

# Op-Amp Line Follower Laboratory

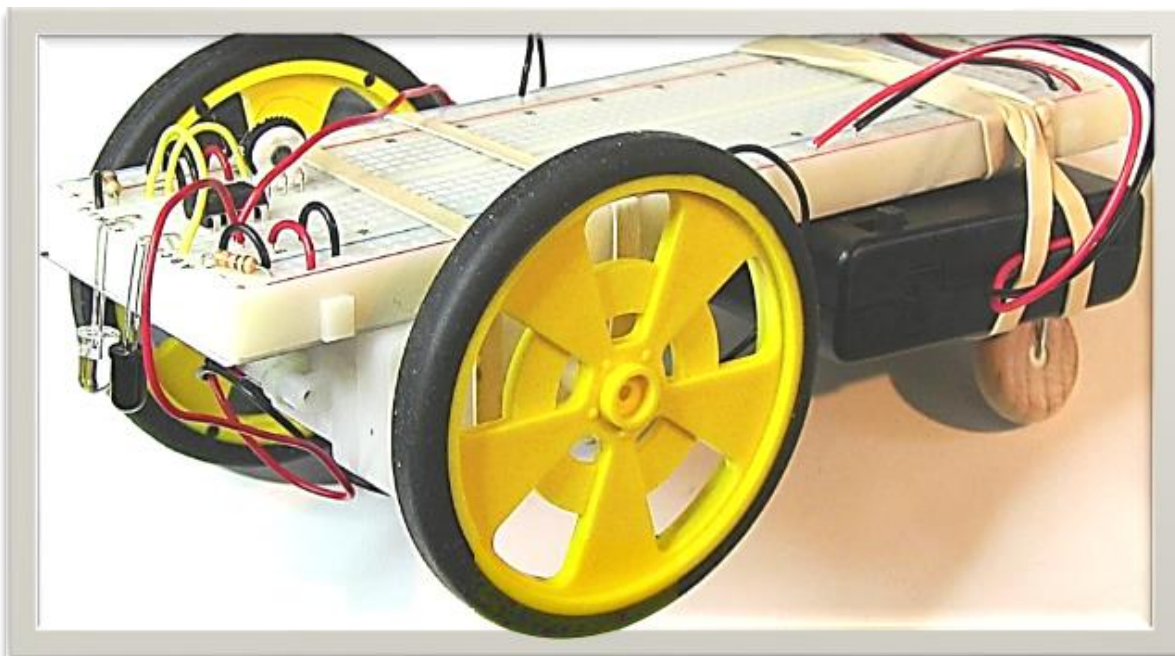
Seattle University

Department of Electrical and Computer Engineering

2018 Video Instructions: <https://youtu.be/VU3Rwsjqxo8>



2014 Video Instructions: <https://youtu.be/PleglLzJvIA>

**The 2014 and 2018 video instructions are a little different. But the 2014 video matches this PDF instructions.**



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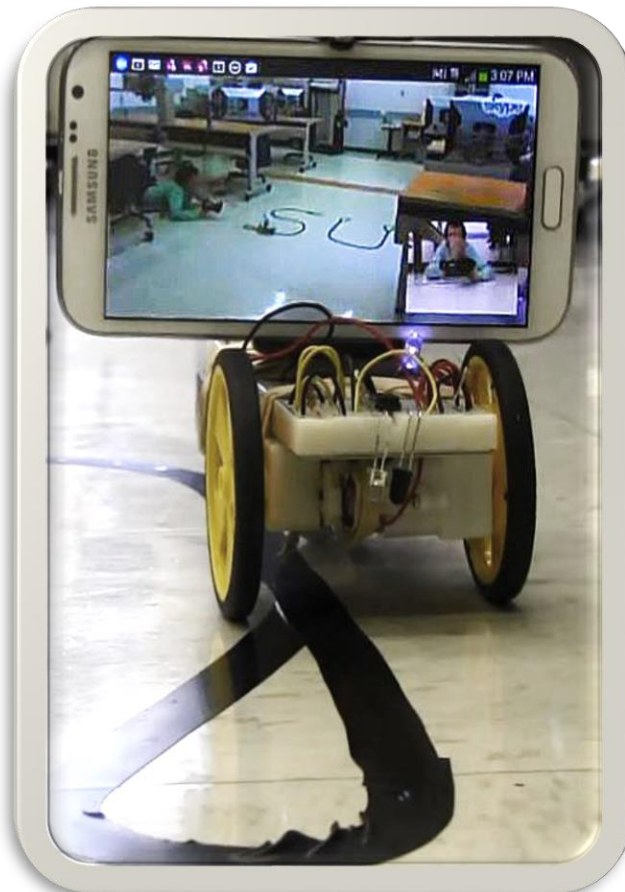
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## 2 INTRODUCTION

In this laboratory experiment, students will build a robot line follower to detect and follow a black line. The robot line follower circuit will consist of an operational amplifier (op-amp), resistors, infrared sensors, motors, wheels, a battery pack, and a unique approach of using a breadboard as both the platform in which the circuit is built and the chassis of the motorized vehicle. This laboratory experiment will provide an introduction to op-amp comparator circuits, infrared sensors, and their use in everyday life.

**YouTube** [http://www.youtube.com/playlist?list=PLo2kAKFSXB\\_0tSr4ffO7vOagMjAuamwoH](http://www.youtube.com/playlist?list=PLo2kAKFSXB_0tSr4ffO7vOagMjAuamwoH)



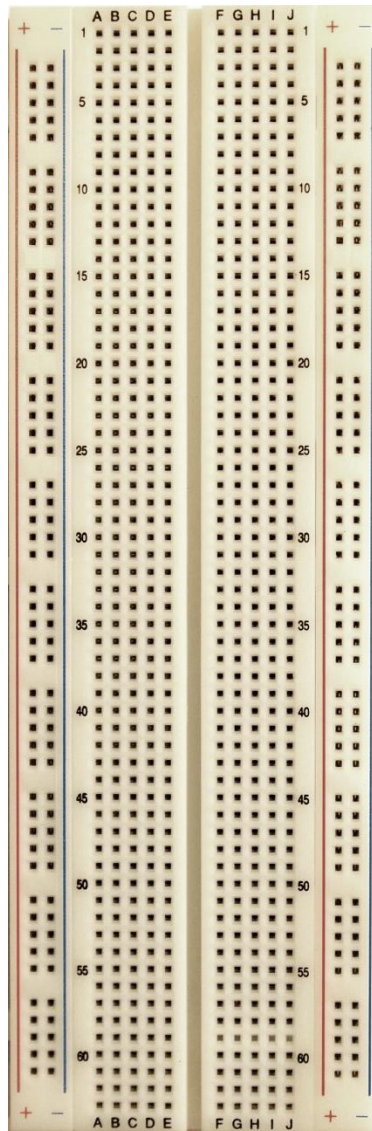
### 3 ASSEMBLY INSTRUCTIONS

This section contains detailed assembly instructions. For short video instructions go to YouTube link [http://www.youtube.com/playlist?list=PLo2kAKFSXB\\_0tSr4ffO7vOagMjAuamwoH](http://www.youtube.com/playlist?list=PLo2kAKFSXB_0tSr4ffO7vOagMjAuamwoH)

#### 3.1 RUBBER BAND ASSEMBLY METHOD

The Line Follower may be assembled in many ways including black tape, cable ties, double sided adhesive tape, and rubber bands. For flexibility and quick assemble and dissemble we will use rubber bands.

- ☐ Take two rubber bands and attach motors to the bottom side of the breadboard near the front.

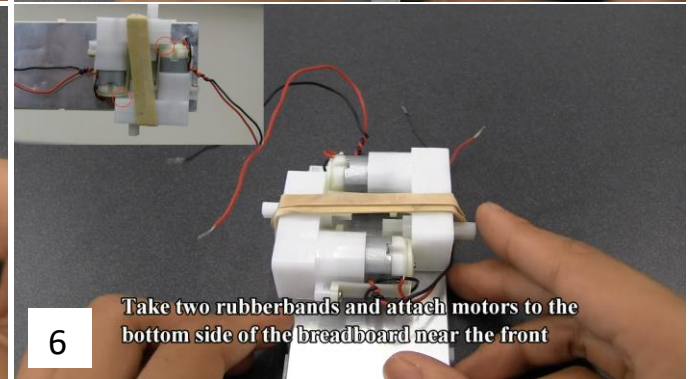
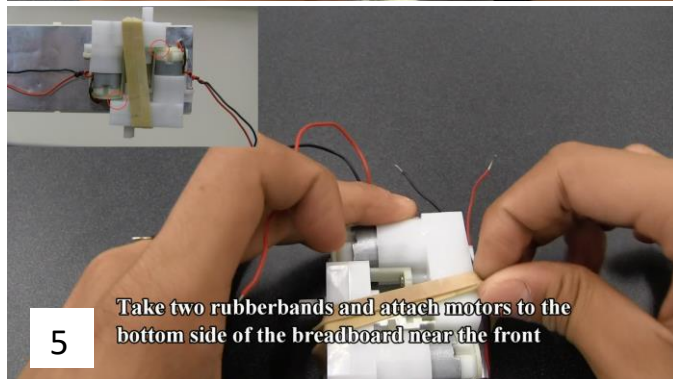
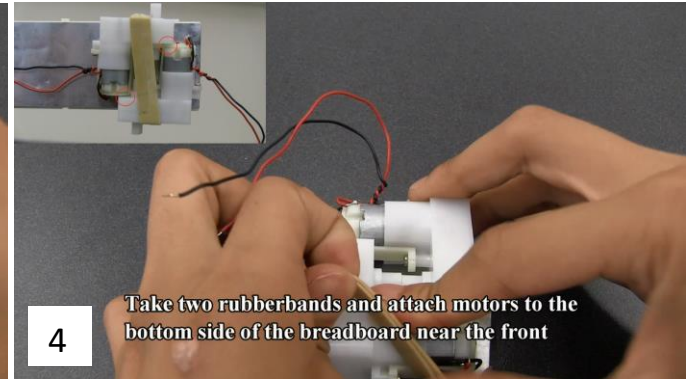
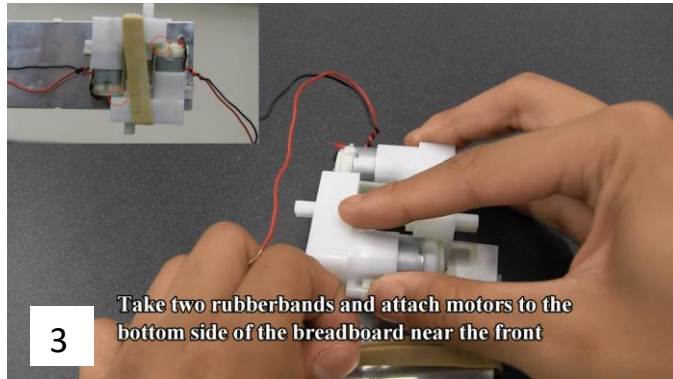
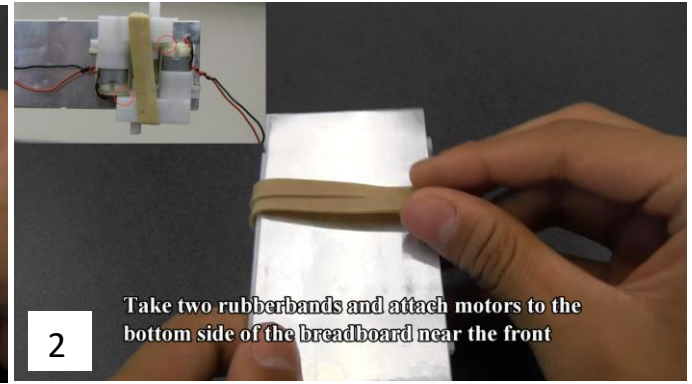
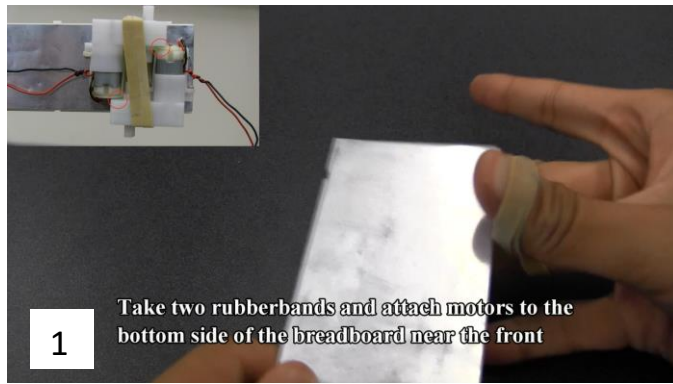


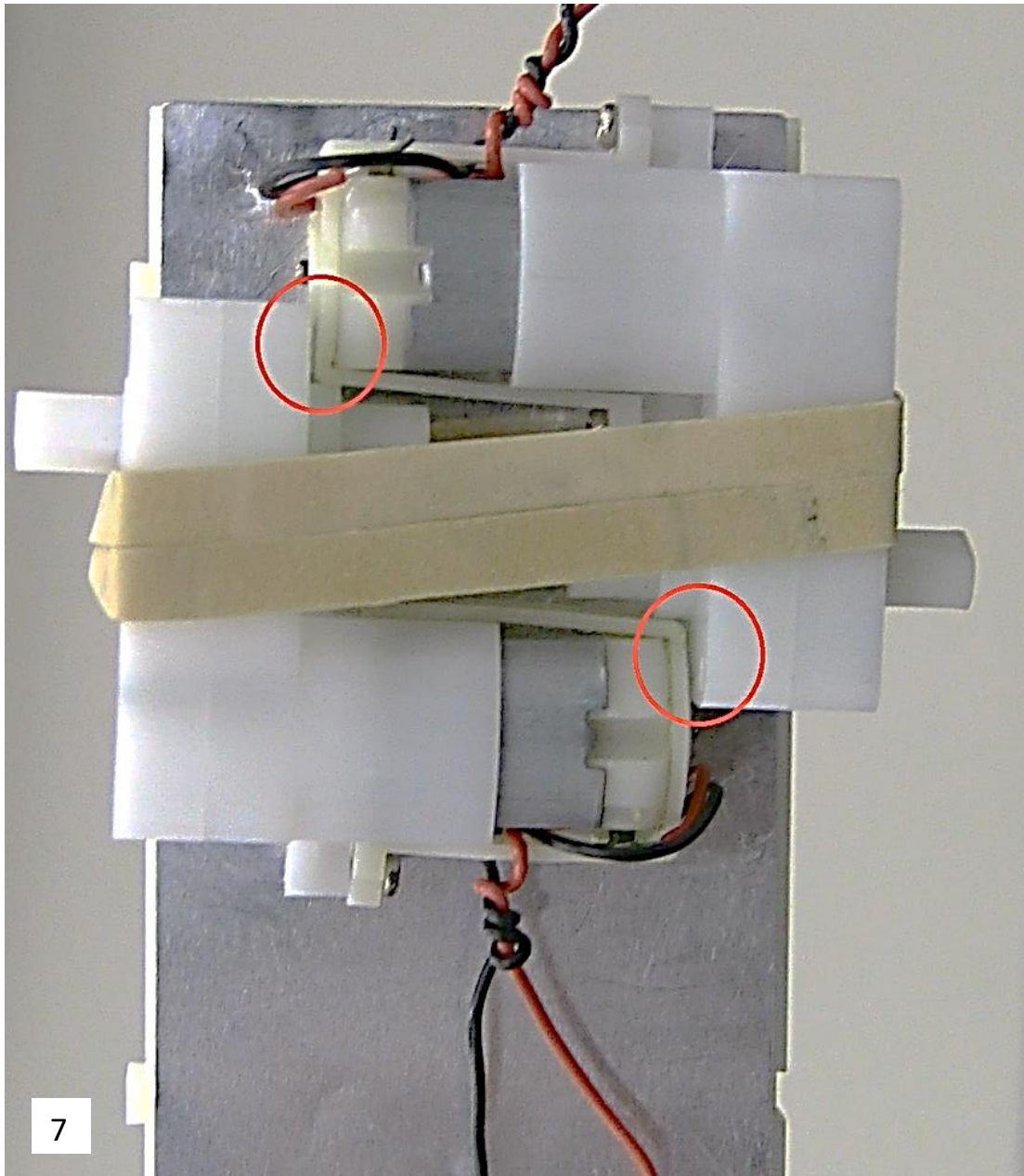
**+ - ABCDE FGHIJ + -**  
**Front of breadboard**

**Attach motors near the front of the breadboard on the bottom side.**

**Rear of breadboard**  
**+ - ABCDE FGHIJ + -**







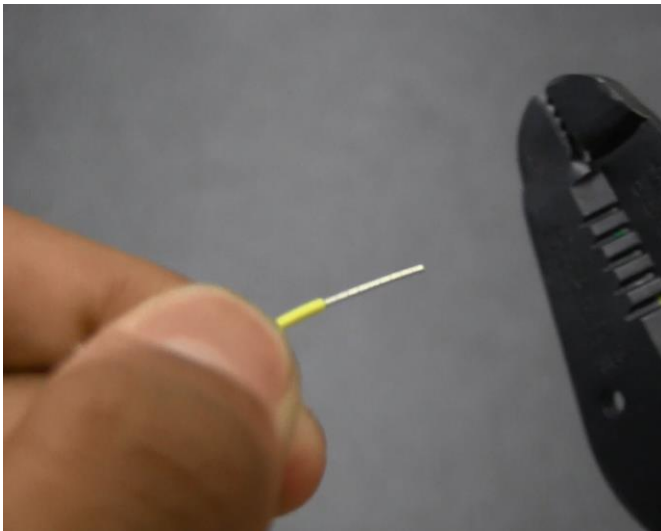
Note in red circles above how motors stack on each other!

