Voltage Comparator

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In the last lesson you completed the photoresistor circuit, which is the “eyes” of the robot. Now you will study and build the voltage comparator circuit, which is the “brains” of the robot. The voltage comparator receives voltage signals from the photoresistor circuit and determines from the signals where the line is under the robot. The voltage comparator sends out signals to the power transistors, which in turn control the motors of the robot. The voltage comparator decides how the robot must be steered to keep the line centered under the robot. That is why we call it the brains of the robot.

The voltage comparator you will be using is a LM393 type. It is an **integrated circuit** (IC). You have already built several circuits. Now imagine that you could reduce the size of components of a circuit and place them all in a small container. Then you would have an integrated circuit. Figure 1 is a photo of the LM393 integrated circuit and a U.S. penny. I put the penny in the photo so that you can see that the LM393 is very small.

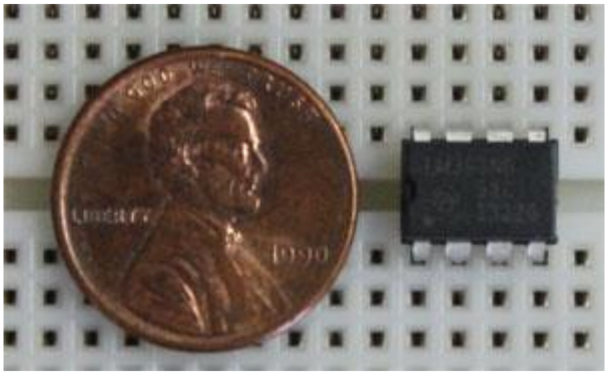

Figure 2. LM393

There is a notch in the left side of the LM393 in the photo which is difficult to see. However, the notch is seen easily in the drawing in Figure 2. The notch is used to help in identifying the pins of this integrated circuit. If the IC chip is oriented as we see it in Figure 2, then pin one is located at the bottom near the left corner. The pin numbers are sequenced from one to eight in a counter-clockwise direction around the chip.

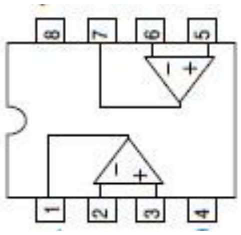

Figure 1. Pinout of LM393.

Inside the LM393 there are two voltage comparators, which are symbolized in Figure 2 as triangles. Pins 1, 2 and 3 belong to one comparator and pins 5, 6 and 7 belong to the other comparator. Pins 2, 3, 5 and 6 are input pins. The input pins are connected to the test points of the photoresistor circuit as you will see soon. Pins 1 and 7 are the output pins. For this lesson you will connect the output pins to LEDs, which will allow you to determine visually when the output is closed (LED on) and when it is open (LED off). Pin number 8 is connected to the positive power bus and pin number 4 is connected to the negative power bus.

In the next lesson you will remove the LEDs and connect each output pin to a power transistor. Each power transistor, controlled by the LM393, delivers electrical power to one robot motor. The robot has only two wheels, one on each side, and one motor connected to each wheel. The robot will turn left when the motor connected to the right wheel is on and the motor connected to the left wheel is off. And it will turn right when the left motor is on and the right motor is off.

Let's take the example of the comparator connected to pins 1, 2 and 3. If a wire connected to pin 2 (the minus input) contains more voltage than a wire connected to pin 3 (the plus input) then the output pin 1 will be connected to pin 4. Pin 1 behaves like a switch. The switch is closed (pins 1 and 4 connected) when pin 2 has a higher voltage than pin 3. If pin 3 has a higher voltage than pin 2, then the switch at pin 1 is open (pin 1 is not connected to pin 4). **The minus input pin of a voltage comparator must have higher voltage than the plus input pin to close its output switch.**

Each voltage comparator is a complicated circuit as you can see in Figure 3. The circuit contains 15 transistors, 3 resistors and 5 diodes. The total number of components in this small IC is 46. That is a wonder of modern electronics. The integrated circuits in computers have so many transistors inside it is hard to imagine the number.

