**Cornerstone Electronics Technology and Robotics I Week 16**
**Voltage Comparators**

- Administration:
  - Prayer
- Robot Building for Beginners, **Chapter 15**, Voltage Comparators:
  - Review of Sandwich's Circuit: To this point we have covered the **electric power source** (a 9V battery) and the **sensors** (the photoresistor network). Now we will add the **brains** - an integrated circuit called a comparator. The **action** (motors) and **body** will be covered later lessons. The words in bold are the parts of a robot included in Lesson 1.
  - Voltage Comparators:
    - A comparator circuit is used to compare two voltage inputs and determine which is the larger of the two.
    - A comparator is a device whose output is **HIGH** when the voltage on the **positive (+)** input is **greater** than the voltage on the negative (-) input and LOW when the positive input voltage is less than the negative input voltage. This is true regardless whether the comparator is set up for inverting or non-inverting operation.

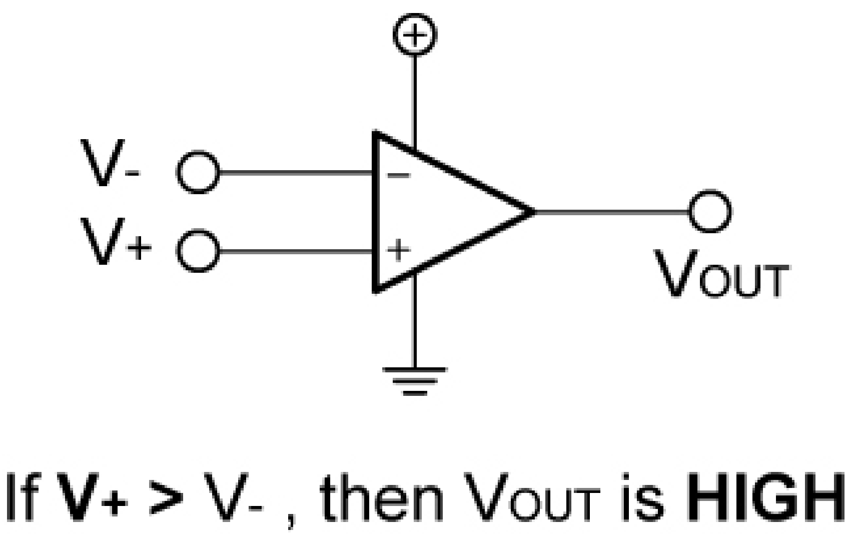



**Figure 1: Basic Relationships for a Comparator**

For example:

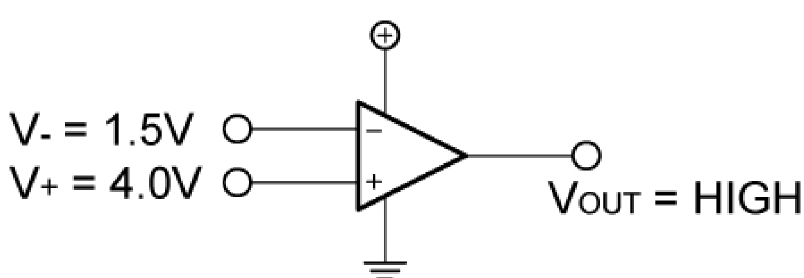



**Figure 2: Example of Basic Relationships for a Comparator**

- Inputs into a comparator can be an analog voltage; the output is digital.
- Two Basic Comparator Operations:
  - **Inverting Operation:** $V_{REF}$ (the reference voltage) assigned to the positive input. When $V_{IN}$ (the input voltage) exceeds $V_{REF}$, the output $V_{OUT}$ goes from HIGH to LOW.