### 3.2 HOW TO CUT WIRE

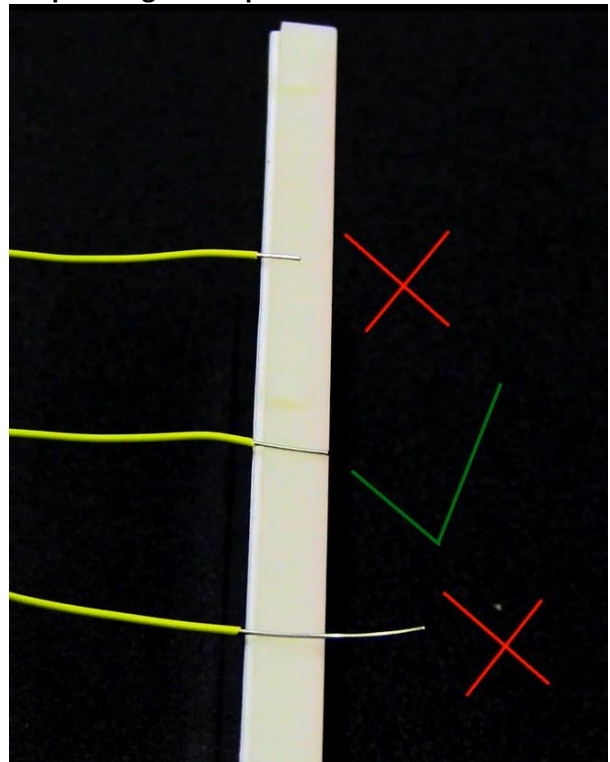
**Insert Wire**



**Cut and Pull**



**Proper Length is important**



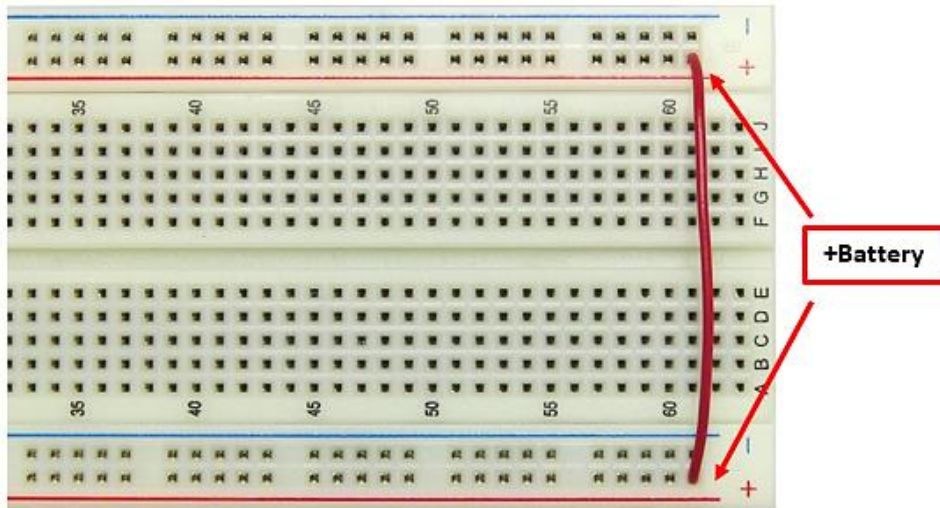


### 3.3 BREADBOARD POWER RAILS

#### 3.3.1 +Battery Schematic Symbol

The + plus red power rails will be used for the battery positive red lead. We will call this power rail +Battery.

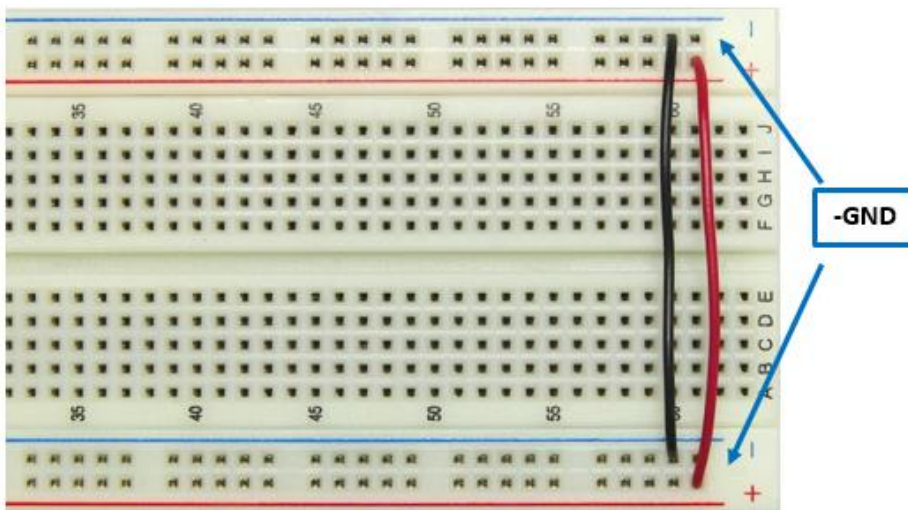
1. ☐ Wire both the breadboard + plus power rails together as shown with the red wire below.



#### 3.3.2 Ground (GND) Schematic Symbol

The – minus blue power rails will be used for the battery negative black lead. We will call this power rail Ground or -GND for short.

2. ☐ Wire both the breadboard – minus power rails together as shown with the black wire below.





### 3.4 INFRARED EMITTER SECTION

1. ☐ Resistor R1: Resistor R1 should be a 1,000 ohm resistor. The color code should match the color bands Brown, Black, Red, Gold = 1,000 ohms resistance 5% Tolerance

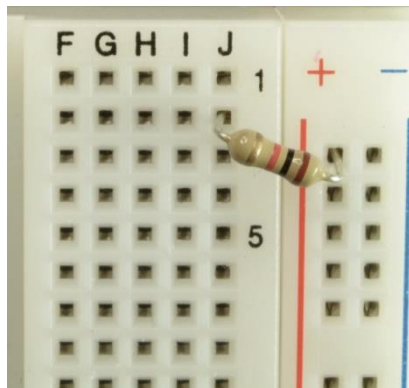


2. ☐ Resistor R1: **Trim the resistor lead length** and bend 90 degrees for insertion into the breadboard. The leads should be long enough to insert deep into the breadboard holes for good contact and overly long is better than too short.



Resistor with **shortened leads**

3. ☐ Resistor R1: Insert one lead into hole J2 and the other lead into a hole +Battery.



#### Infrared Light Emitter Diode D1

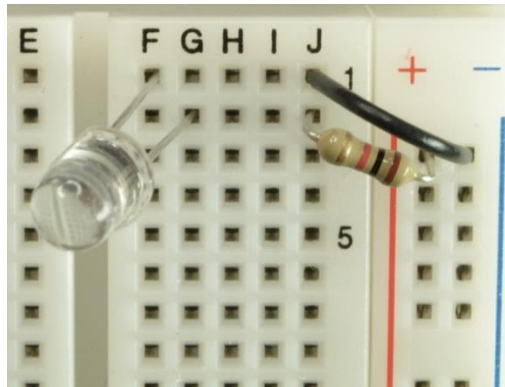


LTE-4208 IR Diode D1

4. ☐ Infrared Emitter Diode D1: Insert the longer lead into hole G2 and the shorter lead into hole F1.



5. ☐ Wire: Wire hole J1 to hole –GND.

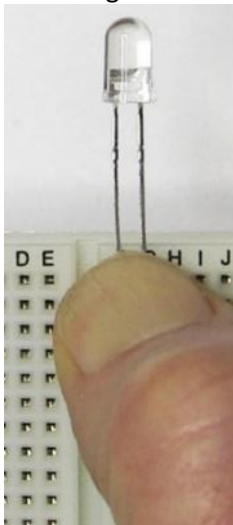


### 3.4.1 Bending Emitter

6. ☐ Bend Infrared Emitter Diode D1 down to face the surface.

Suggested Method: With D1 leads installed deeply into breadboard holes use one thumb to hold the leads in their holes and use your other thumb to bend D1 near the base.

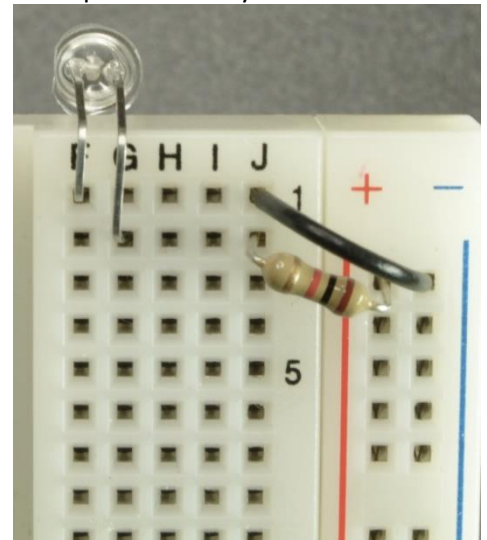
Bent 90 degrees at base



Bend to face surface



D1 points directly down to surface



Long Lead to G2



### 3.5 INFRARED DETECTOR SECTION

1. ☐ Resistor R2: Resistor R2 should be a 47,000 ohm resistor. The color code should match the color bands Yellow, Violet, Orange, Gold = 47,000 ohms resistance 5% Tolerance

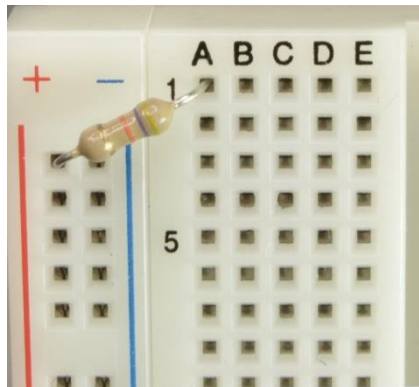


2. ☐ Resistor R2: **Trim the resistor leads** and bend 90 degrees for insertion into the breadboard.



Resistor with **shortened leads**

3. ☐ Resistor R2: Insert one lead into hole A1 and the other lead into hole +Battery.

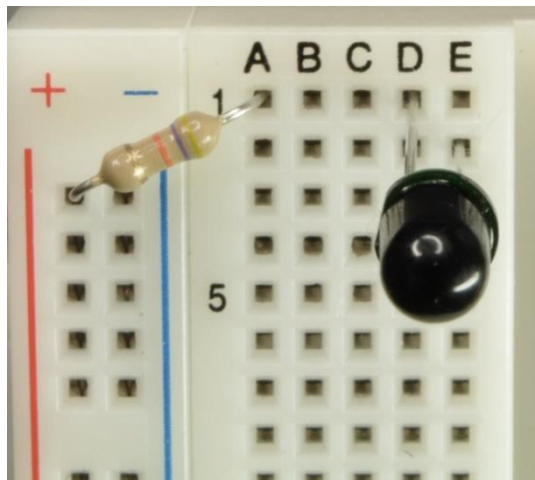


#### Infrared Phototransistor Q1

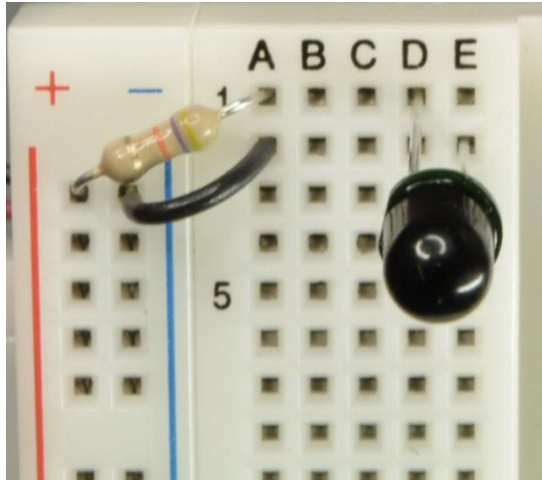


LTR-3208E IR Phototransistor

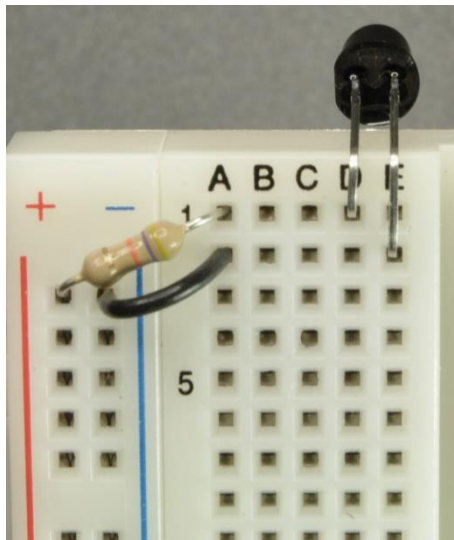
4. ☐ Infrared Detector Transistor Q1: Insert the longer lead into hole E2 and the shorter lead into hole D1.



5. ☐ Wire: Wire hole A2 to hole -GND.



6. ☐ Bend Q1 to face surface. See section Bending Emitter above for instructions on how to properly bend.





### 3.6 REFERENCE VOLTAGE SECTION

#### Thumbnail Potentiometer



3352W-1-103 Potentiometer 10,000 ohms, 0.5W

1. ☐ Potentiometer P1: Insert into holes F9, F10, F11

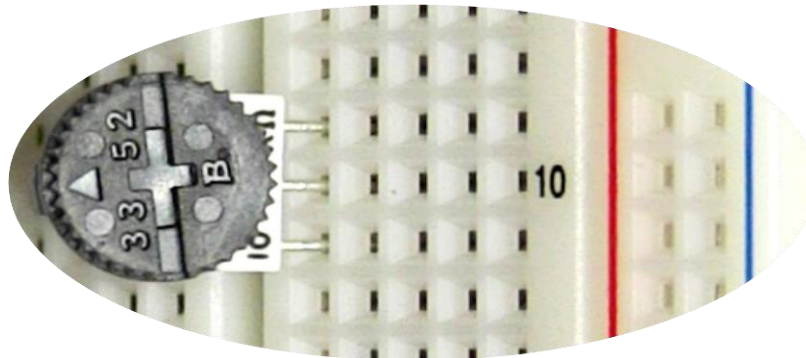


Figure 1 Close-up. P1 inserted into holes F9, F10, F11

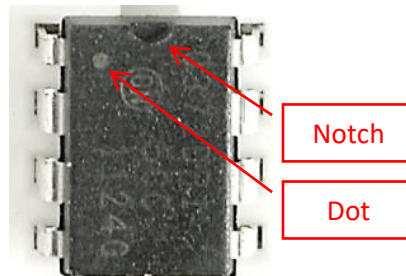
2. ☐ Wire: Wire hole J9 to hole +Battery.
3. ☐ Wire: Wire J11 to hole –GND.



