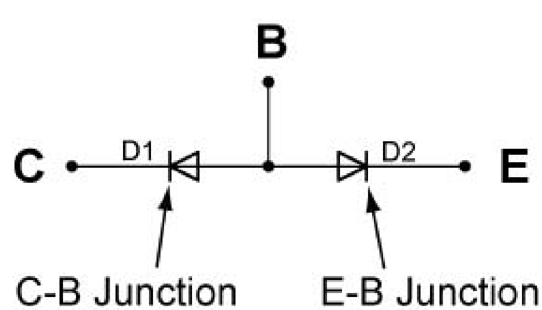


Where C = Collector
B = Base
E = Emitter

- PNP and NPN Transistor Equivalent Diode Models: Two discrete diodes connected back to back will not function as a transistor. The models serve only to help visualize the structure of a transistor. The two PN junctions must be formed on a single wafer of silicon.

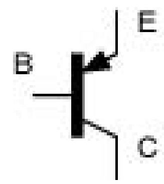


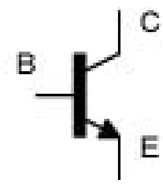
PNP Equivalent Circuit



NPN Equivalent Circuit

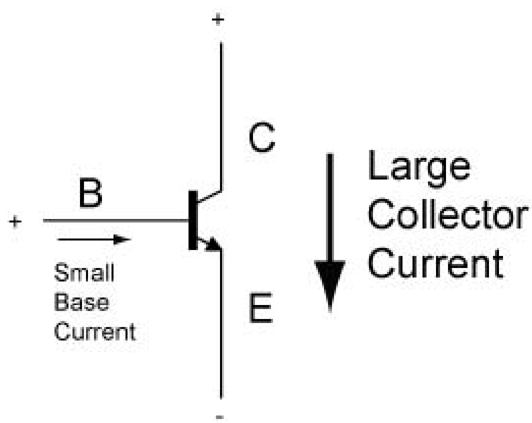
- Schematic Symbols:

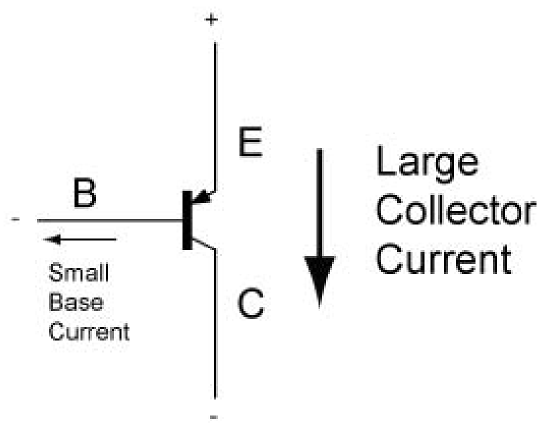




PNP Transistor **NPN Transistor**

  - For a PNP transistor, the arrow points toward the base; for the NPN transistor, the arrow points away from the base (NPN – "**N**ot be **P**ointing i**N**").
  - The arrow points toward the direction of current flow - toward ground.
- Transistors are current controlling devices. A very small current flowing through the base can control a larger current flowing through the collector/emitter junction. See figures below.

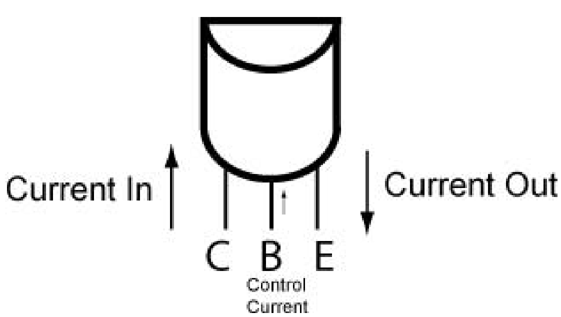


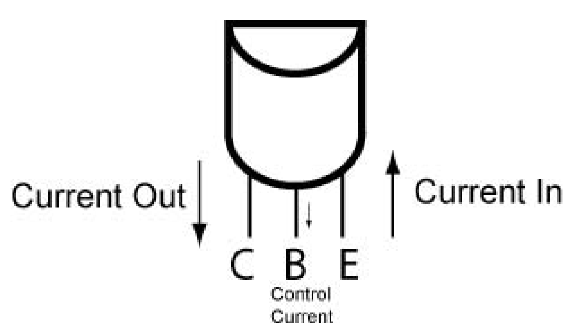


NPN **PNP**

Note that in the NPN transistor, the base current flows into the base while in the PNP transistor, the base current flows out of the base.