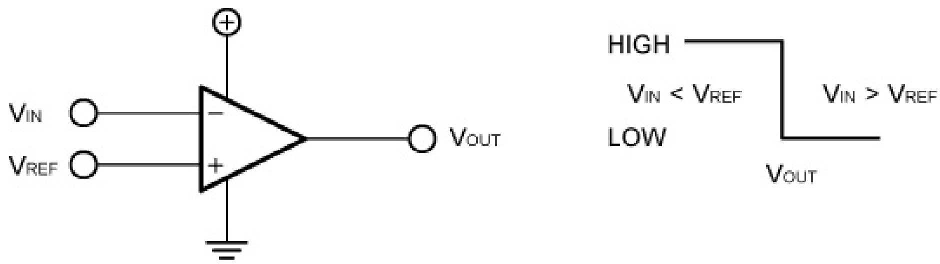



**Figure 3a: Basic Inverting Operation**

The inverting operation can be represented in another graphical form:

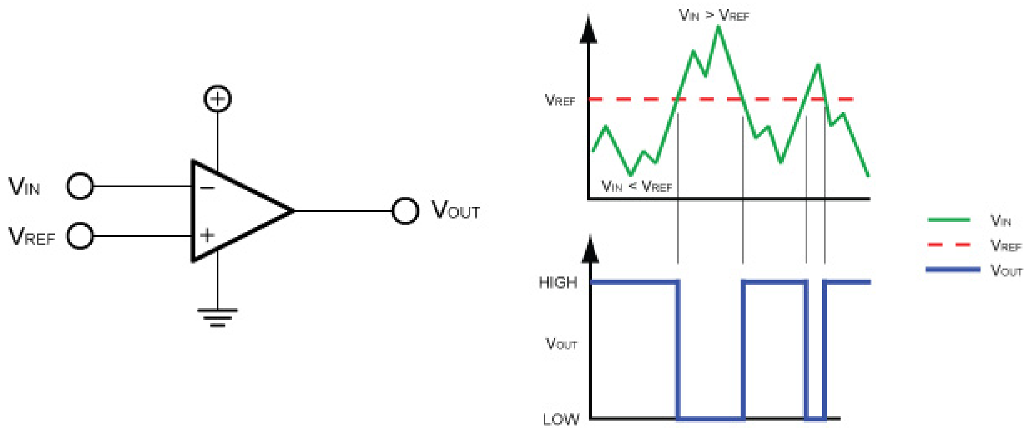



**Figure 3b: Basic Inverting Operation**

- In other words, the comparator set for <u>inverting operation</u> makes the following decisions:

  If $V_{IN} < V_{REF}$, then the output voltage is HIGH and

  If $V_{IN} > V_{REF}$, then the output voltage is LOW

- Remember, in the inverting mode of operation, $V_{REF}$ is connected to the **+** input.

- **Non-inverting Operation:** $V_{REF}$ (the reference voltage) assigned to the negative input. When $V_{IN}$ exceeds $V_{REF}$, the output $V_{OUT}$ goes from LOW to HIGH.

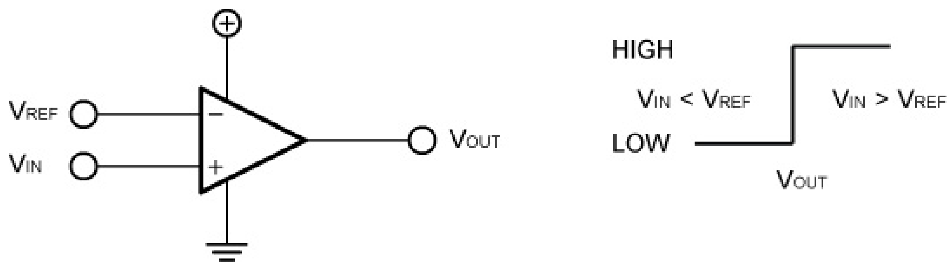



**Figure 4a: Basic Non-inverting Operation**

The non-inverting operation can be represented in another graph:

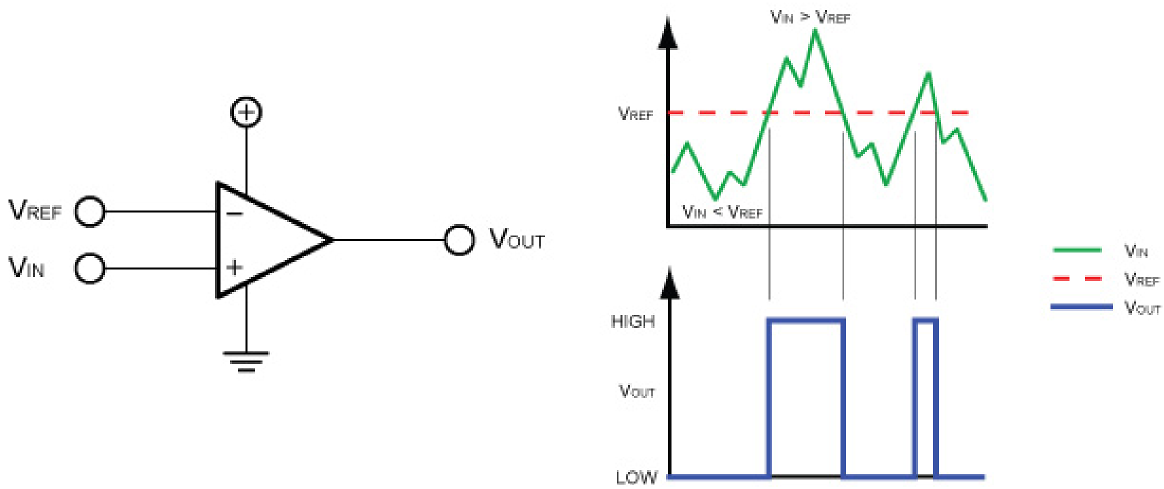



**Figure 4b: Basic Non-inverting Operation**

  - The comparator set for <u>non-inverting operation</u> makes the following decisions:

    If $V_{IN} < V_{REF}$, then the output voltage is LOW and

    If $V_{IN} > V_{REF}$, then the output voltage is HIGH

- How the comparator is used to control Sandwich's motors: The line-following robot Sandwich uses two independent comparators in one IC to control the two motors (Figure 3). The photoresistor sensors send voltages from Test Points 1 and 2 to both comparators. Assume that Test Point 1 is the reference voltage. Comparator A is wired for the inverting mode of operation ($V_{REF}$ is connected to input + and $V_{IN}$ is connected to input -) and the comparator B is set for the non-inverting mode. If one of the comparator's output is HIGH, then the other comparator output will usually be LOW. Normally, only one motor will be on at any one time; which motor that is on is determined by which pair of photoresistor sensors has the least amount of light entering it.

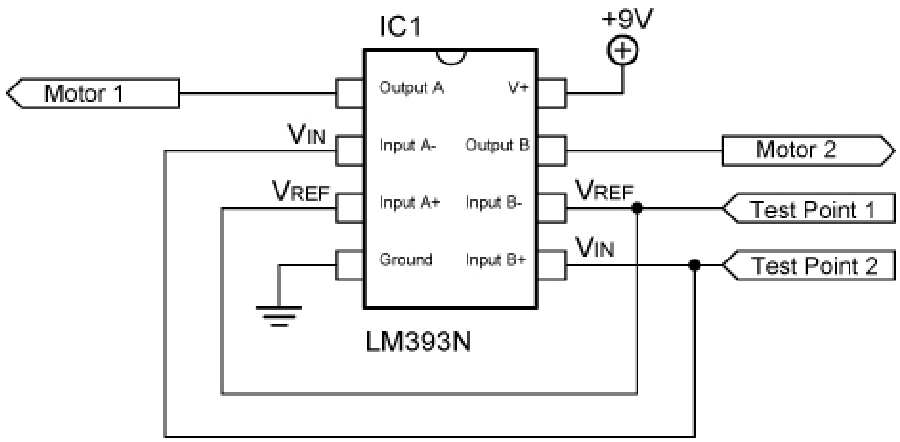
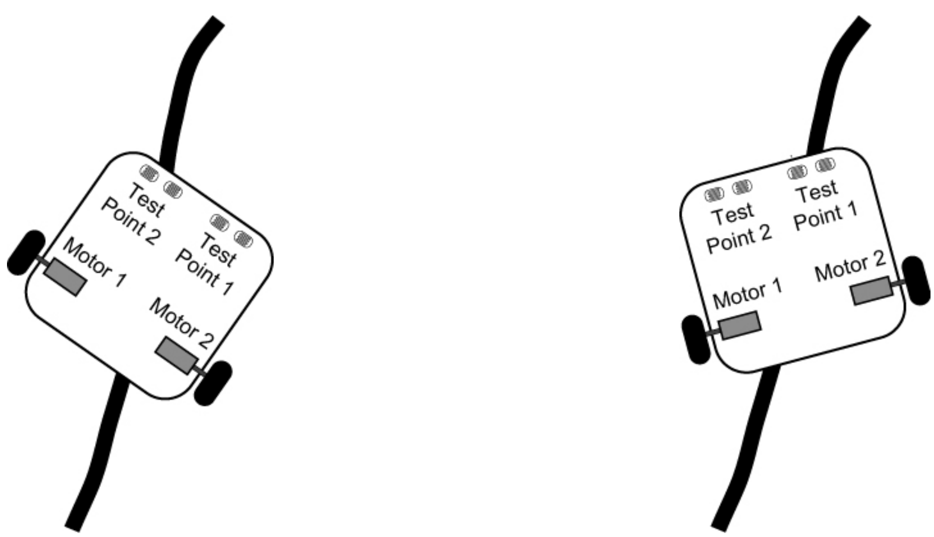