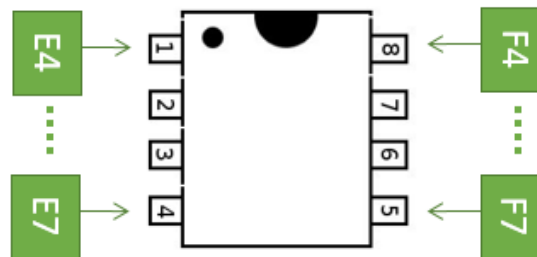
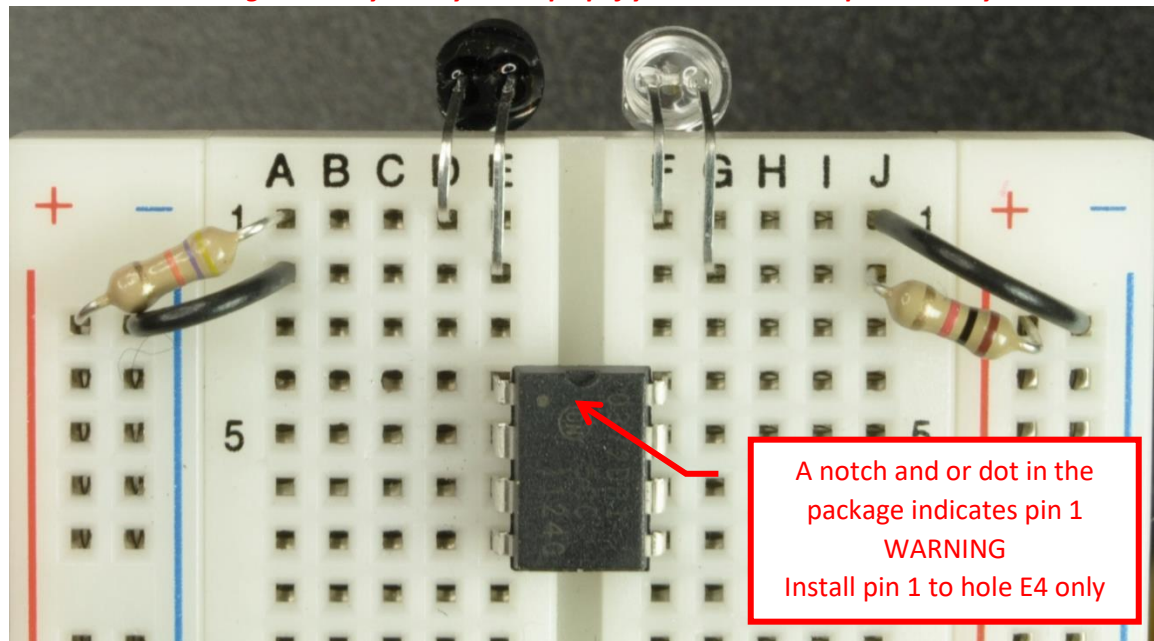
### 3.7 OPERATION AMPLIFIER SECTION

4. ☐ Op-amp chip U1: Insert into hole E4.

**Note:** Pin1 is indicated by a notch and or dot in the physical package. Be sure you do not insert chip into breadboard backwards.



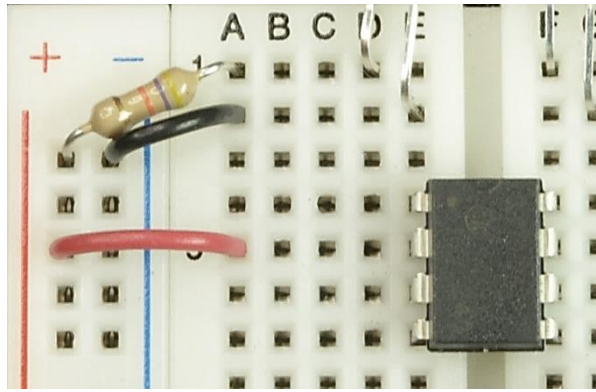
**Warning! You may burn your chip up if you install the chip incorrectly!**



U1 TCA0372 Op-Amp Chip

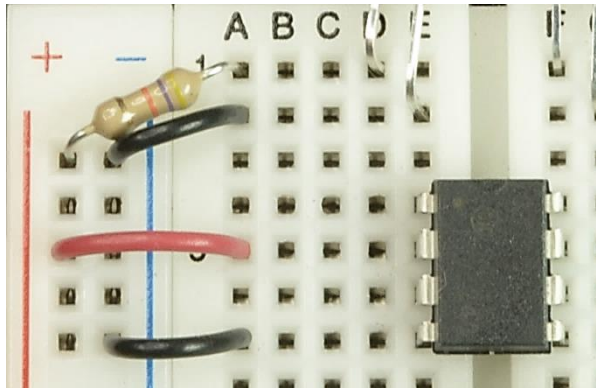
5. ☐ Wire: Wire hole A5 to hole +Battery.

**Warning! You may burn your chip up if you wire the chip incorrectly!**

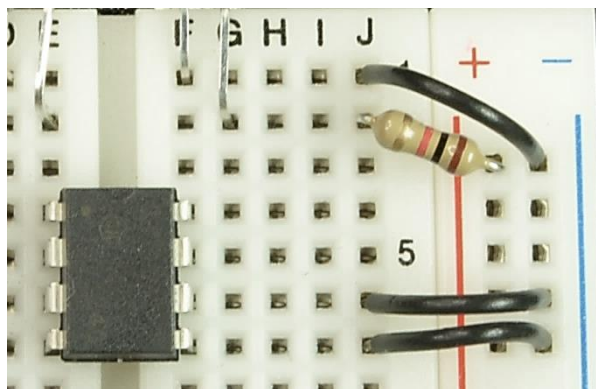


6. ☐ Wire: Wire hole A7 to hole -GND.

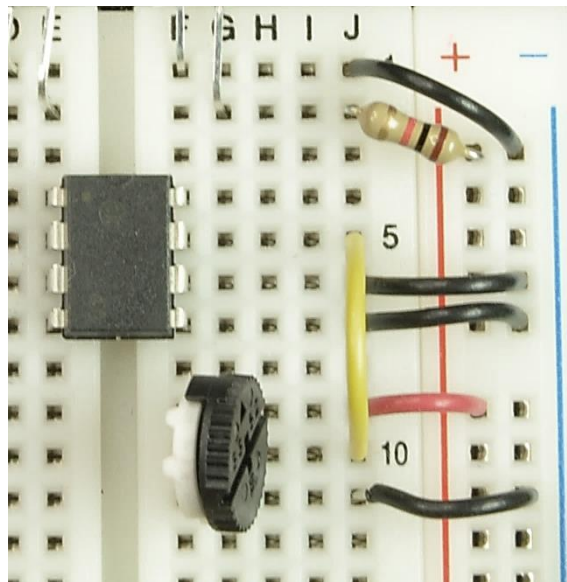
**Warning! You may burn your chip up if you wire the chip incorrectly!**



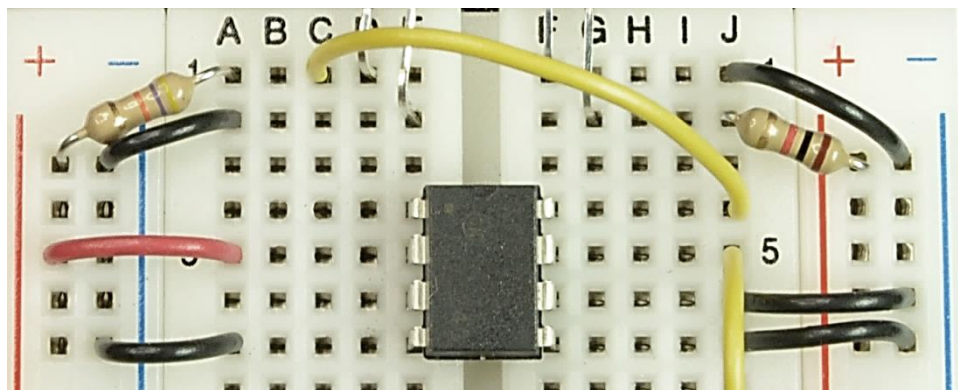
7. ☐ Wire: Wire both holes J6 and J7 to hole -GND.



8. ☐ Wire: Wire hole J5 to hole J10.



9. ☐ Wire: Wire hole J4 to hole C1.





### 3.8 INSTALL WHEELS AND WIRE MOTORS

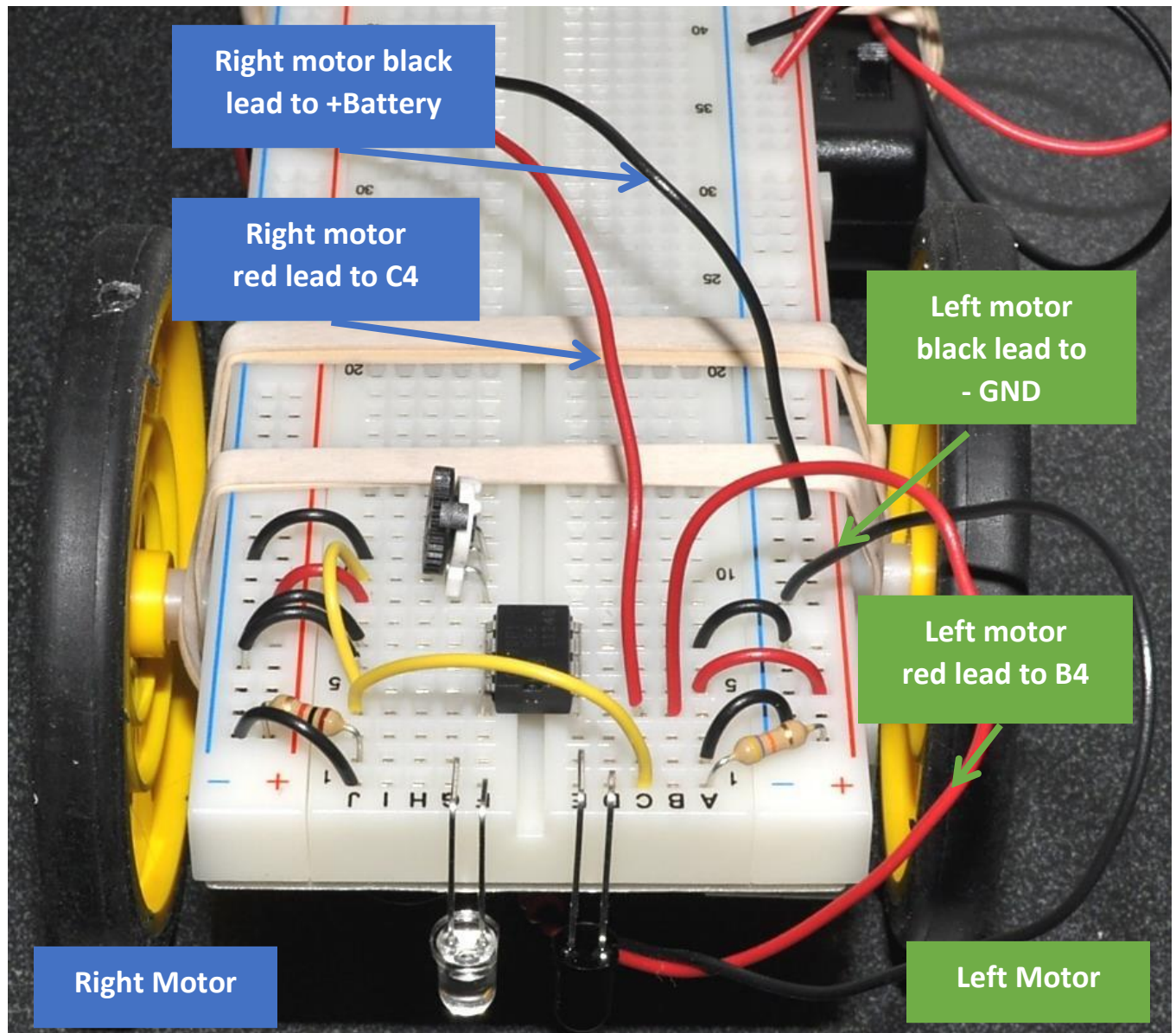
- ☐ Add wheels.

#### Left Motor

- ☐ Insert the black motor lead into hole -GND.
- ☐ Insert the red motor lead into hole B4 (connect op-amp to motor output).

#### Right Motor

- ☐ Insert the black motor lead into hole +Battery.
- ☐ Insert the red motor lead into hole C4 (connect op-amp to motor output).



### 3.9 THE 15 ¢ REAR WHEEL ASSEMBLY

There are many options for a rear wheel including a small swivel wheel, ball caster wheel, and inexpensive toy wheels. In this assembly instructions we will use the least expensive, a wooden toy wheel.

☐ Assemble and attach the super cool rear wheel as shown below



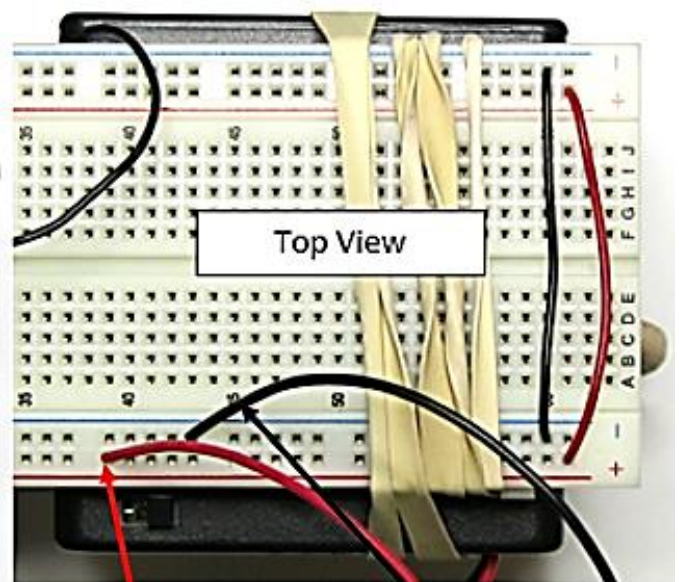
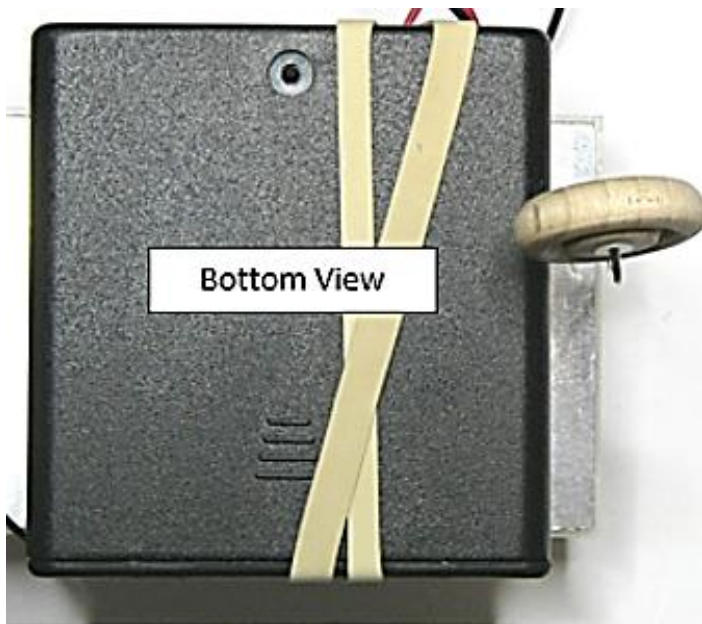
- For best results interweave the paperclip within the rubber band as shown so that the rubber band is on both sides of the paperclip.
- The wooden wheel should point forward so you may need to bend or position it appropriately.
- Try to have the wheel rotate freely without the paperclip stopping rotation.

### 3.10 4xAA BATTERY PACK ASSEMBLY

- ☐ Add four AA batteries to battery pack.



- ☐ Attach battery pack to breadboard with ON/OFF switch on left side.
- ☐ Wire battery pack Black lead to –GND.
- ☐ Wire battery pack Red lead to –Battery.

