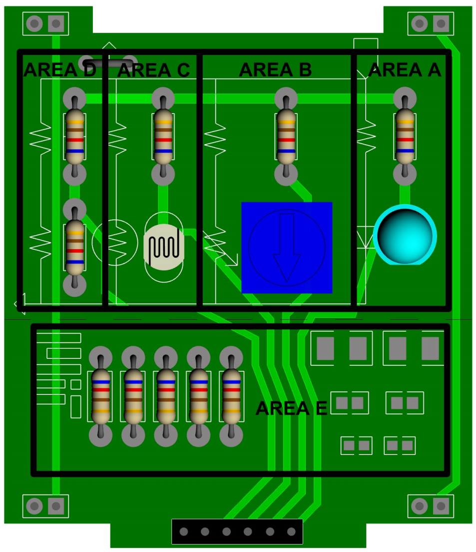
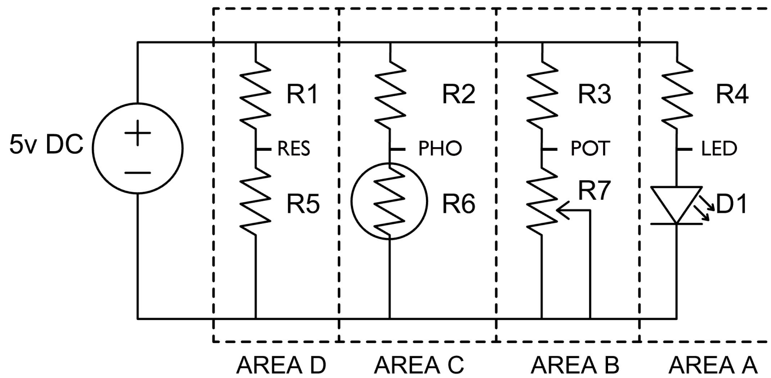
Massachusetts Institute of Technology
Electromechanical Systems Group
Electronics First: DIVIDERS

Board and **Circuit Schematic:**





Materials:

Part	Quantity	Part Number	Vendor
Breadboard	1	377-2646-ND	DigiKey
Breadboard Power Supply	1	BPS	EFirst
Multimeter	1	MN35-ND	DigiKey
6-Pin Header Pins	1	732-5319-ND	DigiKey
2-Pin Rail Connector Pins	4	732-5315-ND	DigiKey
12 Volt Adapter (or USB cable)	1	102-4123-ND	DigiKey
Soldering Iron and Solder Wire	1 ea	T0052918199N-ND	DigiKey
620 Ω Resistors	10	CF14JT620RCT-ND	DigiKey
Potentiometer	1	3386P-102TLF-ND	DigiKey
Photoresistor	1	PDV-P8104-ND	DigiKey
Light Emitting Diode (LED)	1	365-1182-ND	DigiKey

The Build:

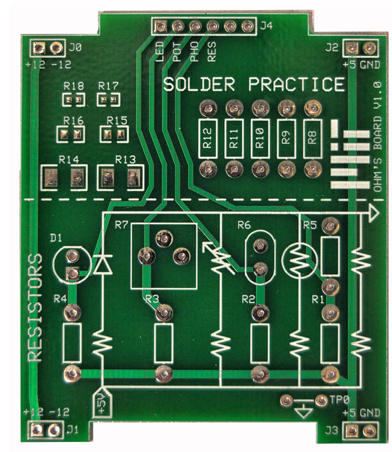
Sensors provide the “eyes” and “ears” for any electronic product you might design and build. You can buy inexpensive components that sense light, sound, temperature, gases, metals, a fingertip, and more. Actuators and displays, such as motors and light emitting diodes (LEDs), let your product interact with the world and your customers. Sensors and actuators often require an electrical circuit that both provides energy and, particularly for sensors, also offers a measurement point for detecting sensed values, e.g., a voltage proportional to light level, mechanical position, or temperature. In this laboratory, you will explore **divider** circuits that let you measure the light level and mechanical angle observed by two sensors: a photoresistor and a potentiometer. You will also use a divider to make an LED glow.