**Figure 5: Sandwich Comparator Wiring**




**When Test Point 2 Is Activated, Motor 2 Turns On and Motor 1 Turns Off**

**When Test Point 1 is Activated, Motor 1 Turns On and Motor 2 Turns Off**

**Figure 6: Sandwich's Movement**

- o **Chip as a Source and as a Sink:**
  - Chip as a Source: In Figure 7 below, when the pin connected to R1 goes HIGH, the chip connects the source voltage (+9V) to the load (the LED), similar to the switch in Figure 8.

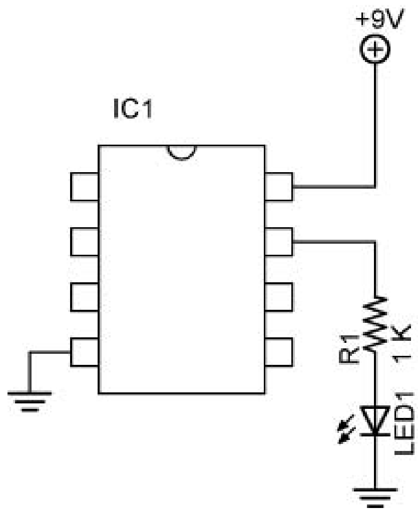



**Figure 7: Chip Acting as a Source**

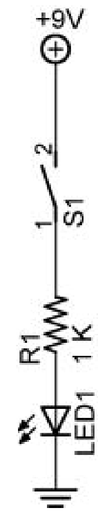



**Figure 8: Chip Acts as a Closed Switch**

  - Chip as a Sink: In Figure 9, when the pin connected to the LED goes LOW, the chip connects the load to ground, similar to the switch in Figure 10.