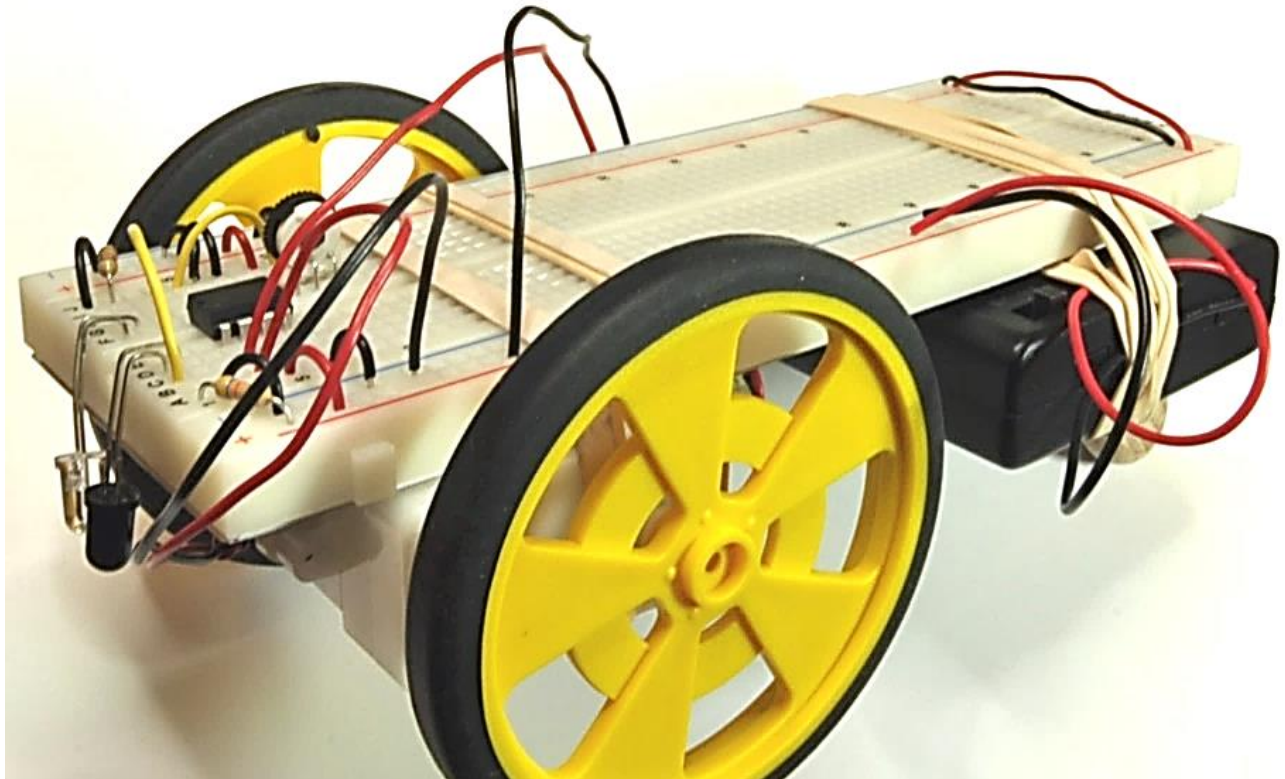
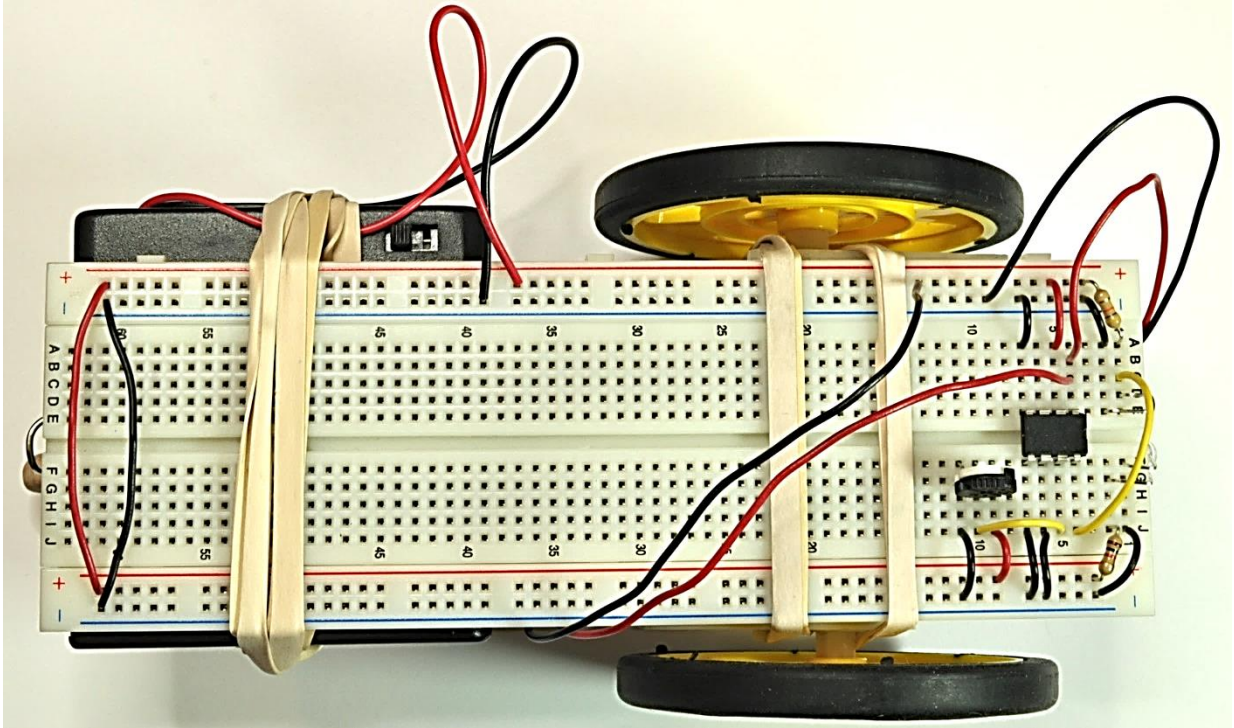


**Battery Pack  
Red lead to  
+Battery**

**Battery Pack  
Black lead to  
-GND**



### 3.11 FINAL ASSEMBLY

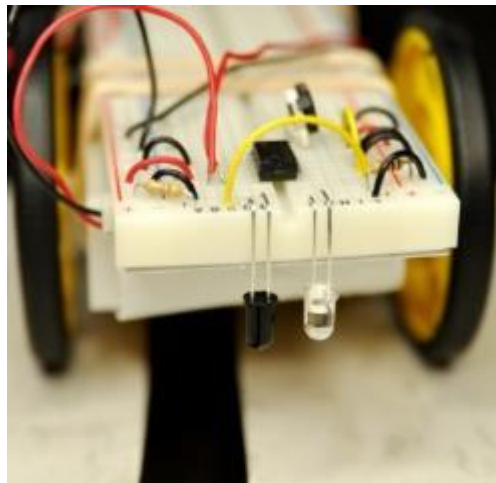
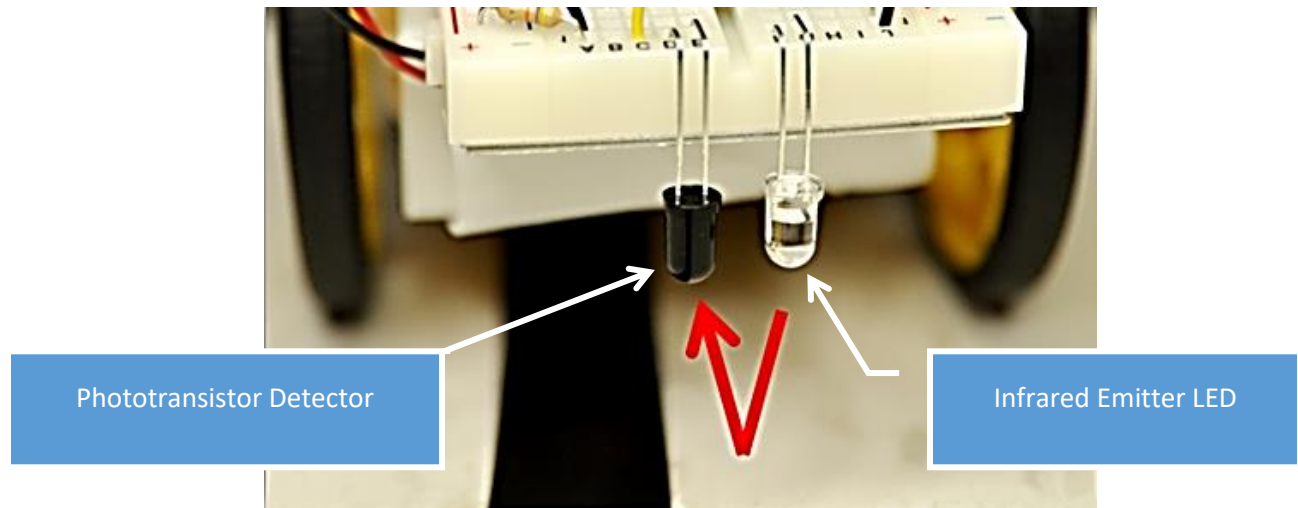




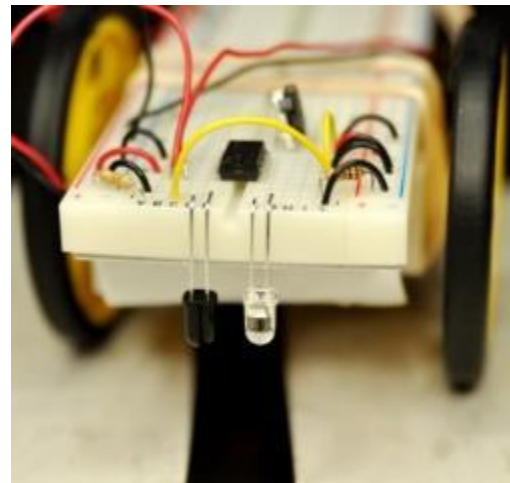
## THE ROBOT EYE

It is a basic observation that a surface that is white reflects light while a surface that is black absorbs light. The electronic 'robot eye' circuit takes advantage of this observation by detecting the difference in the amount of reflected light between two surface materials.

The infrared emitter emits infrared light down onto the floor's surface while the phototransistor detects the amount of reflected infrared light. **Your robot has one basic light detector while the human eye has over 120 million.**




**Greater** Reflected Light Over White Surface

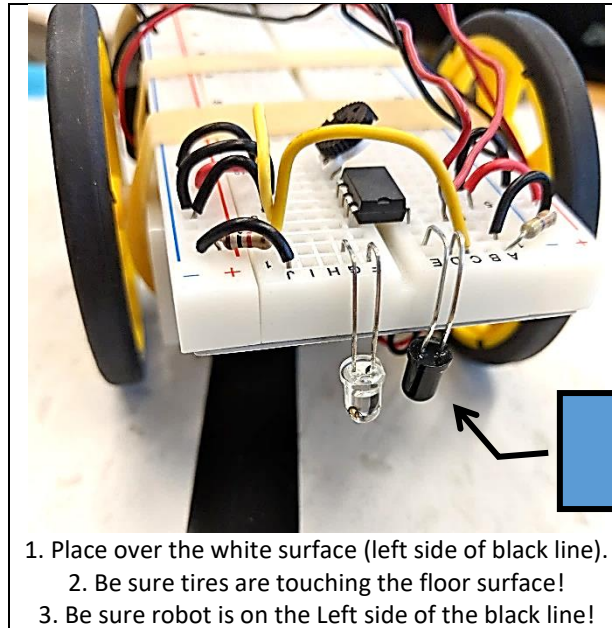


**Less** Reflected Light Over Black Surface

## HERE'S HOW TO ADJUST THE ROBOT'S EYE SENSITIVITY

Your robot has to be adjusted to know the difference between the white and black surfaces.

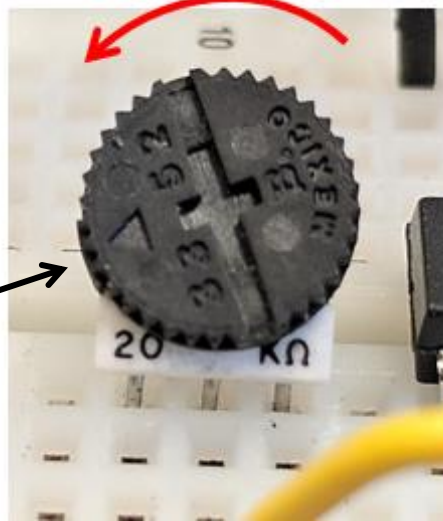
1. Turn ON the robot's power source.
2. As explained earlier, the black phototransistor  is the "eye" of the robot.
3. Place the robot's phototransistor over the white surface area on the **left** side of the black line with the tires touching the surface of the floor. **Be sure the tires are touching the floor surface and are NOT raised above the floor surface.**



Phototransistor  
"eye" of the robot.

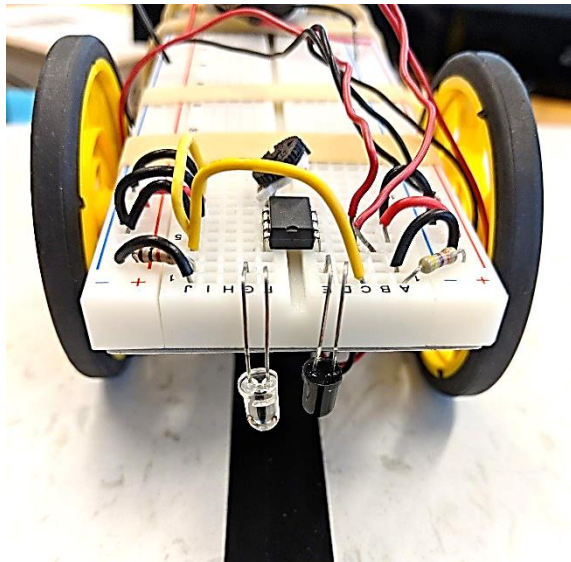
4. While holding the robot steady and in place above the white surface, rotate the potentiometer all the way counterclockwise. The potentiometer has an arrow that needs to be rotated counterclockwise until it stops.  
This should cause only the RIGHT motor to begin rotating. If both or no motors are rotating then your robot is wired incorrectly.

Arrow Indicator



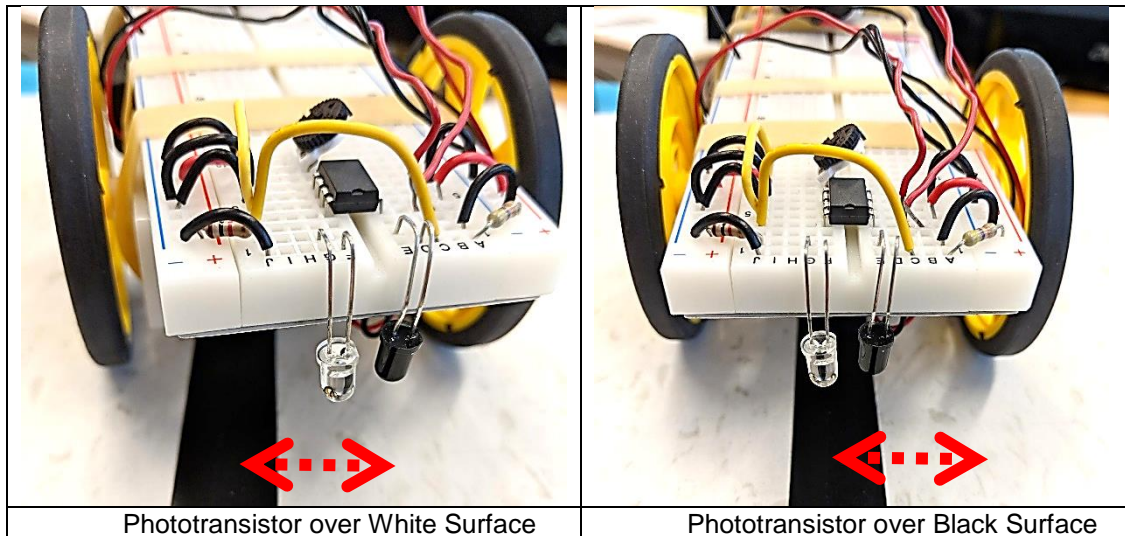
Checks:

- Adjust the potentiometer to the full counterclockwise rotation.
  - Move Robot so that the phototransistor is over the white surface. The RIGHT motor should be rotating.
  - The wheels are slightly touching the surface but you are holding onto the robot so that it doesn't run away.
5. Now Very Very Slowly adjust the potentiometer **clockwise** just to the point when the LEFT motor begins to rotate for a brief second. It's a very small adjustment!
  6. Now see what happens when you move the robot's phototransistor over the black line.
    - When the robot's eye is over the black line = RIGHT motor ON.
    - When the robot's eye is over the white surface = LEFT motor ON



Over Black Surface = RIGHT motor ON

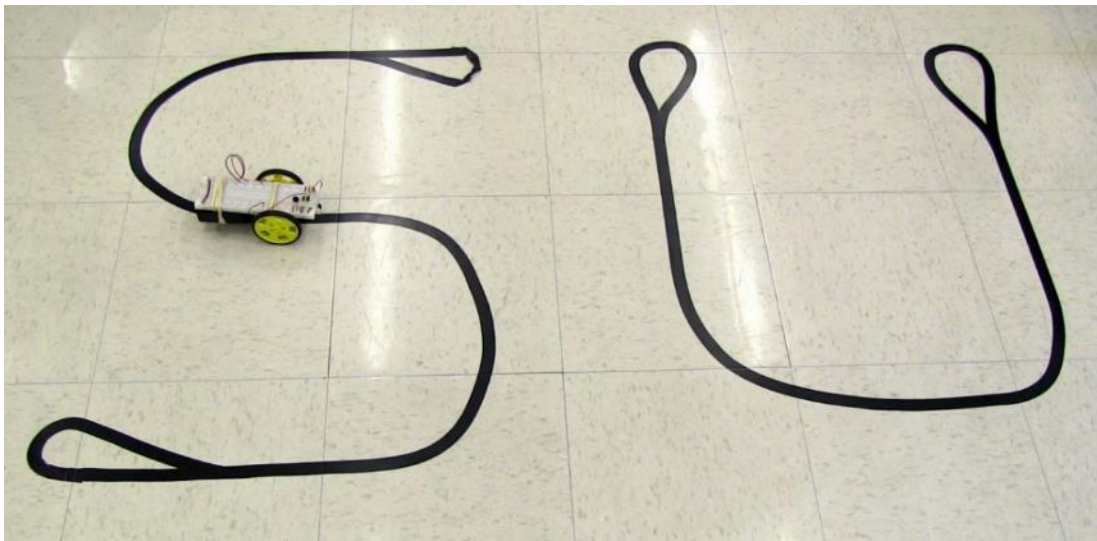
7. While holding onto the robot swing the robot back and fourth between the white surface and the black surface. This should cause the motor's to switch if you have it adjusted correctly.
- Always keep the wheels touching the floor surface while adjusting the potentiometer.
  - Swing the robot's phototransistor back and fourth between white surface and directly over black line while adjusting potentiometer.