- Typical Lead Layout for NPN and PNP Transistors (TO-92 package):





NPN Transistor Lead Configuration **PNP Transistor Lead Configuration**

- Current in Bipolar Transistors (NPN and PNP):

$$I_E = I_C + I_B$$

Where: I_E = Emitter current
I_C = Collector current
I_B = Base current

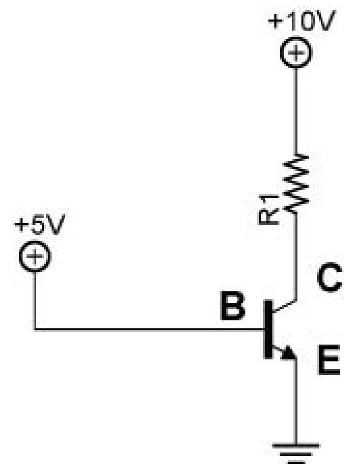
- Amplification (β):

$$\beta = I_C/I_B,\ I_C = \beta\ I_B$$

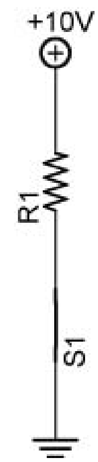
Where: β = Amplification
I_C = Collector current
I_B = Base current

- See: http://www.learnabout-electronics.org/bipolar_junction_transistors_05.php
- Perform Diodes and Transistor Switches Lab 2 – Testing a 2N2222A NPN Transistor.
- Sample Sizes:
  - TO-92
  - SOIC-16
  - SOT-23
  - DIP-14

o Transistors as Switches:
  - On/Off switching in a transistor is controlled by the biasing of the transistor's base-to-emitter junction.
    - If the base-to-emitter junction is forward biased, the transistor turns On. The low resistance between the collector and emitter permits current to flow similar to a closed switch.
    - When a transistor is On, it is driven into saturation, i.e., the bias voltage is increased to such a point that any further increase in bias voltage will not cause any further increase in current through the collector and emitter.

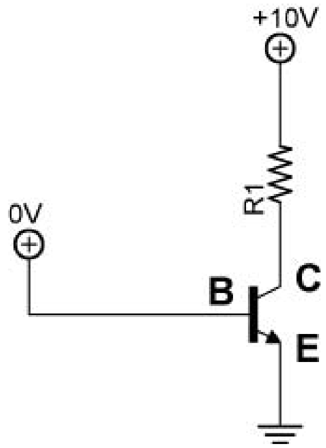


NPN B-E Junction Forward Biased

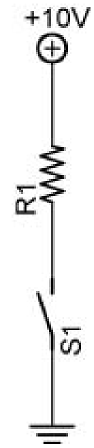


Equivalent Closed Switch Circuit

- If the base-to-emitter junction is reversed biased, the transistor turns Off. The high resistance between the collector and emitter stops current flow similar to an open switch.
- When a transistor is Off, it is driven into cutoff, i.e., the bias voltage is decreased to such a point that it stops current through the collector and emitter.



NPN B-E Junction Reversed Biased



Equivalent Open Switch Circuit

See applets: http://www.falstad.com/circuit/e-pnp.html
http://www.falstad.com/circuit/e-npn.html

- The transistor isn't a perfect switch. When Off there is a small current that flows (measured in nA) and when On it has a small voltage drop (~0.2V depending on the collector & base currents).
- Calculating the base resistor value in a transistor switch circuit:
    1. Calculate the collector current assuming the transistor switch is On. In our case:

       $I_C = V_{R2}/R_2$

       Where: I_C = Collector current
       V_{R2} = Voltage drop across R_2
       R_2 = Resistance of R_2