ELECTRONIC CIRCUITS direct and exploit the flow of electrical charge. The movement of charge through a circuit can be thought of like water flowing through a pipe. The differential pressure of the water measured across two points is analogous to *voltage*. Voltage is measured between two points or *nodes* in a circuit. Sometimes one of these two nodes is designated as *ground*. The flow rate of water as it moves through a pipe can be compared to the *current*, or flow of electric charge past a given point. The diameter and length of a pipe limit the rate of water flow, analogous to electrical *resistance*. A reduced diameter pipe restricts water flow. In an electrical circuit, greater resistance generally reduces the flow of electrical current.

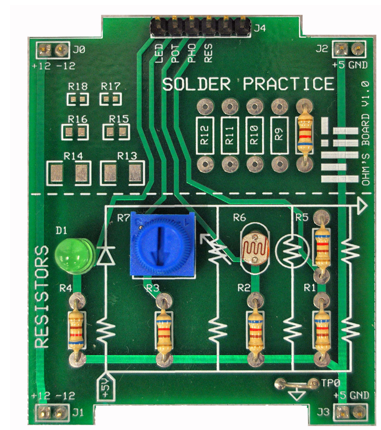
This laboratory introduces you to electronic components and the important principles of physics that govern the operation of basic circuits: Kirchoff's Voltage Law (KVL), Kirchoff's Current Law (KCL), constitutive laws like Ohm's Law for resistors, and devices, like diodes, with different constitutive laws from resistors. In this lab, you will build and explore a circuit structure sometimes called a "divider". A divider is a useful circuit to understand because it is a common way to energize and use sensors, e.g., to connect a photoresistor as an "electronic eye" for a microcontroller like an Infineon/Cypress PSoC®.

In a divider, voltage is applied across a *series* connection of two or more components. Components connected in series share the same current. A fraction of the total applied voltage appears across each component in the divider; that is, the input voltage is "divided" across the series arrangement of components. The divider board you will build demonstrates voltage division occuring in four different divider circuits. Each of these four divider circuits are connected in *parallel* with the other three. Circuits connected in parallel have the same voltage across each circuit. The four dividers on your board include dividers made with discrete resistors, a mechanically-variable resistor divider called a *potentiometer*, a light-dependent resistor or *photoresistor*, and a *light emitting diode* (LED).

The cover page shows a circuit schematic and a cartoon of the assembled divider board that indicates the "Board Areas" A-E. **AREA A** includes a resistor and an LED configured as a divider. **AREA B** includes a resistor and a potentiometer. **AREA C** includes a resistor and a photoresistor, and **AREA D** includes a divider made from two conventional resistors. **AREA E** is for solder practice - use **AREA E** with an instructor to develop your skill in soldering "through hole" and also "surface mount technology (SMT)" components.



Start with this...

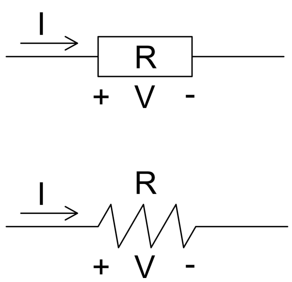


... and finish here.

Theory of Operation and Predictions

BEFORE WE CONSTRUCT AND TEST THE DIVIDER BOARD, let's see if we can understand how we expect the properly assembled board to behave. Begin by considering how the resistor divider in **AREA D** of the divider board will perform. This resistor divider consists of two equal value resistors connected in series between the $+5V$ voltage source and ground.

To describe how a component behaves in a circuit, we first need to establish reference directions for the voltage and current. These reference directions are arbitrary, but must be consistent throughout the circuit for a mathematical description to make sense. A common approach that we will adopt is to label a two-terminal component with a positive (+) and a negative (-) side. This labeling is arbitary. Measured voltage across the component is considered to be "positive" when the potential difference is higher on the positive terminal with respect to the negative terminal. Current is referred to as a "positive" current when it flows into the positive voltage terminal.