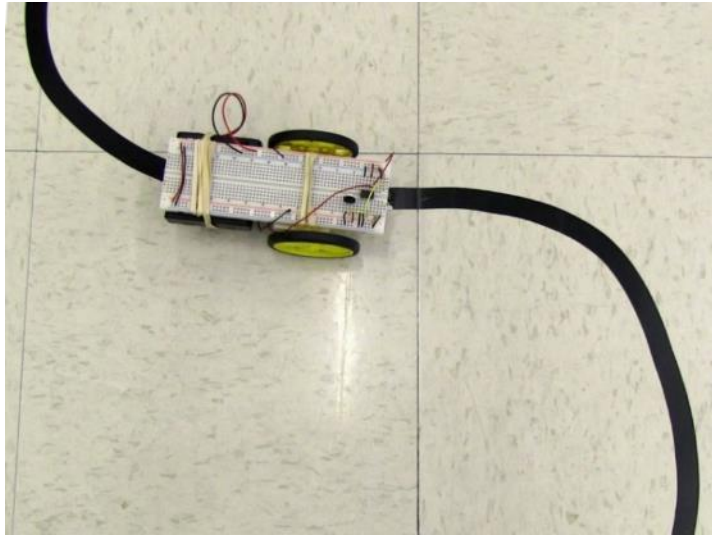
- Adjust the potentiometer so that when the phototransistor is over the white surface the LEFT motor is ON.
- Adjust the potentiometer so that when the phototransistor is over the black line the RIGHT motor is ON.
- Make all adjustments in very small amounts.

### Road Track

1 inch black tape works well for a track to follow.



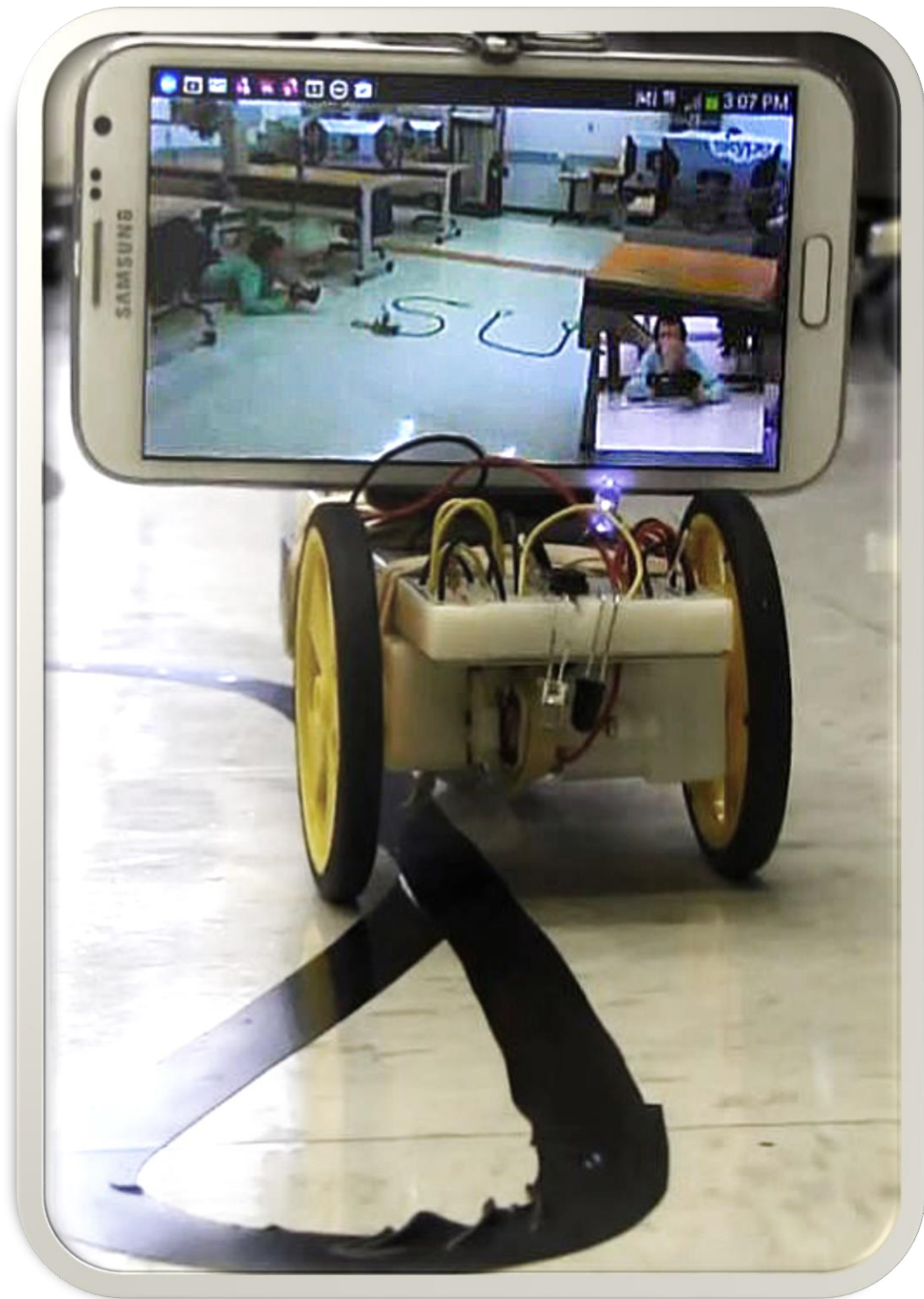




### **Creative Tinkering**

YouTube Phone Attached : <http://youtu.be/z8y3TxWjRWE?t=1m13s>

Be creative and have friends or family Skype to your phone on its long long journeys.



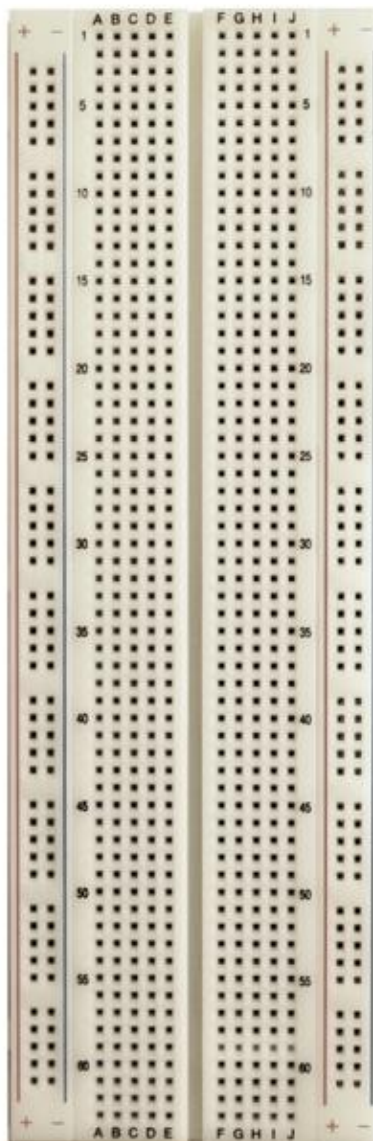
# 1. HOW IT WORKS – THE COMPONENTS USED

Basics.

## a. ANATOMY OF A BREADBOARD

A breadboard is used to build and test simple low speed low gain electronic circuits.

A breadboard is commonly made up of the four main parts consisting of (1) a plastic housing with holes in it. (2) Many metal strips called component strips of 5 hole length. (3) A few long metal strips called power rails which run the length of the breadboard on the side(s). (4) The last part is a bottom plate to cover the metal strips.



Top Side View



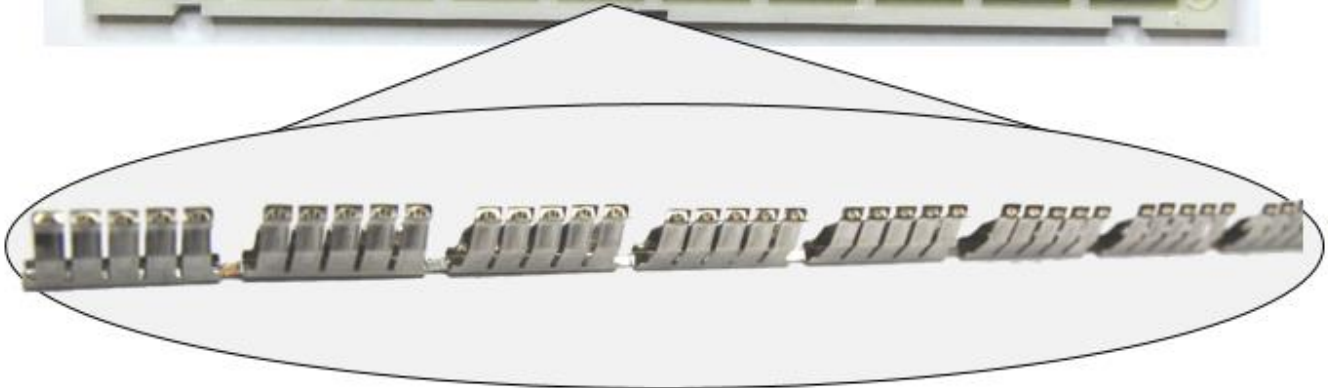
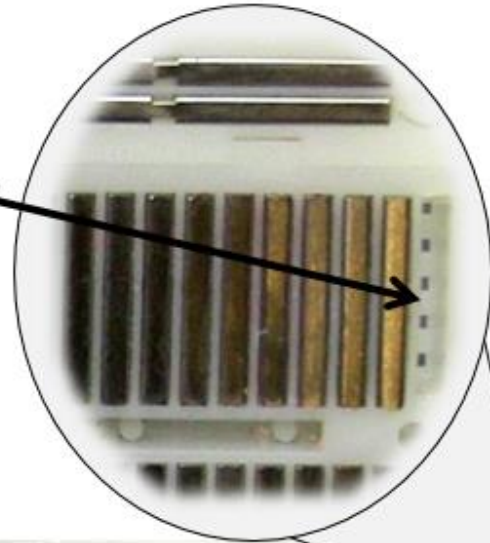
Bottom Side View  
Bottom Plate Removed

Two inner  
columns of  
metal strips  
of 5 hole lengths

Two outer  
columns per  
side of metal  
strips that  
run the length  
of the  
breadboard

Electricity easily passes through metal. The metal strips are used to transfer electricity from point to point.

Electricity does not pass through plastic. The plastic housing holds the metal strips in place.

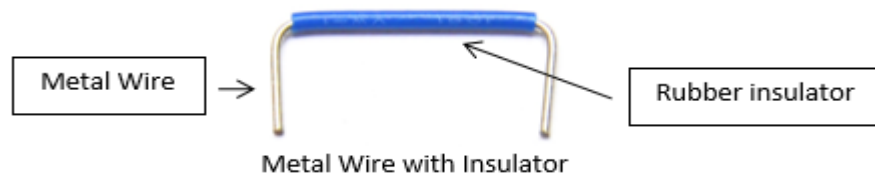


**Plastic & Rubber:** Plastic and rubber are not a good conductor of electricity, they do not allow electricity to easily pass through it. The nonconductive breadboard housing holds and conductive metal strips in place and insulates the metal strips from each other.

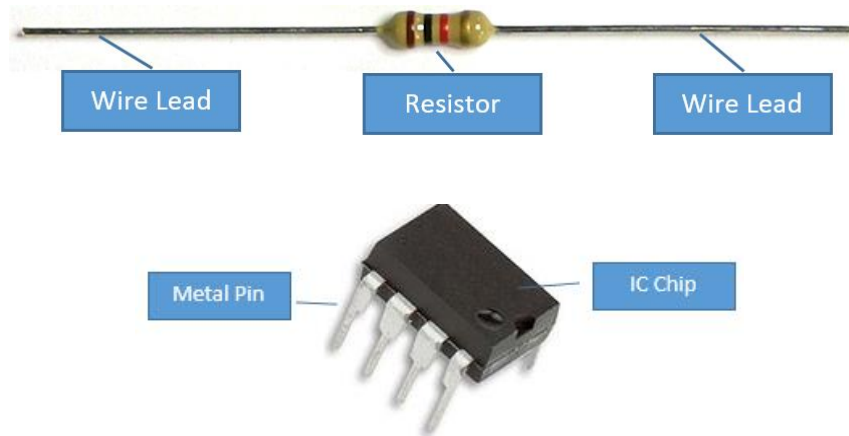
**Metal Strips:** Metal is a great conductor of electricity, it allows electricity to easily pass through it. Metal stamped into the shape of a strip is used in breadboards to transfer electricity from point to point.

**Metal Wire:** Metal rolled into the shape of wire is used to transfer electricity from point to point too. Rubber is used to insulate and cover the metal wire so that your body does not come into contact with electricity.