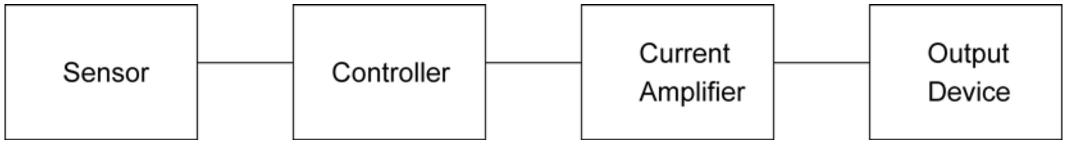
       $I_C = V_{R2}/R_2$
       $I = (9V – 0.2V)/$

    2. First calculate the collector current when the switch is on. I = V/R = (12V – 0.2V)/100? = 118mA. Now calculate the needed base current required to turn on the transistor. Looking at the datasheet, H could be as low as 30 at 100mA. The base current should then be I / H = 118mA/30 = 4mA. We will add a factor of two for safety and use a base current of 8mA (to make sure the transistor turns on fully). Finally calculate the

value for R2, the base resistor. Note: When the transistor is turned on there will be about a 0.7V drop across the base emitter junction. Therefore R2 = V/Ib = (5V – 0.75V)/8mA = 531?. This value isn't critical so use the closest standard value (560?) from http://www.physics.unlv.edu/~bill/PHYS483/transbas.pdf

    - Perform Diodes and Transistor Switches Lab 3 – NPN and PNP Transistor Load Placement
    - Perform Diodes and Transistor Switches Lab 4 – NPN and PNP Transistor Switches.
- 2N2907A Transistor:
    - Bipolar PNP general purpose amplifier transistor
    - Data Sheets:
        - http://www.eletrica.ufsj.edu.br/ensino/eletronica1/pasta/2n2907.pdf
        - http://www.fairchildsemi.com/ds/PN/PN2907A.pdf
    - The 2N2907A can source 800 mA continuously which is greater than our needs for the two motors and six LEDs.
- See applet: http://www.falstad.com/circuit/e-transswitch.html
- Perform Diodes and Transistor Switches Lab 4 – NPN Switch Circuit Application

- Block diagram of Sandwich circuits:



  - Sensor: Photoresistors
  - Controller: LM393 dual comparator
  - Current Amplifier: 2N2907A transistors
  - Output Device: LED’s and dc motors
- Perform Diodes and Transistor Switches Lab 5 – Brightness Comparator

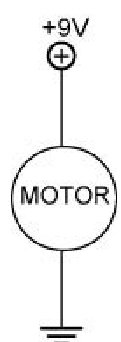
Electronics Technology and Robotics I Week 16
Diodes and Transistor Switches Lab 1 – LM393N Current Limitations

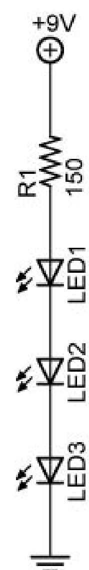
- **Purpose:** The purpose of this lab is to acquaint the student with the current limitations of the LM393 voltage comparator.

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

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

Characteristic	Symbol	LM392, LM393			LM2903, LM2903V			Unit
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage (Note 2) T_A = 25°C $T_{low} \le T_A \le T_{high}$	V_{IO}	 – –	 ±1.0 –	 ±5.0 9.0	 – –	 ±2.0 9.0	 ±7.0 15	mV
Input Offset Current T_A = 25°C $T_{low} \le T_A \le T_{high}$	I_{IO}	 – –	 ±5.0 –	 ±50 ±150	 – –	 ±5.0 ±50	 ±50 ±200	nA
Input Bias Current (Note 3) T_A = 25°C $T_{low} \le T_A \le T_{high}$	I_{IB}	 – –	 25 –	 250 400	 – –	 25 200	 250 500	nA
Input Common Mode Voltage Range (Note 3) T_A = 25°C $T_{low} \le T_A \le T_{high}$	V_{ICR}	 0 0	 – –	 V_{CC} –1.5 V_{CC} –2.0	 0 0	 – –	 V_{CC} –1.5 V_{CC} –2.0	V
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 $V_{in} \ge$ 1.0 Vdc, V_{in+} = 0, $I_{Sink} \le$ 4.0 mA, T_A = 25°C $T_{low} \le T_A \le T_{high}$	V_{OL}	 – –	 150 –	 400 700	 – –	 – 200	 400 700	mV
Output Leakage Current V_{in-} = 0 V, $V_{in+} \ge$ 1.0 Vdc, V_O = 5.0 Vdc, T_A = 25°C V_{in-} = 0 V, $V_{in+} \ge$ 1.0 Vdc, V_O = 30 Vdc, $T_{low} \le T_A \le T_{high}$	I_{OL}	 – –	 0.1 –	 – 1000	 – –	 0.1 –	 – 1000	nA
Supply Current $R_L = \infty$ Both Comparators, T_A = 25°C $R_L = \infty$ Both Comparators, V_{CC} = 30 V	I_{CC}	 – –	 0.4 –	 1.0 2.5	 – –	 0.4 –	 1.0 2.5	mA