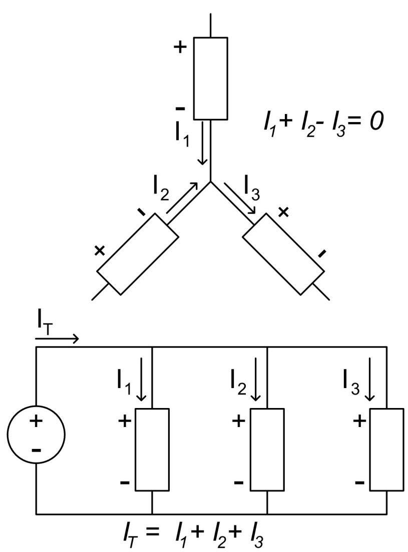


Two common symbols for a resistor.
Resistors obey Ohm's Law, V = IR

Ohm's Law

A resistor is characterized by its resistance, R. The behavior that relates the terminal voltage and current for a device is sometimes called a "constitutive law" or "I-V characteristic." For an ideal resistor, the constitutive law or relationship between current (I) and voltage (V) follows Ohm's Law: **V = IR**.

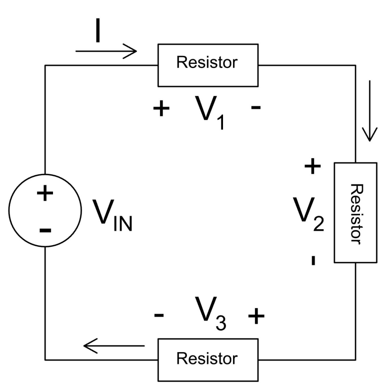
Kirchoff's Current Law



Applications of KCL

Kirchhoff's Current Law (KCL) states that the sum of the individual currents in a network of conductors flowing into a point (or node) is zero. This is essentially a statement of conservation of mass. Any charge that flows into a node must flow out. In the specific case of branch circuits in parallel, the sum of the individual currents (I_1, I_2, $I_3 ... I_N$) flowing through each branch of a parallel circuit is equal to the total current, I_T.

Kirchoff's Voltage Law



$$-V_{IN} + V_1 + V_2 + V_3 = 0$$

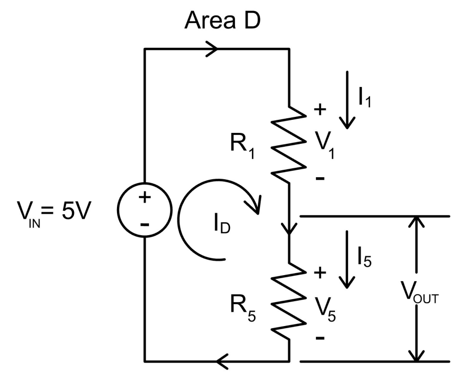
Kirchoff's Voltage Law

Kirchoff's Voltage Law (KVL) states that the sum of all voltage drops around any closed circuit loop is zero. Kirchoff's voltage law is an approximation of reality that assumes that the magnetic fields flowing through the center of the loop (e.g., corresponding to in or out of the "paper page" upon which the circuit is drawn) do not change very quickly in time. Kirchoff's voltage law is essentially a statement of conservation of energy. If we track the path of a charged particle around the loop, we expect it to accelerate and decelerate as it traverses the various voltage drops, ultimately experiencing a net acceleration of zero as the particle returns to the start point. If this did not happen, we could add more and more energy to the particle every time it traversed the loop; KVL says that we expect the particle to end with the same energy with which it started.

Let's make some predictions for the behavior of each of the areas **A-D** on the properly assembled and energized divider board.

Voltage Divider

A voltage divider is a circuit designed to produce an output voltage that is a specific fraction of the input voltage. The particular "output" voltage is a function of the input voltage and the constitutive laws associated with the components in the divider. In its simplest form, a voltage divider looks like what you will build in **AREA D** – a pair of resistors in series.



Voltage Divider Circuit

The input voltage is applied across the series combination of the resistors, but the output voltage in this case is measured across the second resistor, labeled for R_5 on the divider board. By varying the ratio of the first and second resistors in the series pair, you can produce a desired voltage across the second. By KCL, you know that the currents I_1 and I_5 are equal to I_D. By KVL you know that $V_{IN} = V_1 + V_5$. Using Ohm's law, you know that $V_1 = I_D R_1$ and $V_5 = I_D R_5$. Therefore, you can substitute the Ohm's law expressions into the KVL equation to reveal

$$V_{IN} = I_D R_1 + I_D R_5.$$

This simplifies to $V_{IN} = I_D(R_1 + R_5)$. Rearranging this equation to solve for the current reveals