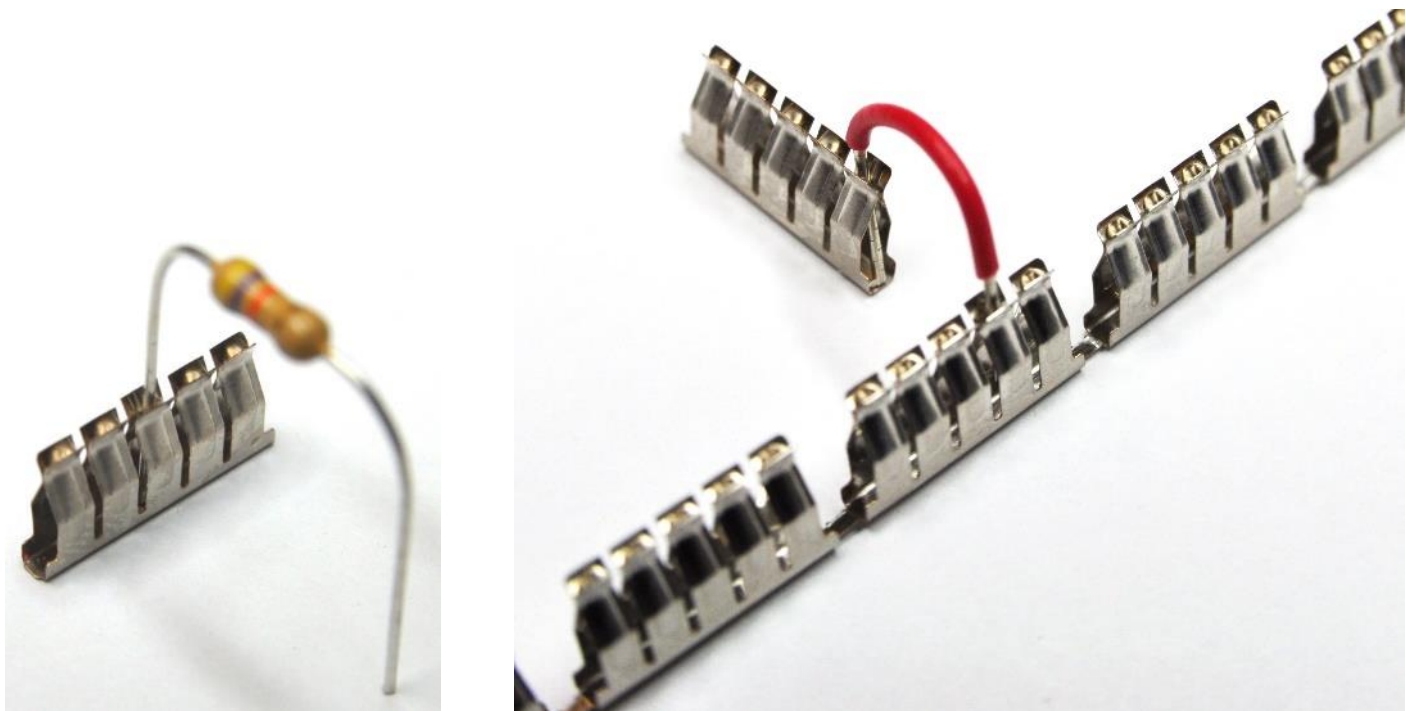


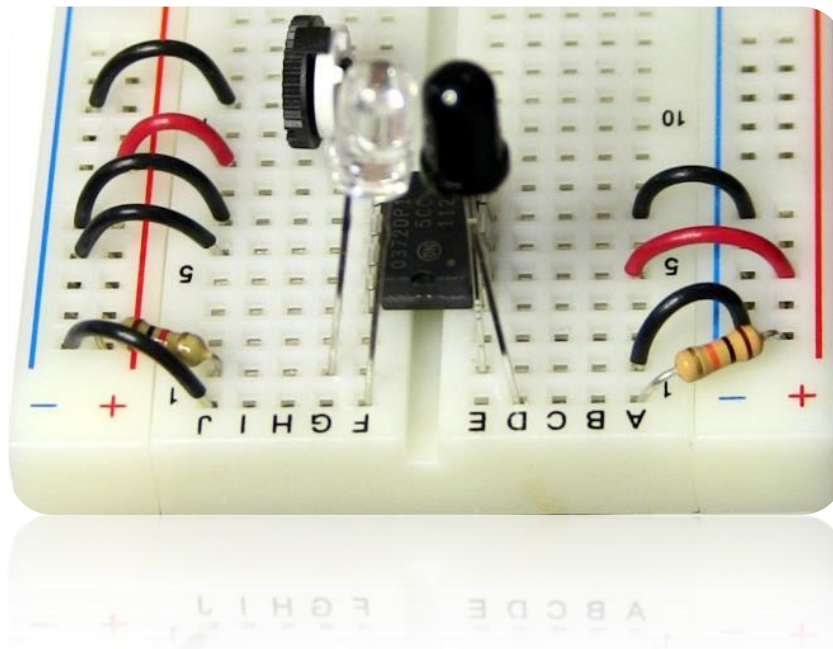
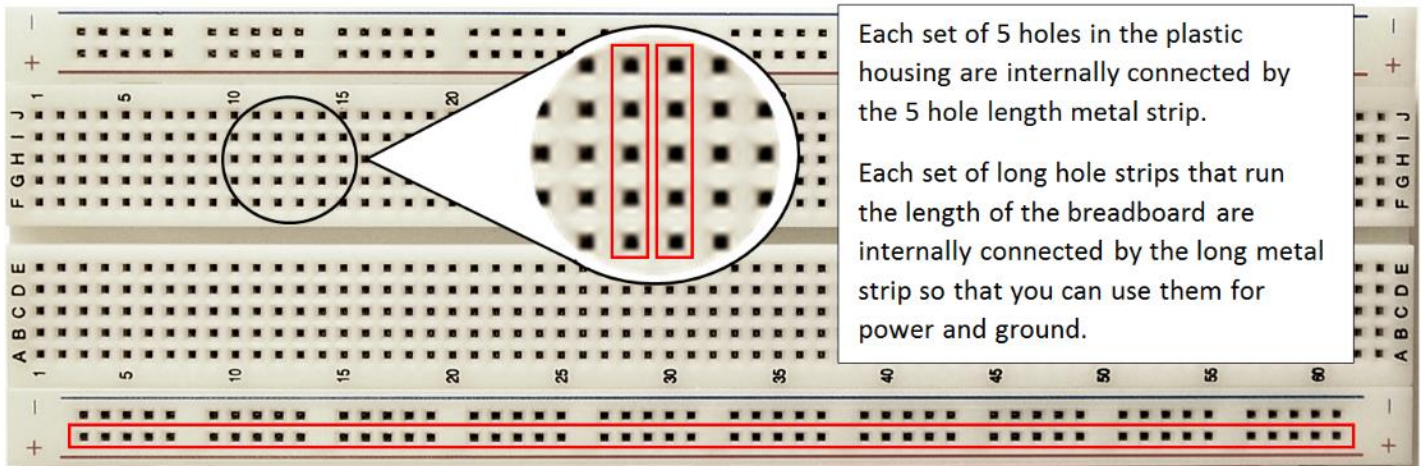


**Component Leads & Pins:** Electronic components have leads or pins consisting of a length of metal wire or metal pin that comes out of the component to make electrical contact to your circuit. For example the resistor below has two leads.



The tops of the metal strips are shaped to pinch a wire or component lead when inserted. This forms a good electrical contact so that electrical may flow from point to point.





## b. RESISTORS

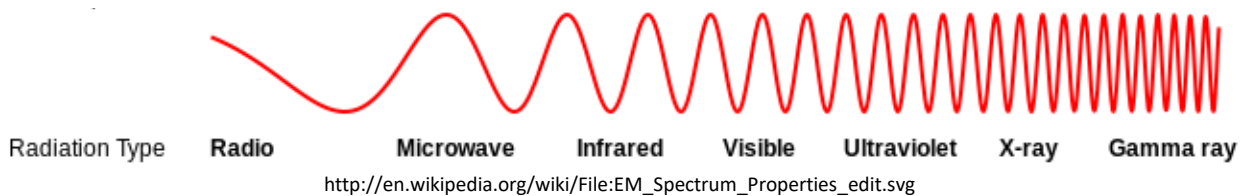
Resistors act to reduce electrical current flow and are an essential element of nearly every electronic circuit. Other electronic components such as sensors often need to have their current limited otherwise they may burn up. The batteries create a voltage and voltage is like water pressure; too much pressure causes too much water current to flow and can do you harm. If you add resistance to the flow you can tame and control it. Resistors resist the flow of electrical current much like a water valve resist the flow of water current.



Drinking from a fire hydrant is a bad idea unless you add a resistor such as a valve.

## c. PHOTOELECTRIC SENSORS

Photoelectric sensors are used in everyday life. In this lab we will use sensors that operate in the Infrared spectrum in order to help avoid interference from visible light sources such as building or home lighting.



Infrared (IR) sensors are most commonly used in TV remote controls, industrial controls, printers to detect paper flow and supply, sink faucets when you wave your hand to turn on, door openers, CD Players, and to detect the time of a race at the finish line.

- Is infrared light visible to the human eye?
- Can you feel infrared light with your skin?
- What is a CD player?

### i. Infrared Emitter (IR Emitter)

An IR emitter, also called an infrared light emitting diode (LED), emits infrared light. It's like a candle but human eyes cannot see infrared light.



Figure 2 Infrared Light Emitter Diode D1

### ii. Infrared Detector (IR Detector)

An IR detector reacts to infrared light. There are several types of detectors in use in industry and in our case we are only going to use what is called a Phototransistor. A phototransistor is like a variable valve in that it allows more electrical current to pass through it when more light energy is received within its field of view.



Figure 3 infrared Phototransistor Q1

#### d. POTENTIOMETER

Component P1 is a potentiometer (POT) or called a trimmer. Essentially a potentiometer is a three pin resistor with a sliding-contact (wiper) and can be used as a voltage divider to create a reference voltage. If only the wiper pin and one other pin are used, it acts as a variable resistor.

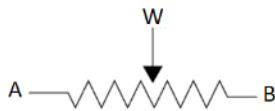


Figure 4 Schematic Symbol

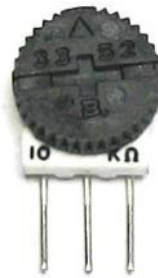


Figure 5 Potentiometer

As shown in the figure below, a potentiometer has three pins A, W (Wiper), and B. The opposite ends of the resistor material are connected to pin A and B. The resistance between A and B is the maximum resistance and does not change. On the other hand, the wiper is connected to a knob or dial so that the wiper may be moved along the path of the resistor material. The wiper is in contact with the resistive material and because of this the resistance between W and both A and B varies with the rotation of the knob.

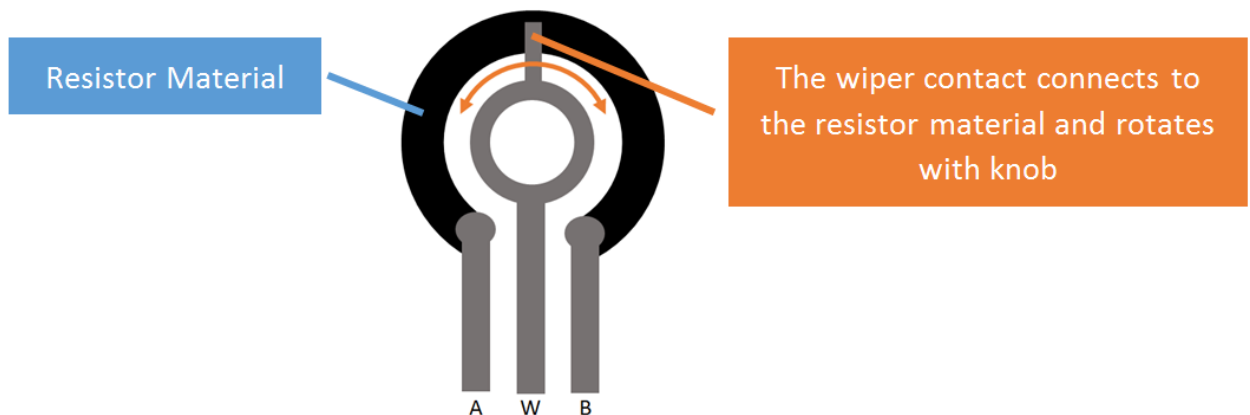
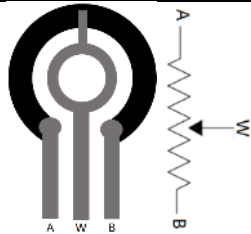
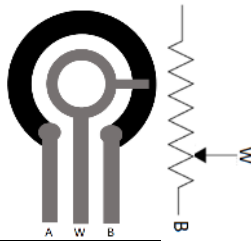
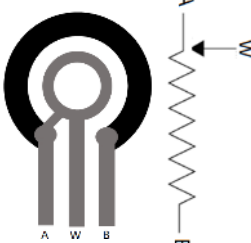
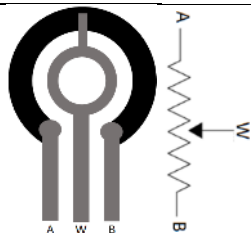


Figure 6



	<p><b>Example A</b></p> <p>In this example the wiper is in the middle of the resistor material. If the resistance between A and B is 100,000 ohms then the resistance between A and W is 50,000 ohms and between W and B is 50,000 ohms. There are equal amounts of resistor material between W and pins A and B so the resistance is equal.</p>
	<p>The more resistor material there is, the greater the resistance; the less material, the less resistance.</p> <p><b>Example B</b></p> <p>In this example the wiper is <math>\frac{3}{4}</math> rotated clockwise. If the resistance between A and B is 100,000 ohms then the resistance between A and W is 75,000 ohms and between W and B is 25,000 ohms.</p>
	<p><b>Example C</b></p> <p>In this example the wiper is rotated all the way counterclockwise. In this case there is no resistor material between pin A and W, they are connected together with 0 ohms resistance. If the resistance between A and B is 5,000 ohms then the resistance between A and W is _____ ohms and between W and B is _____ ohms.</p>
	<p><b>Example D – Voltage Divider</b></p> <p>What is a voltage divider?</p> <p>In this example the wiper is in the middle of the resistor material. 10 volts is applied to pin A and Ground is applied to pin B; the voltage on pin W is _____.</p>

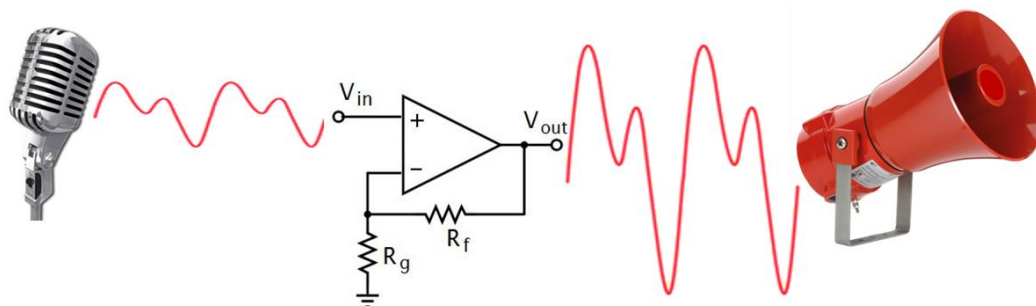
### e. OPERATIONAL AMPLIFIER (OP-AMP)

The operational amplifier (op-amp) is an integrated circuit (IC) built on a very small semiconductor material wafer (chip) and is the brain of the robot line follower. It's not a large brain but we won't judge the robot any less.

An op-amp can perform mathematical operations when external components such as resistors, capacitors, and sensors are connected to the op-amp pins. An op-amp circuit can be designed to take a signal applied to the op-amp inputs and perform the mathematical operations of addition, subtractions, multiplications, division, differentiations, and integration. An example of multiplication is to use an op-amp to amplify tiny signals to larger signals.



Figure 7 Op Amp IC chip



An op-amp chip does not work by magic but may have been designed by a wizard engineer. Internally an op-amp consists of a complex arrangement of transistors, diodes, resistors, and capacitors.

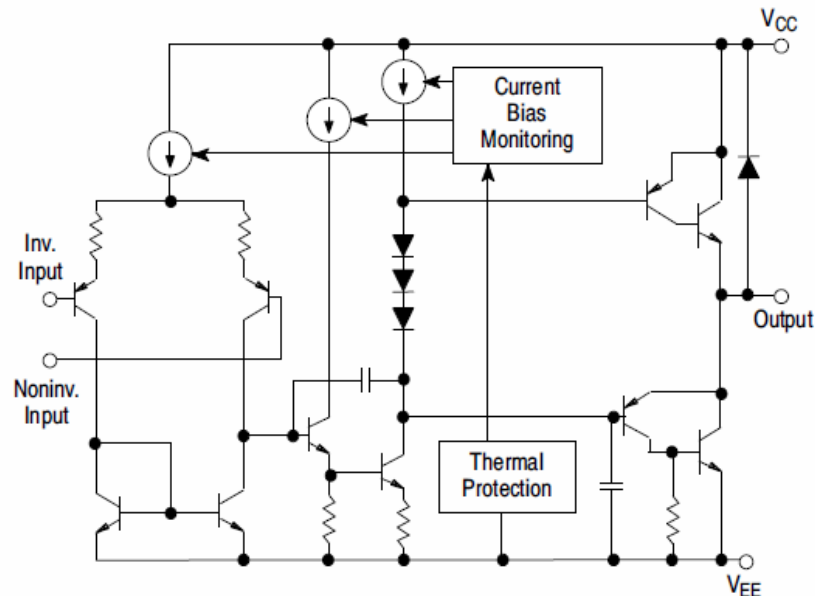
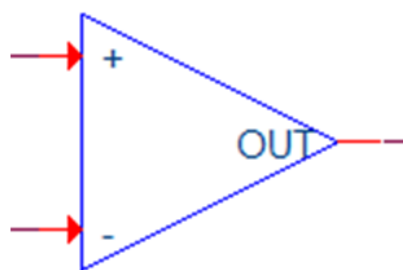


Figure 8 Cool Stuff! What's inside a TCA0372 Op-Amp

#### i. Op-Amp Comparator

A comparator is used to compare two voltages and outputs a signal indicating which input is larger. Integrated circuit (IC) manufacturers make many styles of op-amp and comparator chips customized to their application environment for performance and costs. This robot line follower circuit uses an op-amp as a comparator. In practice, there are disadvantages in using an op-amp chip as a comparator when compared to using a dedicated comparator chip. However, an op-amp operating in open loop configuration can be used as a low performance comparator. Using the TCA0372 dual op-amp chip is a good choice for this circuit project because the chip is inexpensive, readily available, and has a high current drive output of 1 ampere, enough to drive the motors directly. Driving the motors directly without external transistors makes this simple circuit even simpler.

A comparator compares two input voltages and outputs a voltage signal indicating which input is larger.



Schematic Symbol for a comparator

The comparator output satisfies the following simply rules:

- When the + input is larger than the – input, the output goes to a high voltage near the power voltage.
- When the + input is smaller than the – input, the output goes to a low voltage near ground voltage.