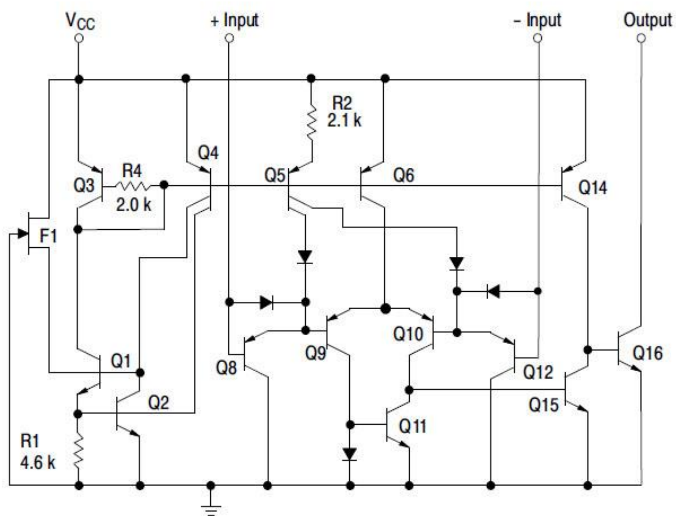

Figure 3. Schematic for one voltage comparator of LM393

Find the transistor labeled Q16 on the right side of the schematic. This is the transistor that acts like a switch. Q16 is connected to the output pin (upper right) and to ground. Ground is connected to pin 4. Ground is this symbol  in the schematic.

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The voltage comparator circuit of the robot

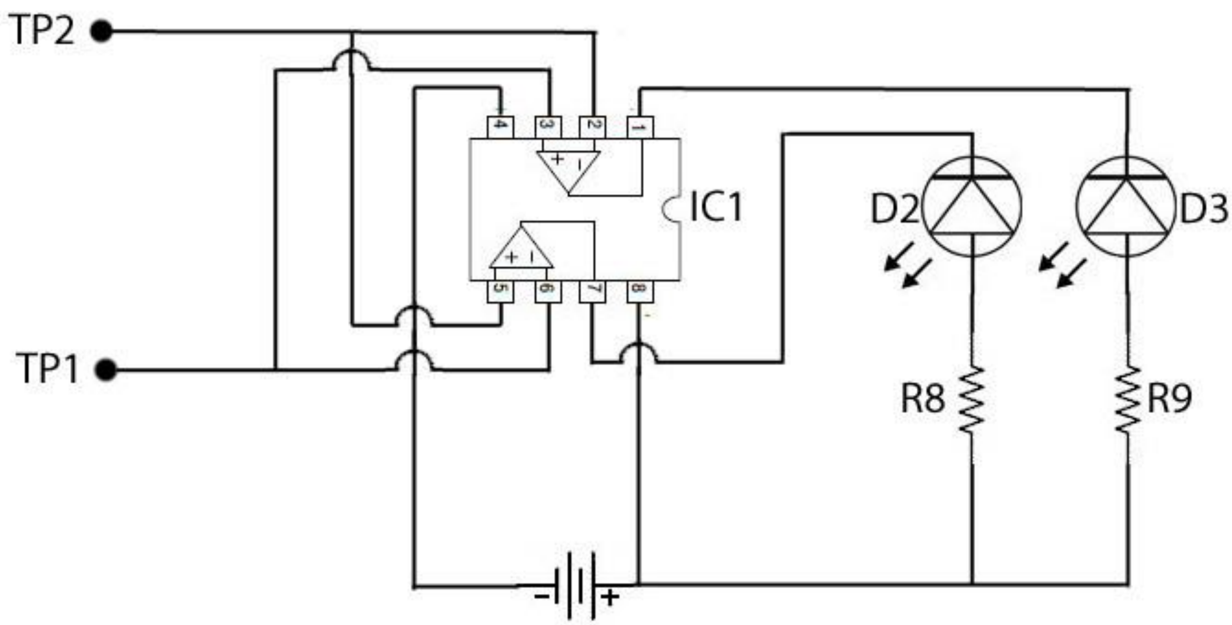

Figure 4. Voltage comparator circuit schematic

IC1 is the LM393 integrated circuit (see Figure 4). In the schematic you can’t see all the components that are inside IC1. That would make the schematic very confusing. Instead, I have used a simple diagram to represent the IC, with the two voltage comparators appearing as triangles. Test point 1 (TP1) and test point 2 (TP2) are on the left side of the schematic. These are the points that connect the photoresistor circuit to the voltage comparator circuit. The comparator is the most complicated circuit of the robot. It is difficult to draw the wires without crossing over other wires. When a wire crosses over another wire, but is not connected to that wire, I use this symbol .