$$I_D = \frac{V_{IN}}{R_1 + R_5}.$$

Knowing this expression for I_D, we can substitute into the Ohm's law equations for each resistor to solve for the individual resistor voltages V_1 and V_5. For example, since $V_1 = I_D R_1$, then

$$V_1 = \frac{R_1}{R_1 + R_5} V_{IN}$$

and similarly

$$V_5 = \frac{R_5}{R_1 + R_5} V_{IN}.$$

1.) Use the equations above to solve for V_1, the voltage across R_1, and V_5, the voltage across R_5. Assume an input voltage of $+5V$ and the resistor values given on the cover page. Other questions to consider: If we replaced the series combination of R_1 and R_5 with a single equivalent resistor with resistance R_{eq}, what value of equivalent resistor would draw the same current I_D from the input source? What would the voltages V_1 and V_5 be if we doubled the resistance of R_5 but left everything else unchanged? What would happen to the voltage V_5 if we added a 100Ω resistor in parallel with R_5? Suppose we left the resistors R_1 and R_5 as originally built, but changed the input voltage to $3.3V$ – what would the voltages V_1 and V_5 be in this case?

V_1:

V_5:

Prediction 1

Photoresistor

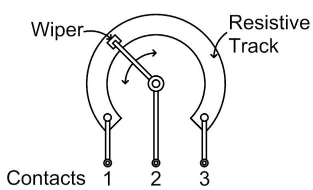
The divider provides exciting design and sensing opportunities if one of the "resistors" exhibits a variable resistance that changes with some environmental parameter like light or temperature. In **AREA C** of your divider board, you will install a type of variable resistor called a *photoresistor*. This is a light-dependent resistor that is typically more resistive when kept in the dark and less resistive when exposed to the light. In other words, when you build **AREA C**, you will

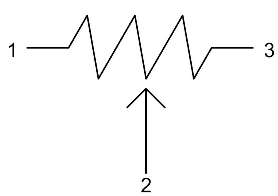
Resistance	Voltage
Increase Decrease	Increase Decrease
(Circle One)	(Circle One)

Prediction 2

Resistance	Voltage
Increase Decrease	Increase Decrease
(Circle One)	(Circle One)

Prediction 3





Potentiometer Function - pin 2 effectively moves to the right as the knob is rotated in the clockwise direction.

Clockwise
________ Ω to ________ Ω
CCW
________ Ω to ________ Ω

Prediction 4

have built another divider just like the one in **AREA D**, but the previously "fixed" resistor R_5 will now exhibit a resistance that varies with light level.
2.) Think about the photoresistor in **AREA C** on your board. If you covered it with your hand, would you expect the resistance to increase or decrease? What about the voltage drop across it? Would that increase or decrease?
3.) What happens if you shine a flashlight on the photoresistor in **AREA C**?

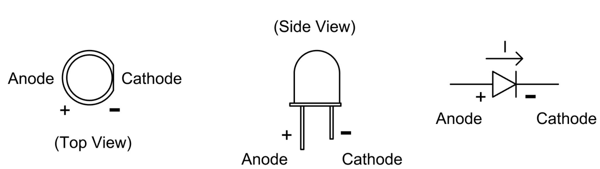
Potentiometer

A potentiometer ("pot") is an adjustable voltage divider. It consists of a resistive trace or track with a fixed resistance between the pot's pins 1 and 3. A moving wiper, connected to the pot's middle pin 2, can be positioned anywhere along the trace between pins 1 and 3. Effectively, the knob setting divides the trace into two resistors, one between pins 1 and 2, the other between pins 2 and 3. The two "resistors" always sum to the same total value, but the mechanical position sets the ratio of the resistances. Note that you do not have to use all three pins on a pot. For example, you can use just pins 1 and 2, in which case the pot looks like a two-pin resistor whose resistance can be set by the knob.

In **AREA B**, you will replace one of the fixed resistors with pins 2 and 3 of a pot when you build the divider. Specifically, you will install a single-turn, 1 kΩ potentiometer. By turning the knob in a clockwise direction, you can decrease the distance between pins 2 and 3 on the potentiometer trace, and thus the resistance between the two pins.
4.) Given an operational tolerance of $+/-10\%$, predict the range of values of the resistance across pins 2 and 3 when the knob is rotated fully in the clockwise direction. Repeat this for when it is rotated back all the way counterclockwise. If the knob of the pot were turned by a mechanical shaft connected to the elbow of a robot arm, what would the pot effectively be sensing?