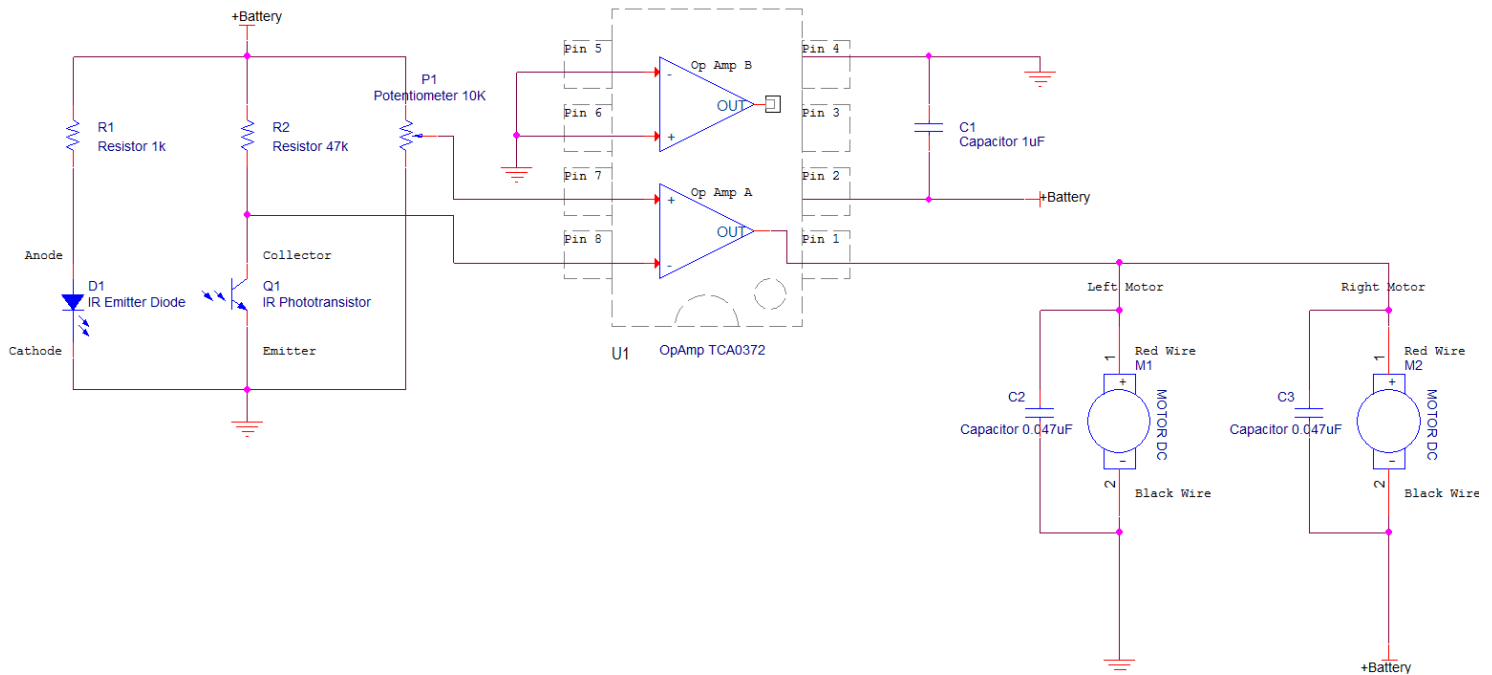
$$V_o = \begin{cases} 1, & \text{if } V_+ > V_- \\ 0, & \text{if } V_+ < V_- \end{cases}$$

ii. Adding Hysteresis

See section Reducing Switching and Motor Noise

f. BATTERIES AND DC MOTORS

I'd prefer to use them than talk about them.



## 2. HOW IT WORKS – THE CIRCUIT

### Electrically Invigorating Basics

#### a. RESISTORS R1 AND R2

Resistors act to reduce electrical current flow.

*It's been said by the guru engineer that your mind is a great big resistor to love current through the heart and if you think less more love may potentially flow; this circuit will not help heart conditions but when finished will put a smile on your face.*

**R1:** Resistor R1 is in series with the infrared LED D1 and is used as a current limiting resistor to prevent D1 from burning up.

The part number for D1 is LTE-4208 and if you were to look up the electrical specification, the [datasheets](http://optoelectronics.liteon.com/en-global/Led/LED-Component/Detail/411), for D1 you would find that D1 has a maximum electrical rating for safe normal operation. What is the maximum Continuous Forward Current that may be applied to D1? \_\_\_\_\_. As an electrical engineer, you must select a proper resistance value for R1 to work within the manufacture's specifications and the goals of the product. <http://optoelectronics.liteon.com/en-global/Led/LED-Component/Detail/411>

**R2:** R2 is used as a current limiting resistor and to create a voltage divider in series with Q1.

**Notes to the tinkerer:** R1 & R2 values can be changed to improve performance where environments require. This very simple circuit was designed during a gray winter month and inside a building. Other environments such as outside in summer light could affect circuit performance. The R1 value can be decreased in order to emit more light as long as you do not exceed the manufacture's electrical specifications for D1. The R2 value can be increased-decreased to increase-decrease light sensitivity as long as Q1 is operated within its electrical specifications from the manufacture.



## b. INFRARED EMITTER AND DETECTOR

It is a basic observation that a surface that is white reflects light while a surface that is black absorbs light. This electronic circuit takes advantage of this observation by detecting the difference in the amount of reflected light between two surface materials.

Component D1 is an infrared LED that is used as a source of infrared light. As shown in Figure 9 D1 emits light onto the surface.

Component Q1 is an infrared phototransistor. Remember that a phototransistor reacts to light energy. Q1 is used to detect and convert the amount of infrared light that is reflected from the surface into an electrical signal. Essentially Q1 acts like a variable resistor being less resistance and allowing more current to pass through it when positioned over a white surface or being more resistance and allowing less current to pass when positioned over a black surface.

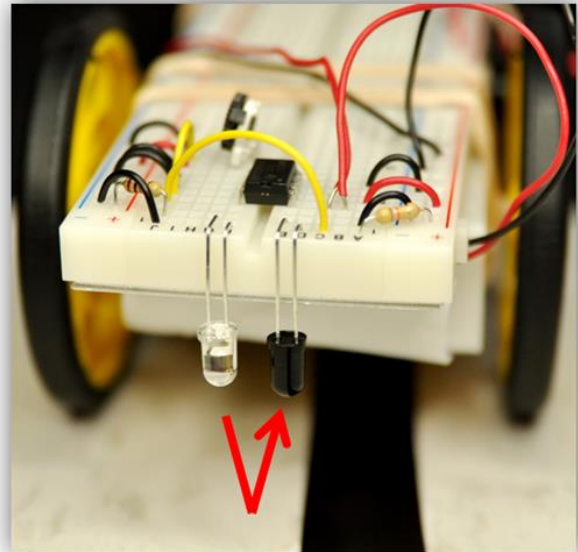
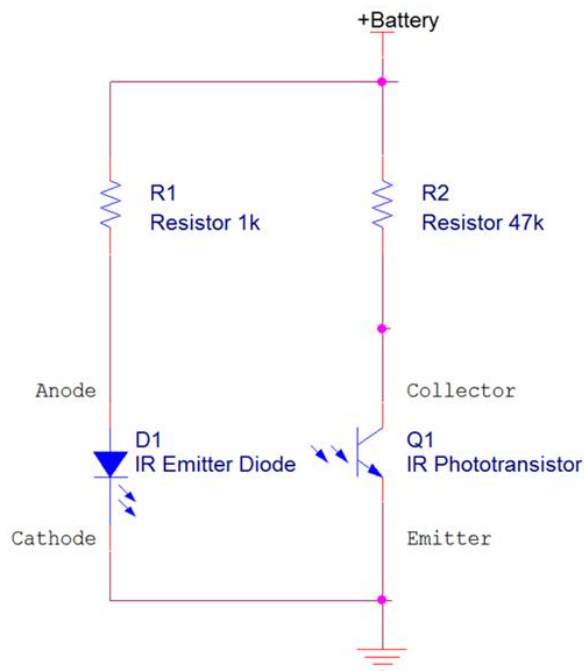


Figure 9

R2 and Q1 are in series with the battery voltage and form a voltage divider. A voltage divider is a simple circuit which turns a large voltage into smaller voltages. +Battery voltage is divided into two smaller voltages by R2 and Q1.

Ohm's law ( $v = iR$ ) states that the voltage  $v$  across a resistor is directly proportional to the current  $i$  flowing through the resistor. The voltage across R2 and Q1 vary as a function of the amount of light reflected. As more light is reflected Q1 allows more current  $i$  to pass. The voltage across Q1 can be stated as

$$V_{Q1} = +Battery - R2(i)$$

*Q1 can be thought of as the robot's eye and the varying voltage across Q1 as the eye's signal to the brain. The great eye looks to see if it is over the line or not. It's a real smart robot. "OH I see I'm over a white surface, time to move over to the black surface" then "OH I see I'm over a black surface, time to move over to the white surface" again and again the robot's only thoughts. No dreams of wondering off to find another cute robot.*

### C. COMPARATOR - COMPARING THE REFERENCE VOLTAGE & PHOTOTRANSISTOR VOLTAGE

Potentiometer P1 is used to create a reference voltage. The voltage across phototransistor Q1 (VQ1) is compared to the reference voltage (VRF) by the op-amp. As seen in the figure below, if VQ1 is less than VRF then the op-amp output goes to a high voltage. If VQ1 is greater than VRF then the op-amp output goes to a low signal. For proper operation VRF must be set to a voltage between VQ1low (white surface) and VQ1high (black surface).

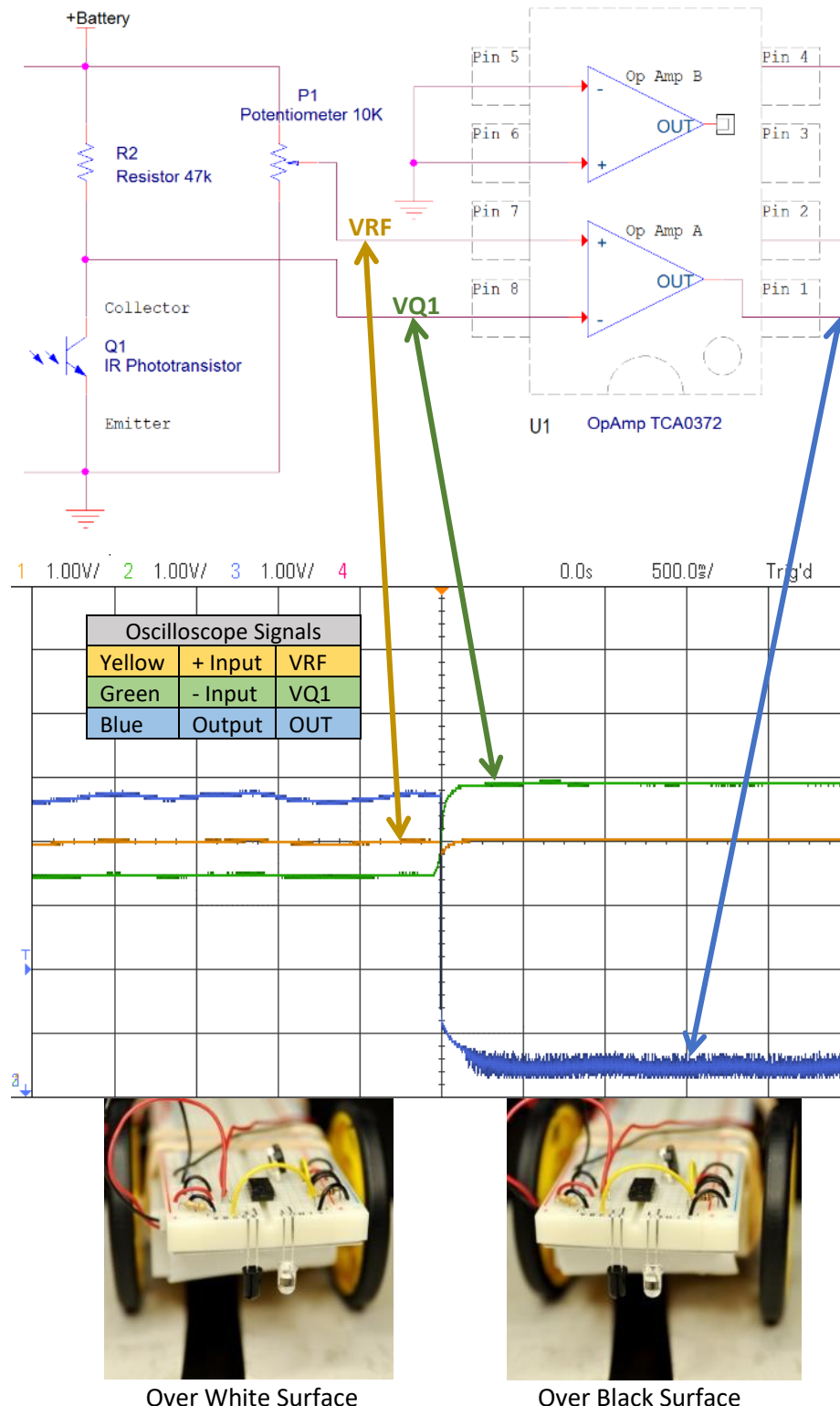

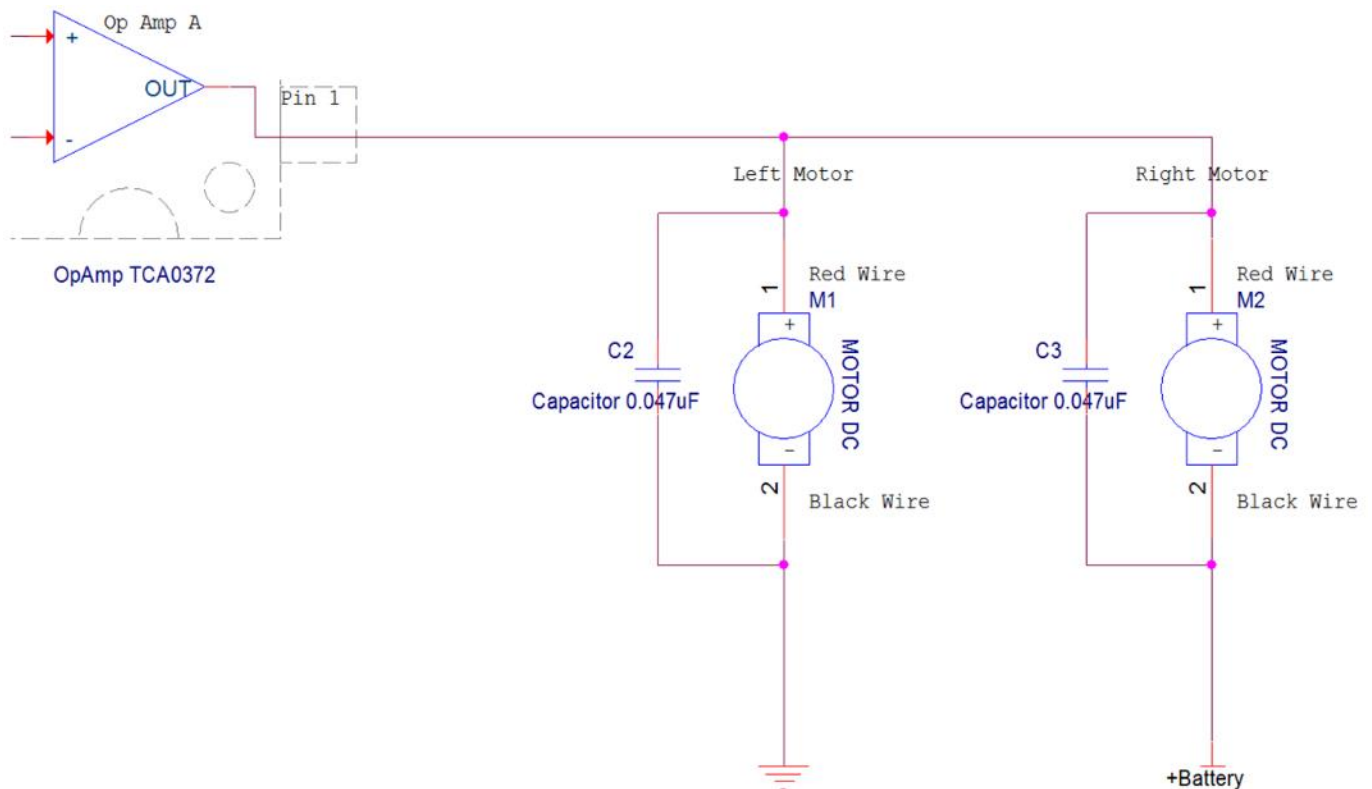


Figure 10

#### d. MOTOR DRIVE

A DC motor has two wires. One is called the positive terminal and the other is the negative terminal. For the motor to rotate it must receive a positive voltage and a negative voltage. +Battery is the positive voltage and the Ground, symbolized by the symbol  is the negative.

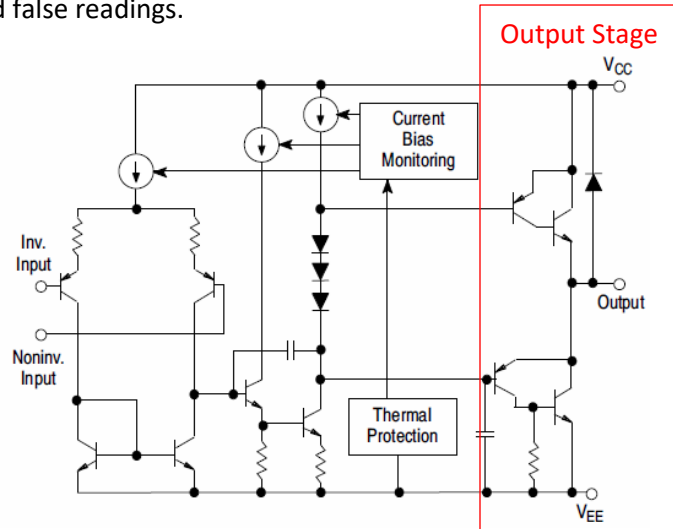
When the robot is over the white surface the op-amp OUT is set to +Battery turning on motor M1. When the robot is over the black surface the op-amp OUT is set to Ground turning on motor M2. When M1 is turned on M2 does not turn on because both of M2's terminals are connected to +Battery. When M2 is turned on M1 does not turn on because both M1's terminals are connected to Ground.