*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

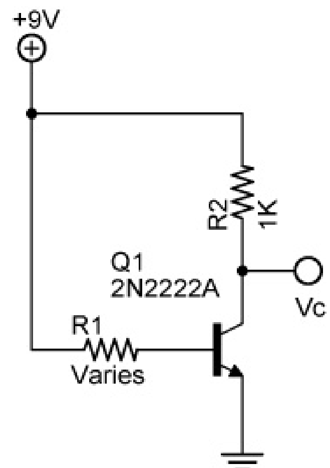
NOTES: 2. At output switch point, $V_O \simeq$ 1.4 Vdc, R_S = 0 Ω with V_{CC} from 5.0 Vdc to 30 Vdc, and over the full input common mode range (0 V to V_{CC} = –1.5 V).
3. Due to the PNP transistor inputs, bias current will flow out of the inputs. This current is essentially constant, independent of 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

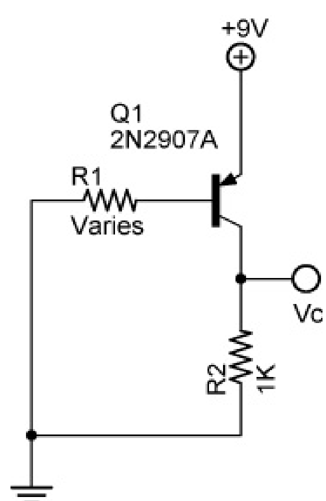
- **Purpose:** The purpose of this lab is to measure important variables for the operation of a 2N2222A NPN and 2N2907A PNP transistors.

- **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:**
  - 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 β remain relatively constant?
  - At what value of resistor do you think the transistor acts as a switch?

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

R2 (R_C) = 1K Ohm:

R_1 (Ω)	I_B (mA)	I_C (mA)	V_C (V)	β
10M	0.0007	0.176	8.86	251
1M	0.0084	1.91	7.14	228
820K	0.0099	2.08	6.94	210
680K	0.0123	2.42	6.55	197
560K	0.0150	2.98	5.97	199
470K	0.0179	3.44	5.46	192
390K	0.0214	4.24	4.64	198
330K	0.0249	4.92	3.93	198
270K	0.0304	6.84	2.22	225
220K	0.0380	8.33	0.75	219
180K	0.0463	8.67	0.39	187
150K	0.0555	8.71	0.36	157
120K	0.0691	8.74	0.34	126
100K	0.0827	8.75	0.33	106
47K	0.174	8.78	0.30	50
33K	0.254	8.79	0.28	35
10K	0.827	8.86	0.23	11
3.3K	2.53	8.87	0.20	4
1.0K	8.30	8.85	0.20	1

R2 = 100 Ohm:

R_1 (Ω)	I_B (mA)	I_C (mA)	V_C (V)	β
				#DIV/0!
10M	0.0007	0.177	8.98	256
1M	0.0082	1.88	8.80	231
820K	0.0099	2.32	8.83	234
680K	0.0122	2.86	8.78	234
560K	0.0149	3.52	8.71	236
470K	0.0179	4.25	8.63	237
390K	0.0213	5.09	8.55	239
330K	0.0251	6.01	8.45	239
270K	0.0305	7.47	8.30	245
220K	0.0381	9.34	8.11	245
180K	0.0465	11.70	7.88	252
150K	0.0555	13.78	7.64	248
120K	0.0687	17.05	7.31	248
100K	0.0821	20.5	6.92	250
47K	0.171	42.4	4.69	248
33K	0.245	58.4	3.01	238
10K	0.784	79.9	0.90	102
3.3K	2.39	79.6	0.83	33
1.0K	7.93	80.7	0.70	10

Base and Collector Currents through a Random 2N2222A Transistor for a Varity of Base Resistors (5% Tolerance)
(Test setup according to the 2N2222A schematic in this lab.)

- 2N2907A PNP Transistor Sample Results:

R2 = 1K Ohm:

R_1	I_B	I_C	V_C	β
(Ω)	(mA)	(mA)	(V)	
				#DIV/0!
10M	0.0007	0.128	0.12	183
1M	0.0084	1.29	1.28	153
820K	0.0099	1.52	1.51	153
680K	0.0122	1.86	1.84	153
560K	0.015	2.25	2.25	150
470K	0.0179	2.66	2.66	149
390K	0.0214	3.15	3.15	147
330K	0.0252	3.69	3.69	146
270K	0.0305	4.48	4.47	147
220K	0.0382	5.57	5.55	146
180K	0.0465	6.64	6.62	143
150K	0.0558	7.73	7.71	139
120K	0.0692	8.58	8.55	124
100K	0.0829	8.76	8.73	94
47K	0.175	8.80	8.78	50
33K	0.254	8.83	8.79	35
10K	0.829	8.87	8.84	11
3.3K	2.51	8.88	8.85	4
1.0K	8.26	8.88	8.85	1

R2 = 100 Ohm:

R_1	I_B	I_C	V_C	β
(Ω)	(mA)	(mA)	(V)	
				#DIV/0!
10M	0.0008	0.130	0.01	163
1M	0.0084	1.32	0.13	157
820K	0.010	1.56	0.16	156
680K	0.0120	1.92	0.19	160
560K	0.0150	2.36	0.24	157
470K	0.0179	2.82	0.29	158
390K	0.0214	3.37	0.34	157
330K	0.0252	3.99	0.40	158
270K	0.0306	4.90	0.50	160
220K	0.0383	6.10	0.62	159
180K	0.0467	7.44	0.75	159
150K	0.0559	8.99	0.91	161
120K	0.0694	11.46	1.16	165
100K	0.0829	13.44	1.36	162
47K	0.175	29.7	2.99	170
33K	0.253	41.0	4.14	162
10K	0.810	79.2	8.00	98
3.3K	2.45	82.0	8.28	33
1.0K	8.09	82.3	8.32	10

Base and Collector Currents through a Random 2N2907A Transistor for a Varity of Base Resistors (5% Tolerance)
(Test setup according to the 2N2907A schematic in this lab.)

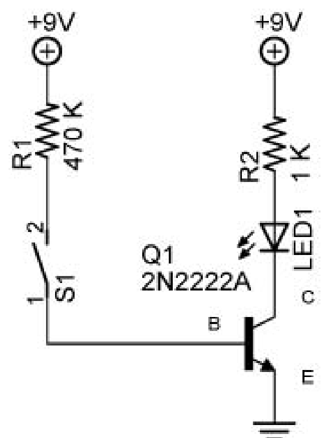
Electronics Technology and Robotics I Week 16
Diodes and Transistor Switches Lab 3 – NPN and PNP Transistor Load Placement

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

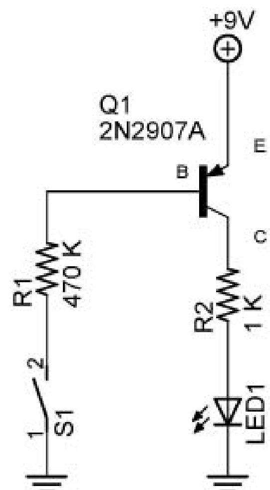
- **Apparatus and Materials:**

  - 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 Ω Resistor
  - 1 – 1 K Ω 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