Light Emitting Diode

A light emitting diode (LED) emits visible light when sufficient current passes though it. Too little current and you get no light. Too much current and the diode is destroyed. The diode is *polarized*; i.e., it matters which way the diode is inserted in the circuit. Current will only pass through the diode and produce light in one direction. You will install an LED in D1 in **AREA A** on your divider board. Be **very** careful to insert the diode in the correct orientation when you build the divider board!



LED Symbols and Orientation

LEDs are not resistors and they do not obey Ohm's law. You can approximate the behavior of an LED by imagining that it operates with a fixed voltage across the LED whenever it is "on" or glowing, i.e., when it has sufficient current to light up. Typically, the LED might operate with a current anywhere between $5mA$ (less bright) and $20mA$ (brighter). For any current in this range, the voltage across the LED might be approximately $1.7V$, for example. When the LED is "on," the resistor in series with the LED sets the current through the LED; the voltage across the current-setting resistor will be the input voltage minus the LED voltage. The numbers here are just examples. Check the specification sheet for the LED you are using to find reliable numbers. If you exceed the maximum current, e.g., $20mA$ in our example, the LED will fail permanently.

5.) Assuming that the LED "forward" (operating) voltage is about $1.7V$ and the resistor in series with the LED is 620 Ω, what current will flow through the LED in **AREA A** with a $5V$ input?

6.) Assume that the rated current for this LED is 20mA. In the proposed **AREA A** circuit arrangement, at what applied input voltage would you predict the LED would fail?

I_{LED}:

Prediction 5

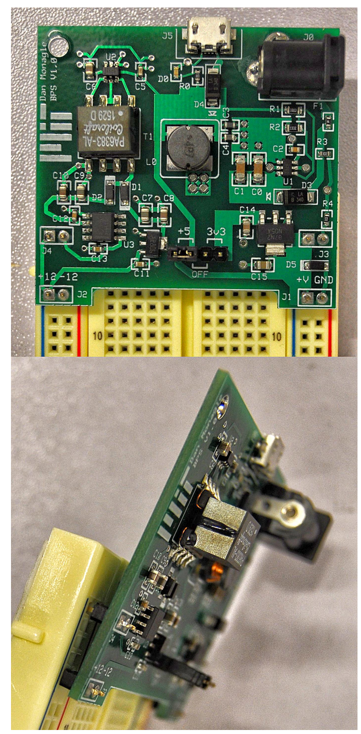
V_{FAIL}:

Prediction 6

Assembly

Let's build. In addition to the materials listed on the cover page, you should have a power supply board. We will use a solderless "breadboard" as a convenient base for connecting the power supply board to the divider board. Use the breadboard to construct temporary circuits for testing and prototyping. Install your power supply board on the breadboard as shown in the figures.

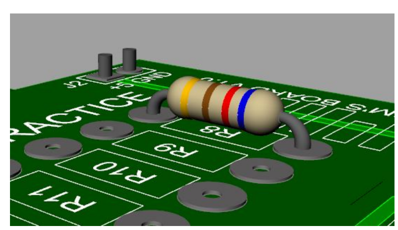
The power supply board can be energized from either a micro-USB connection (on the top of the power supply board) or a 9-12V "wall wart" plugged into the cylindrical jack. Choose one. *Do not use both the wall wart and the USB connection at the same time.* The power supply board provides +12V, -12V, and your choice of +5V or +3.3V outputs. You choose +5V or +3.3V output with the jumper the power supply board. The outputs are provided on the "rails" of the breadboard — the outermost vertical columns on the breadboard.



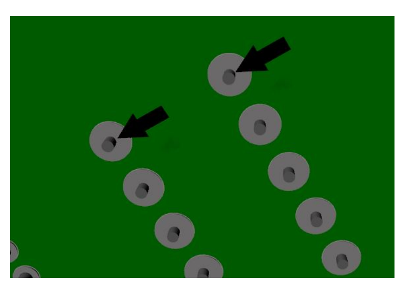
Power supply on the breadboard.