TP1 is connected to pins 3 and 6 of IC1 and TP2 is connected to pins 2 and 5. In this arrangement the switch at output pin 7 will be CLOSED and the switch at output pin 1 will be OPEN when TP1 has a higher voltage than TP2. Remember that the voltage must be higher at the minus input pin than the plus input pin to close the comparator switch. You may need to study the schematic carefully to understand this part of the circuit.

When TP2 has a higher voltage than TP1, then the switch at output pin 1 will be CLOSED and the switch at output pin 7 will be OPEN. Said another way, when TP1 is high, the switch at pin 7 is CLOSED and when TP2 is high, the switch at pin 1 is CLOSED. Output pin 1 controls one motor and output pin 7 controls the other motor of the robot (you will not make connections to the motors until a later lesson). If only one motor is running, the robot will turn left or right, depending on which motor is running. This is how the voltage comparator steers the robot, by turning either one or the other motor on.

Output pin 7 of IC1 is connected to the cathode of the yellow LED (D2) and output pin 1 is connected to the cathode of the green LED (D3). The anode of each LED is connected to a 2,200 ohm resistor (R8 and

R9), which controls the amount of current through the LEDs, just like in the power circuit. According to the data sheet for IC1, the maximum output current is 20 milliamps. With 2,200 ohm resistors, the current consumed by each LED will be about 3 milliamps. If both LEDs are on, the output current will be 6 milliamps, well below the 20 milliamp limit. The LEDs allow you to see when the switches at pins 1 and 7 are CLOSED.

I have to admit that my description is difficult to follow. Let me list what happens in steps for review. You can also compare the steps to what you can see in the schematic in Figure 4.

When a dark line is under photoresistors R4 and R5 the following things happen

1. The voltage at TP1 becomes higher than the voltage at TP2
2. The voltage at pins 3 and 6 of IC1 becomes higher than the voltage at pins 2 and 5
3. Output pin 7 is connected to the negative power bus (switch closed) , output pin 1 is NOT connected to negative power bus (remember that the minus input pin must be higher than the plus input pin to close the switch)
4. The yellow LED (D2) connected to pin 7 is ON, the green LED (D3) connected to pin 1 is OFF

When a dark line is under photoresistors R6 and R7 the following things happen

1. The voltage at TP2 becomes higher than the voltage at TP1
2. The voltage at pins 2 and 5 of IC1 becomes higher than the voltage at pins 3 and 6
3. Output pin 1 is connected to the negative power bus, output pin 7 is NOT connected to the negative power bus
4. The green LED (D3) connected to pin 1 is ON, the yellow LED (D2) connected to pin 7 is off

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Assemble the voltage comparator circuit