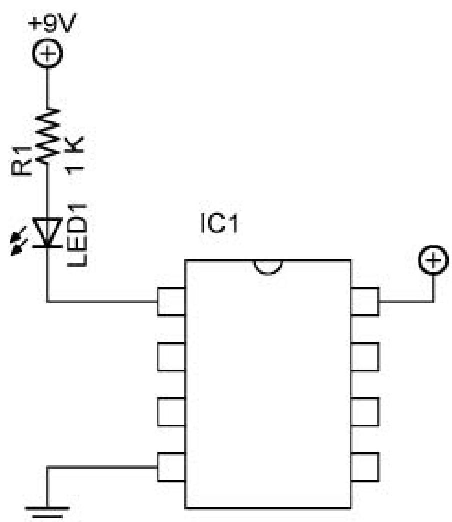



**Figure 9: Chip Acting as a Sink**

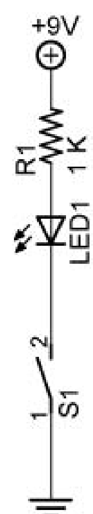



**Figure 10: Chip Acts as an Open Switch**

- **741 Op Amp:**
  - A 741 op amp can be used to function as a comparator.
  - The 741 functions as a comparator when it is operated in an open-loop mode, that is, there is no feedback resistor.
  - The output varies from full on to full off with very small changes in the input voltage due to the high gain.
  - Perform Voltage Comparators Lab 1 – 741 Comparator
- **LM393 Dual Comparator:**
  - Comparators are specifically designed for high-speed switching when matched up to an op amp.
  - LM393 consist of two independent voltage comparators designed to operate from a single power supply over a wide voltage range.
  - LM393 datasheet:
    - http://www.fairchildsemi.com/ds/LM%2FLM393.pdf
  - LM393 Characteristics:
    - Two independent voltage comparators
    - Single power supply, 2V – 36V
    - Operate over a wide range of voltages, up to about 36 V
    - Low input offset voltages in the mV range. This means that the LM393 can compare voltages that are very close to each other.
    - Like many older chips, the LM393 can not source as much current as it can sink. The terminology source and sink is from the water analogy, where water comes out of the source and then goes into the sink.
  - Comparator Pull-up Resistor:
    - If you refer to the datasheet for the LM393, the schematic reveals that the comparator uses an internal transistor whose collector is connected to the output and whose emitter is connected to ground. To enable the LM393 to have a high output state (when $V_+ > V_-$), the comparator output must be connected to a positive voltage source through an external pull-up resistor. If the pull-up resistor is not present, then the output voltage "floats", meaning it is not tied to any known voltage level.
    - Value: The pull-up resistor must be small enough to drive the load connected to the comparator output, yet large enough to limit the power consumption. Below are two examples of pull-up resistors used in two different applications.

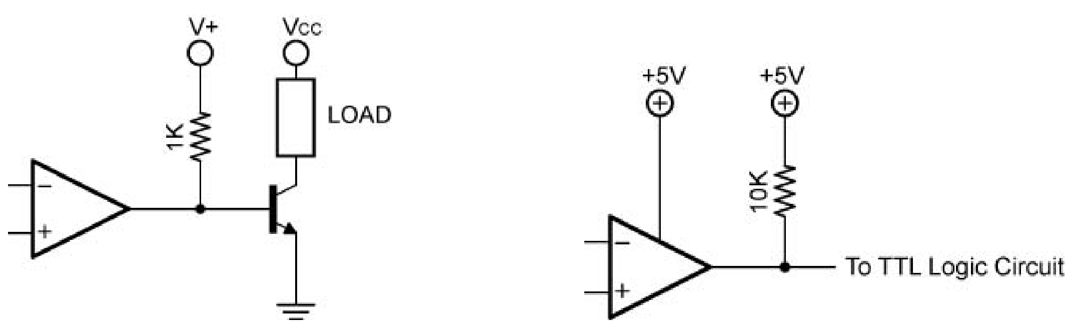



**Figure 11: Power Switching and TTL Logic Circuit Applications**

- Pin Layout:

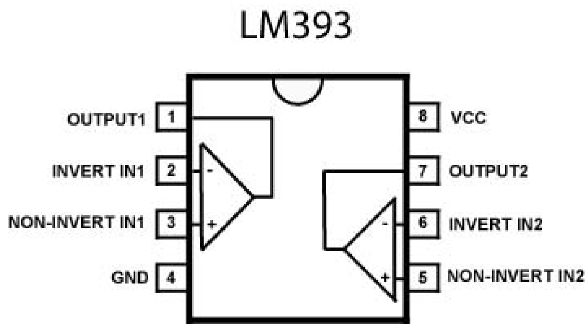



**Figure 12: Pinout of LM393**

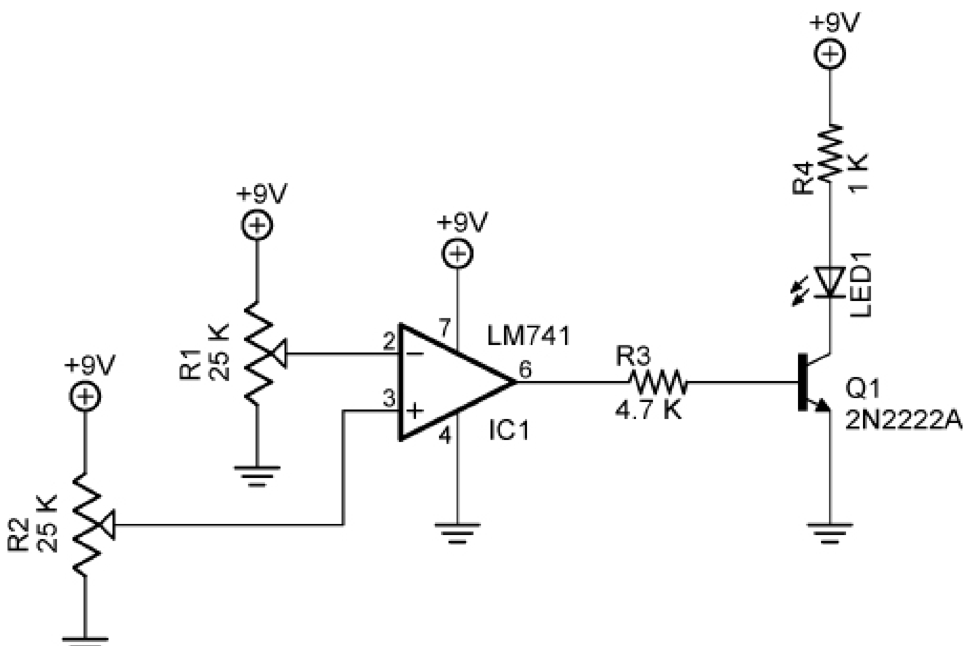
The semi-circle notch in the chip locates pin 1.