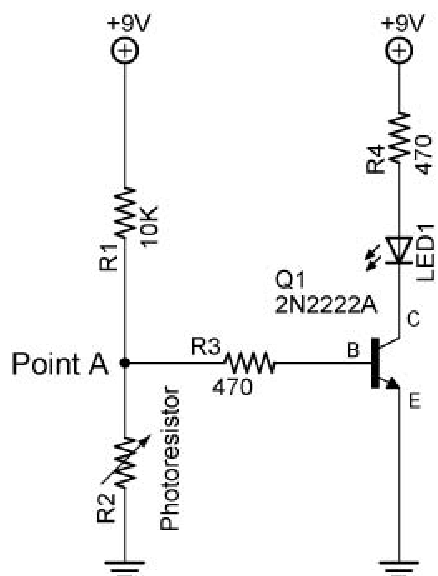
Electronics Technology and Robotics I Week 16
Diodes and Transistor Switches Lab 4 – NPN Switch Circuit Application

- **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 Ω Resistor
  - 1 – Photoresistor
  - 2 – 470 Ω 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	

- **Conclusions:**

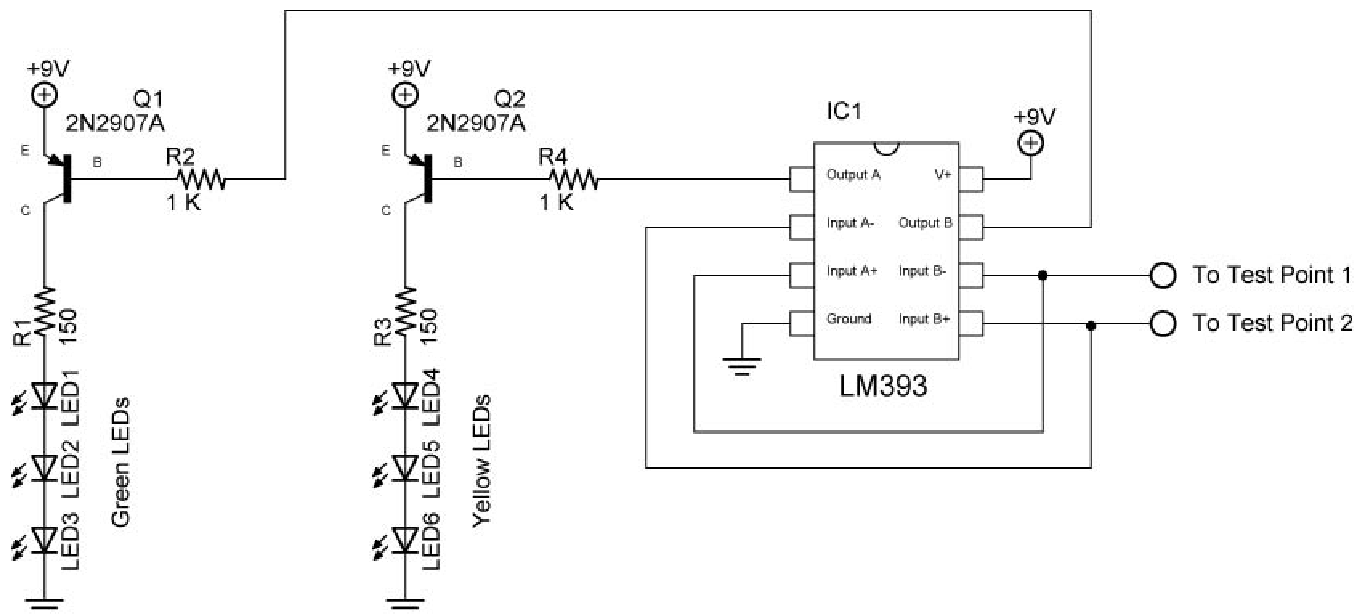
Electronics Technology and Robotics I Week 16
Diodes and Transistor Switches Lab 5 – Brightness Comparator

- **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 Ω Resistors
    - 2 – 1 K Ω 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