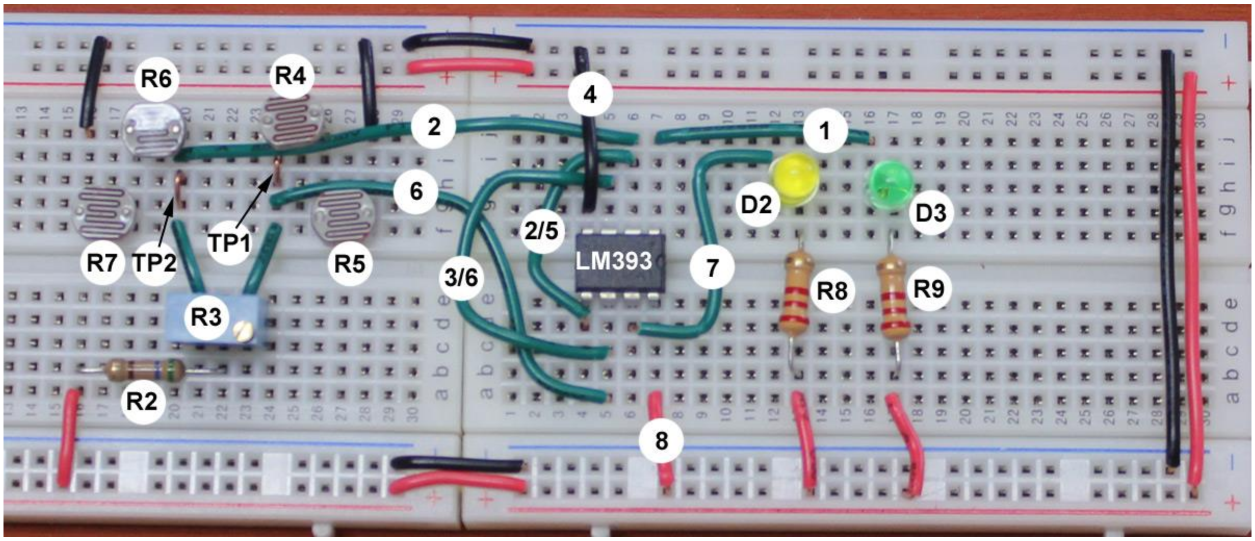

Figure 5. Wiring for the voltage comparator circuit.

1. Disconnect the battery from the breadboard as a safety measure
2. First, note that the LM392 is oriented with the notch on the right, which places pin one near the top right corner and pin eight near the bottom right corner. Connect a red wire to the same row that contains pin 8 of LM393. Connect the other end of the wire to the bottom positive power bus. This wire is labeled number 8 in Figure 5.
3. Connect a green wire to test point 2 (TP2) and the other end of the wire to the same row that has pin 2 of LM393. This wire is labeled number 2 in Figure 5.
4. Connect a green wire to test point 1 (TP1) and the other end of the wire to the same row that has pin 6 of LM393. This wire is labeled number 6 in Figure 5.
5. Connect a green wire to the same row that contains pin 2 of LM393 and the other end of the wire to pin 5. This wire is labeled 2/5 in Figure 5.
6. Connect a green wire to the same row that contains pin 3 of LM393 and the other end of the wire to pin 6. This wire is labeled 3/6 in Figure 5.
7. Connect a black wire to the same row that contains pin 4 of LM393. Connect the other end of the wire to the top negative power bus. This wire is labeled number 4 in Figure 5.
8. Insert the yellow and green LEDs (D2 and D3) into the board to the right of LM393 (see Figure 5). All four wires of the LEDs must be in different rows. The cathode wire of each LED should be on its left side as in the photo.
9. Connect resistor R8 (2,200 ohms) to the same row of holes that contains the anode of the yellow LED (D2). Connect the other end of R8 to a row on the other side of the gap (see Figure 5)
10. Connect a red wire to the same row that contains R8 (see Figure 5). Connect the other end of that wire to the bottom positive power bus.
11. Connect resistor R9 (2,200 ohms) to the same row of holes that contains the anode of the green LED (D3). Connect the other end of R9 to a row on the other side of the gap (see Figure 5)

12. Connect a red wire to the same row that contains R9 (see Figure 5). Connect the other end of that wire to the bottom positive power bus.
13. Connect a green wire to the same row that contains the cathode of the green LED (D3). Connect the other end of that wire to the same row that contains pin 1 of LM393. This wire is labeled number 1 in Figure 5.
14. Connect a green wire to the same row that contains the cathode of the yellow LED (D2). Connect the other end of that wire to the same row than contains pin 7 of LM393. This wire is labeled number 7 in Figure 5.

The voltage comparator circuit should now be complete. Have an adult check your circuit now. After the check, connect the battery to the power bus of the breadboard.