- Perform Voltage Comparators Lab 2 – LM393N Comparator
- Perform Voltage Comparators Lab 3 – Brightness Comparison Circuit

- Other web references:
  - http://www.techitoutuk.com/knowledge/electronics/buildingblocks/opamp/index.html
  - http://www.technologystudent.com/elec1/opamp3.htm
  - http://www.uoguelph.ca/~antoon/gadgets/741/741.html
  - http://booksbybibin.14.forumer.com/a/ic741-tutorial_post38.html

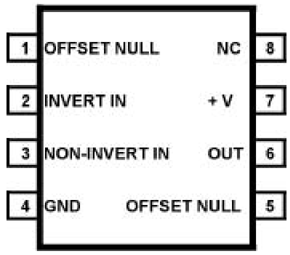
**Electronics Technology and Robotics I Week 16**
**Voltage Comparators Lab 1 – 741 Comparator**

- **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 – 4.7K Resistor
  - 1 – 1K Resistor
  - 1 – 2N2222A NPN Transistor
  - 1 – LED
- **Procedure:**
  - Build Circuit 1 and use three multimeters to measure $V_{REF}$, $V_{IN}$, and $V_{OUT}$ (pin 6).
  - 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




**741 Pin Layout or Pinout**

**Results:**

- Test 1- Non-inverting Operation:
  - 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
- Test 2 – Inverting Operation:
  - 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:**
  - How do the results from Test 1 compare to the results of Test 2?

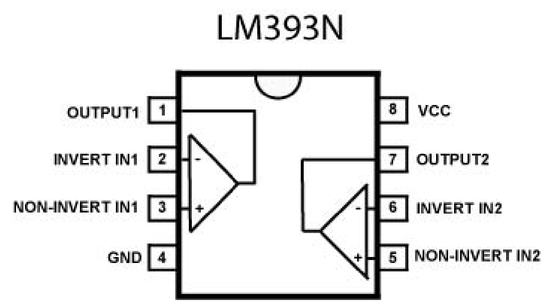
**Electronics Technology and Robotics I Week 16**
**Voltage Comparators Lab 2 – LM393N Comparator**