Op-amp OUT	Motor M1 Function	Motor M2 Function	M1		M2	
			+ Terminal	- Terminal	+ Terminal	- Terminal
HIGH	Rotate	Brake	HIGH	LOW	HIGH	HIGH
LOW	Brake	Rotate	LOW	LOW	LOW	HIGH

### 3. REDUCING SWITCHING AND MOTOR NOISE

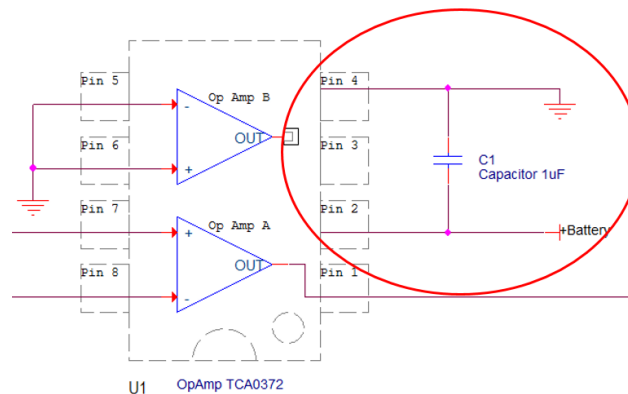
In our application the TCA0372 op-amp with high current drive is a convenient chip to use but there are potential circuit problems. One potential problem is that the chip does not have isolated VCC and VEE power for the input stage and output stage; VCC and VEE are internally connected to each stage. When the output stage is switching high currents or noisy inductive loads, noise from the output stage may be coupled into the input stage. The input stage may be used to compare or amplify very small signals and noise coupled from the output stage into the input stage may create distortion and false readings.



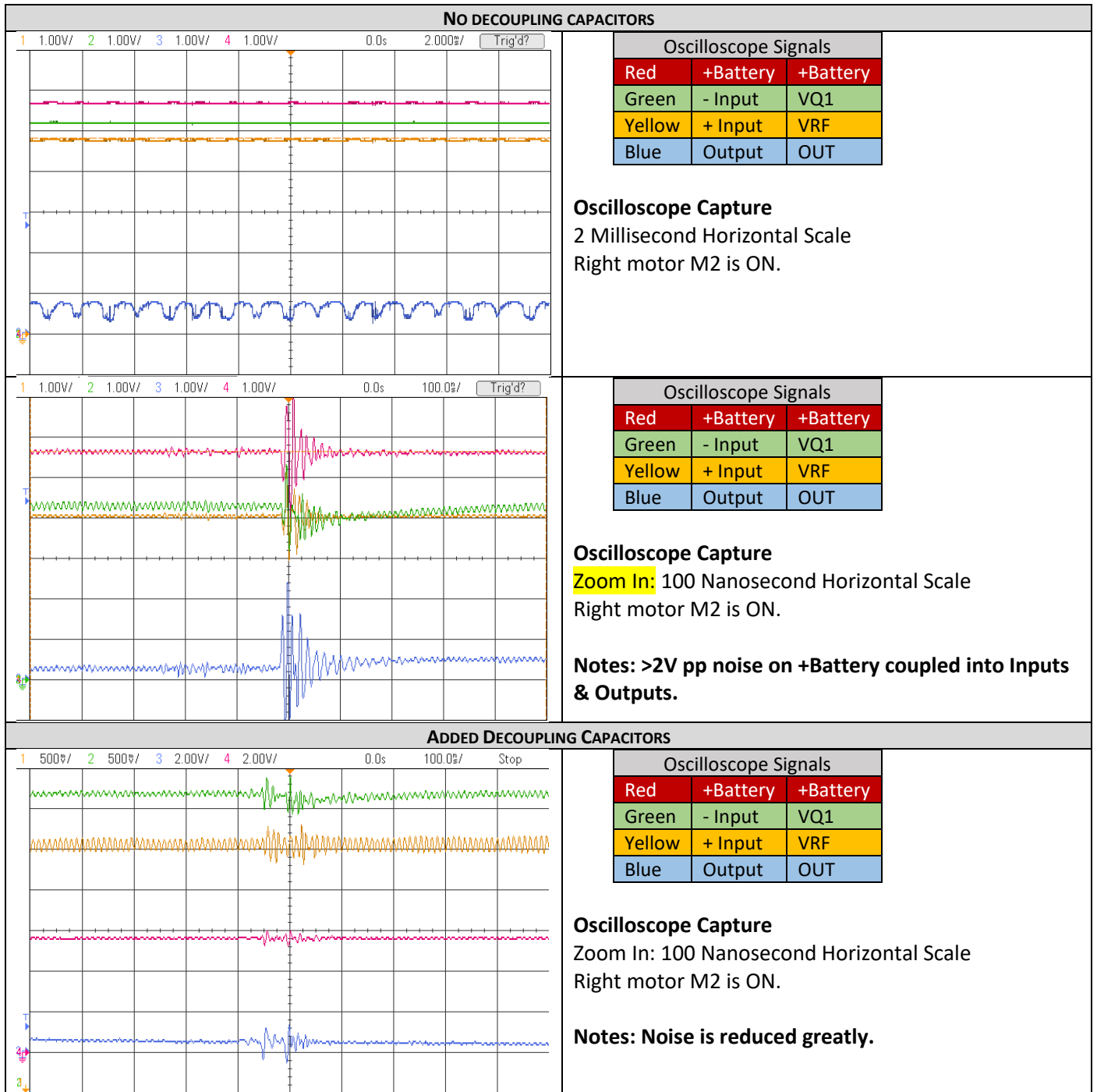
#### i. Bypass (Decoupling) Capacitors

A decoupling capacitor is used to prevent circuit noise, in one area of a circuit, from coupling into main power and ground and into other areas of the larger circuit. A good design, non-hobbyist circuit, would have included capacitors to decouple the noise produced by the large output current switching and load (motor) noise. The assembly instructions used to build this robot line follower did not include decoupling capacitors simple for simplicity's sake.

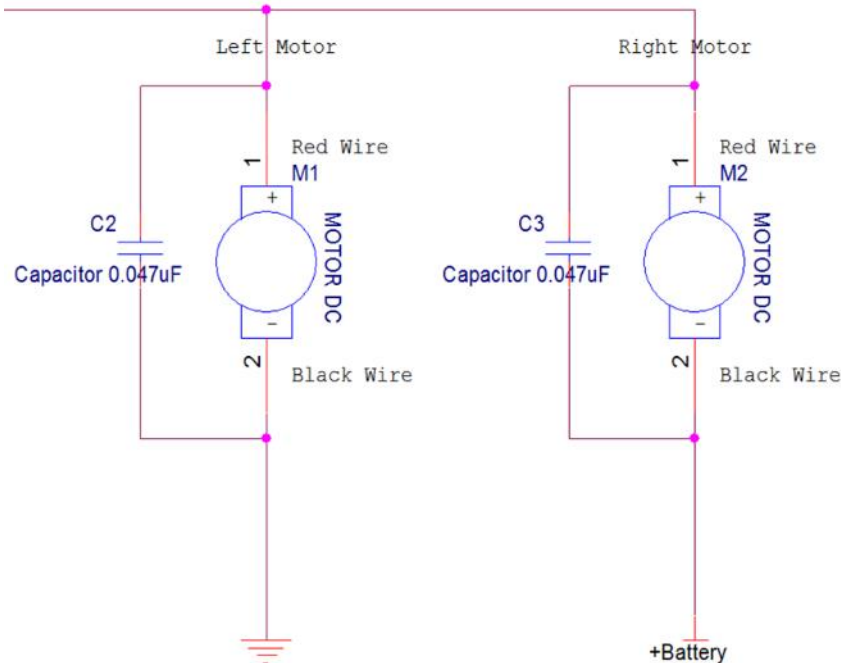
Notes: Noise from U1 could couple into +Battery and ground and then show up in other parts of the circuit, such as R2 & Q1. Capacitor C1 may be added in close proximity, as close as possible to U1 power & ground pins, for decoupling providing local energy storage. Capacitor C1 only stores a small amount of energy but this energy can be placed very close to U1 and respond very quickly to fast changing current demands. The decoupling capacitor effectively maintains the power supply voltage. The battery current must travel through extended wires. Wires have extremely small resistances but must be taken into account because they produce very small voltage drops ( $iR$ ) that can affect sensitive circuits, such as the inputs of U1.







## ii. Reducing Motor Noise



[http://www.beam-wiki.org/wiki/Reducing\\_Motor\\_Noise](http://www.beam-wiki.org/wiki/Reducing_Motor_Noise)

## iii. Motor Snubber Diode

<http://en.wikipedia.org/wiki/Snubber>

[http://en.wikipedia.org/wiki/Flyback\\_diode](http://en.wikipedia.org/wiki/Flyback_diode)

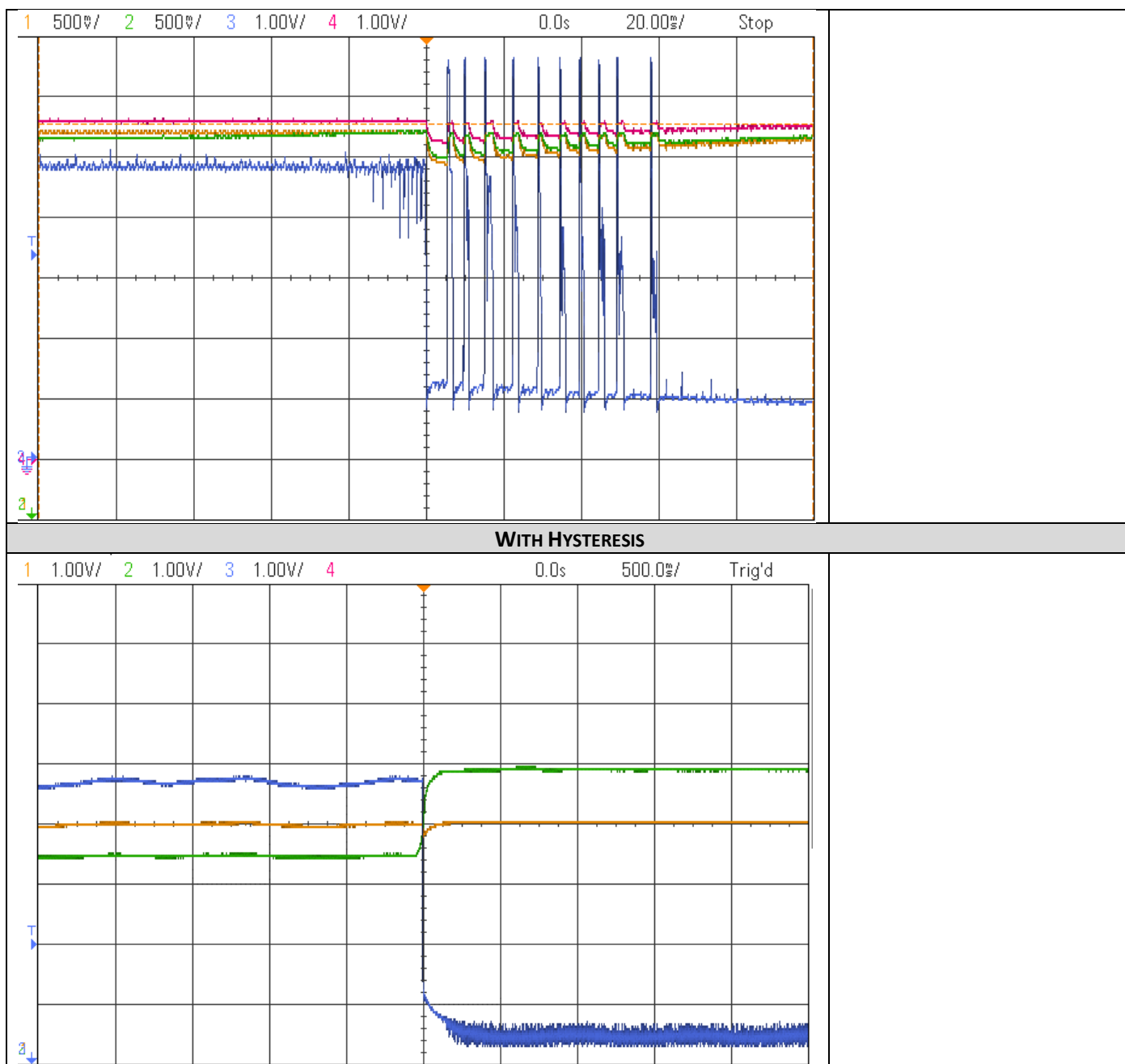
## iv. Hysteresis

Dedicated comparator chips have built in hysteresis and standard op-amp chips do not. ... mention some of the pluses to comparators versus op-amps.

When using open-loop op amps as comparators, a small amount of noise combined with the input signal can cause undesirable switching of the output state, see figure .

Substituting the op-amp with a comparator with built in hysteresis may prevent the rapid output changes and oscillation. Or, you can create external hysteresis by applying positive feedback to a comparator. Because positive feedback guarantees a fast output transition from one state to the other, the comparator output spends a negligible amount of time in the indeterminate state.

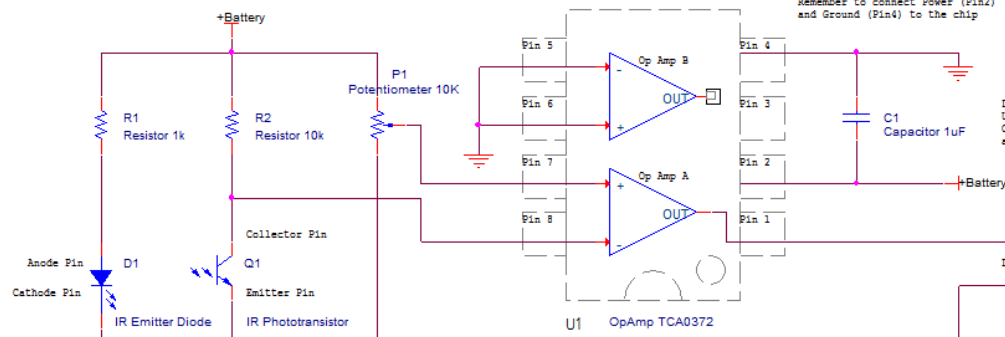
WITHOUT HYSTERESIS



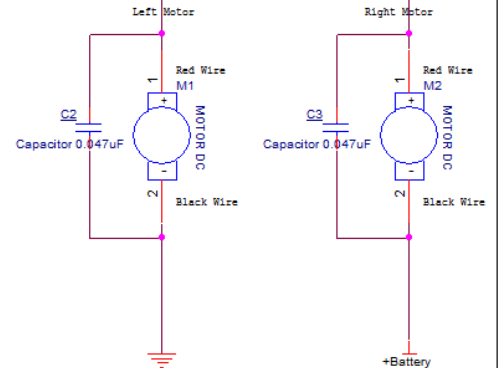




Adjust the voltage reference set by P1 until the line edge is detected as indicated by opposite motor beginning to turn

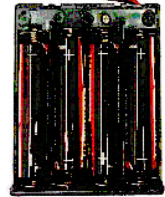


Decoupling Capacitor C1 should be placed nearest U1 pins 2 & 4.  
Capacitor Filter C2 & C3: Best if applied directly across motor terminals.

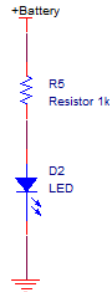


CONNECT RED LEAD(Battery Positive) to circuit +Battery

CONNECT BLACK LEAD(Battery Negative) to circuit GROUND

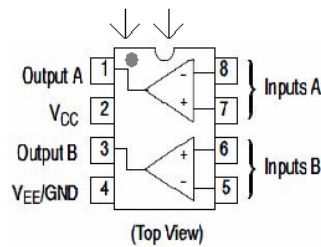


4 X AA Battery Pack



Power Indicator.  
LED is ON when power is applied.

Pin 1 is indicated by a notch or dot in the physical package.  
As viewed from the top the remaining pins are numbered counterclockwise.



Owner			
Gary Fernandes			
Title			
Simple Op Amp Line Follower -Comparator Version 1			
Size A	Document Number		Rev 00
Date:		Sheet 1 of 1	