Adjusting and testing the voltage comparator and photoresistor circuits

1. Turn the power on. The power circuit red LED should be glowing.
2. If you have wired the voltage comparator circuit properly, either the yellow or green LED (D2 or D3) should be glowing. If the voltage at test point 1 (TP1) is higher than test point 2 (TP2), then the yellow LED should be glowing. If the voltage at test point 2 (TP2) is higher than TP1, then the green LED should be glowing. It is time now to adjust the potentiometer R3 in the photoresistor circuit to balance the voltages at test points one and two.
3. When making the adjustment of R3, **it is very important that you don't cast a shadow on any of the photoresistors (R4, R5, R6 and R7).** There should be the same amount of light shining on all photoresistors. Insert a small screwdriver into the adjusting screw of R3. Rotate the screw clockwise and counterclockwise. If you turn the screw enough both ways, you should notice that there are positions of the screw where the green LED is on and other positions where the yellow LED is on. You should adjust the screw to the position where there is a change from one of the LEDs on to the other LED on. Try to get the screw as close to the change-over point as possible. Then your photoresistor circuit will be balanced. The voltages at test points one and two will be nearly the same when the same amount of light shines on all photoresistors.
4. Now that you have balanced the photoresistor circuit, it is time to test out the function of the voltage comparator and photoresistor circuits. Place your finger over photoresistors R4 and R5 (hold your finger over the photoresistors but don't touch them). When you do this the resistance of R4 and R5 will increase and the voltage at test point one will rise above that at test point two. This will cause LM393 to turn on the switch that connects the yellow LED to the negative power bus. In other words, when you cast a shadow on R4 and R5, the yellow LED should be on and the green LED should be off.
5. Place your finger over photoresistors R6 and R7. When you do this the resistance of R6 and R7 will increase and the voltage at test point two will rise above that at test point one. This will cause LM393 to turn on the switch that connects the green LED to the negative power bus. In other words, when you cast a shadow on R6 and R7, the green LED should be on and the yellow LED should be off.
6. Move your finger back and forth, casting a shadow alternately over R4/R5 and R6/R7. The green and yellow LEDs should flash on and off. The same thing will happen with the complete robot

when it is following a line. The flashing LEDs indicate the steering decisions the robot is making to follow the line. When one LED is on the robot is turning right and when the other LED is on the robot is turning left. The robot is constantly turning left and right to keep the line centered underneath the robot.

Did the yellow LED turn on when you cast a shadow on R4 and R5? ______________ yes or no

Did the green LED turn on when you cast a shadow on R6 and R7? ______________ yes or no

If you answered yes to both questions above, then your circuits are operating properly. If not, you should check your work for errors. Ask an adult to help you check your circuits. It is easy to make a mistake in wiring.

When I was testing this circuit myself, it did not work on my first try. I was getting frustrated because I did not know why it was not working. I finally realized that I did not have the LEDs connected properly to the breadboard. I had inserted both the anode and cathode wires of each LED into the same row. My circuit had a short circuit for each LED because both wires were connected together. When I realized this I changed the wiring to correct the problem. Then the circuit worked fine.

Now that you have your circuits operating properly, you will make some measurements with the meter. **During your measurements, make sure you do not cast a shadow on any of the photoresistors.**

Measure the voltage drop at test point 1

1. Turn the power on. The red LED should be glowing.
2. Set your meter to read DC volts (the voltage will probably be between 1.5 and 5 volts)
3. Touch the black meter probe to the black wire of the battery, where it connects to the battery holder.
4. Touch the red meter probe to TP1.
5. The meter will display the voltage drop at TP1. Record the voltage below.

_______________ volts at TP1

Measure the voltage drop at test point 2

1. Turn the power on. The red LED should be glowing.
2. Set your meter to read DC volts (the voltage will probably be between 1.5 and 5 volts)
3. Touch the black meter probe to the black wire of the battery, where it connects to the battery holder.
4. Touch the red meter probe to TP2.
5. The meter will display the voltage drop at TP2. Record the voltage below.

_____________ volts at TP2

Now compare the voltages at TP1 and TP2. They should be almost the same value because you have already balanced the photoresistor circuit.