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

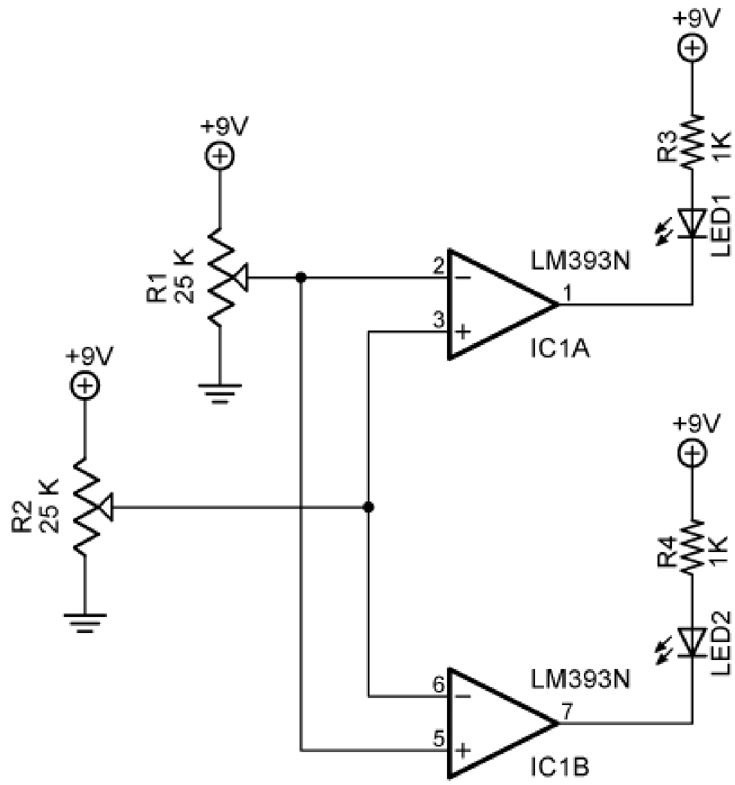
- **Apparatus and Materials:**

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

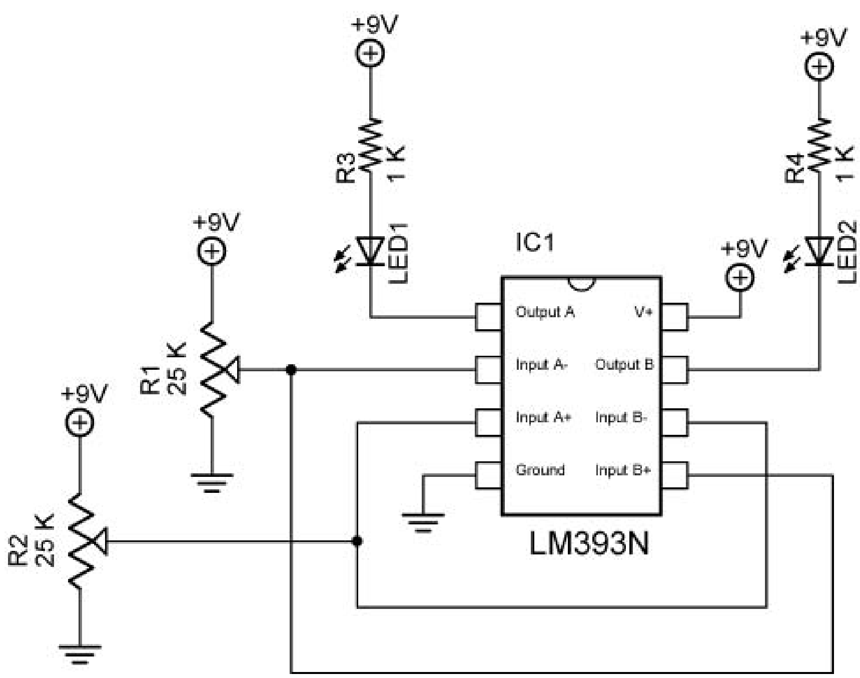
- **Procedure:**
    - Build Circuit 2. Wiring Diagram 1 may assist in the assembly of the circuit.
    - In this test, let pins 2 and 5 be the reference voltage ($V_{REF}$). Adjust $R_1$ to set pins 2 and 5 to about 4.5 V.
    - Adjust $R_2$ so that the voltage input ($V_{IN}$) into pins 3 and 6 varies 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 Pinout:




    - <u>Always</u> 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 5 of IC1B is set as $V_{REF}$, what mode is IC1B in? Inverting or non-inverting?

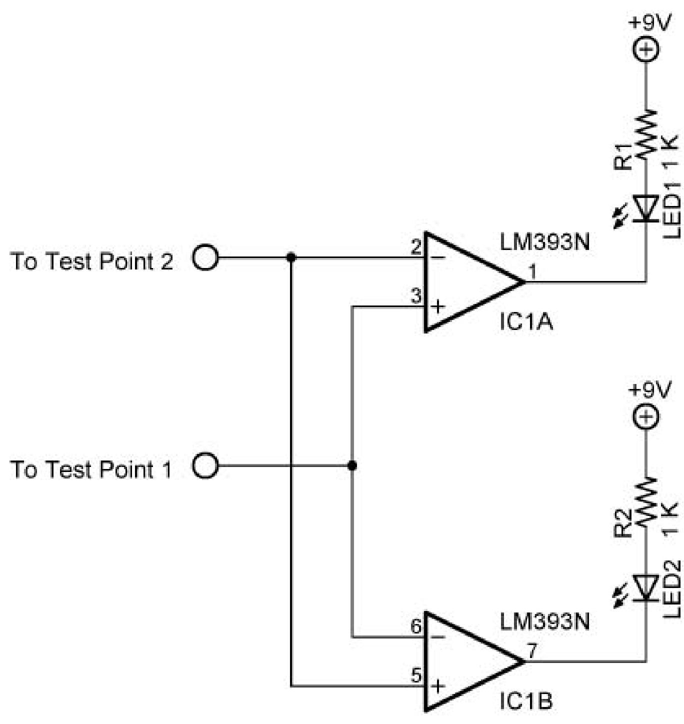
**Electronics Technology and Robotics I Week 16**
**Voltage Comparators Lab 3 – Brightness Comparison Circuit**

- **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:**

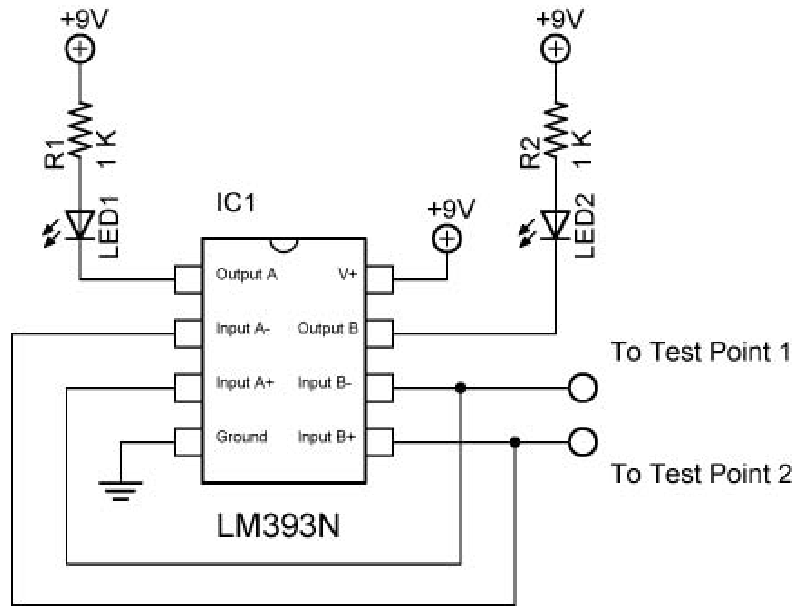
  - 1 – Solderless Breadboard with 9 V Power Supply
  - 1 – LM393N Comparator
  - 2 – 25 K Potentiometers
  - 2 – 1 K Ω Resistors
  - 2 – 470 Resistors
  - 2 – LEDs (Regular)
  - 2 – LEDs (Bright White)

- **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 12. 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.

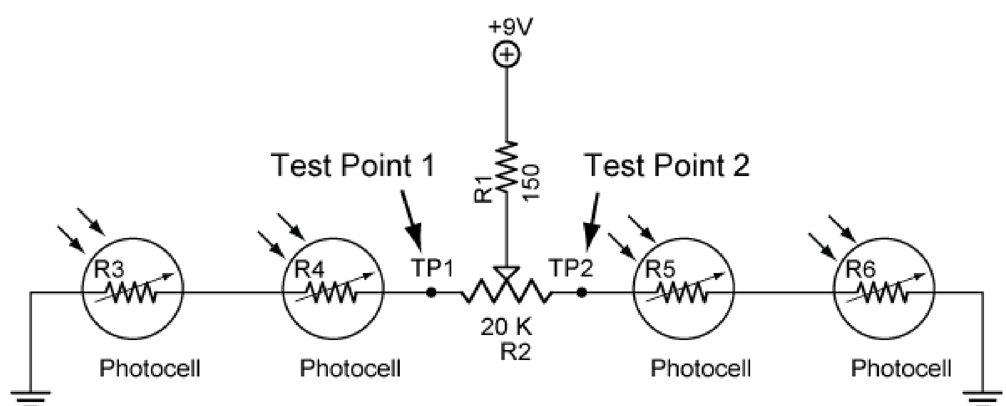



**Circuit 3**

Pin 8 +9V
Pin 4 Ground

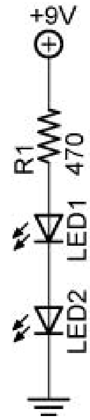



**Wiring Diagram 2**




**Circuit 4 (from Week 12)**

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




**Circuit 5**