Soldering Practice

You will assemble the divider board by soldering components on to the printed circuit board (PCB). First, **practice** soldering with an instructor using practice components and **AREA E** on the divider board. Make certain you are comfortable with soldering and trimming the leads off before proceeding with assembly of the rest of the divider board. *Do not connect the divider board to the power supply board while constructing the divider board. Wear safety glasses and be careful to avoid burning yourself with the soldering iron.*

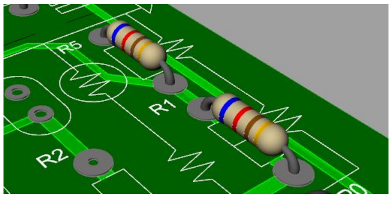


Resistor Orientation



Solder Joint Location

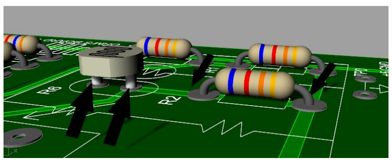
First, take one resistor and bend the leads to fit squarely into the pads of the component location labeled for R_8. Pull the leads through the holes until the resistor is resting on the surface of the board. Solder the resistor to the two R_8 pads. The two surfaces you are joining through the soldering process are the metal pads on the printed circuit (PC) board and the leads of the resistor. Practice soldering spare resistors into the spots labeled for R_8-R_{12}. Trim excess resistor wire from under the board after the joints are soldered. *Save the trimmed pieces of wire for later use.*



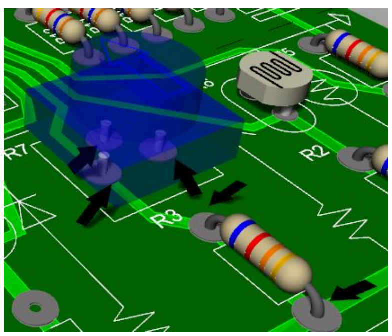
Voltage Divider Construction

Divider Construction

Begin by constructing the voltage divider in **AREA D**. Insert two resistors into slots R_5 and R_1, just as in the practice section. Make soldered joints in the proper locations beneath the board. Trim the remaining leads.

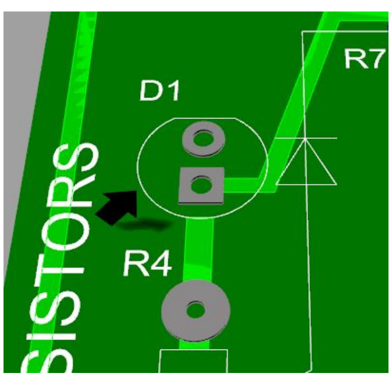

Photosensor Construction

Next, construct the photosensor divider in **AREA C**. Install the photoresistor into the section labeled for R_6. Install another resistor into the slot labeled for R_2. Like before, make soldered connections at the proper locations beneath the board. Note that, like the resistors, the directionality of the photoresistor wires does not matter – it functions in either direction. *Do NOT take this for granted – other, "polarized" components operate only in one direction.*



Potentiometer Construction

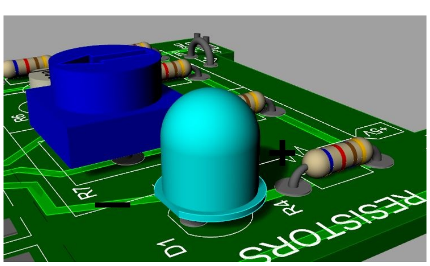
Now, construct the potentiometer divider in **AREA B**. Install the blue, rotating knob potentiometer into the section labeled for R_7. It has three leads arranged in a triangle, and three corresponding points of contact on the board for proper installation. Install another resistor into the slot labeled for R_3. Make soldered connections and trim the leads.



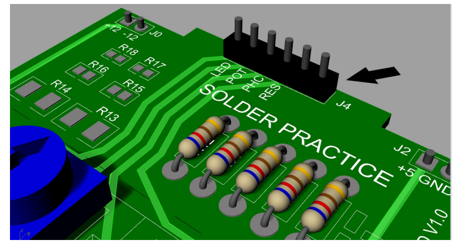
The flat side of this circle is the negative side. Use this as a guide to help position the LED.

Next, construct the Light Emitting Diode (LED) divider in **AREA A**. Before installing the LED into the pads labeled for D_1, note that the LED is polarized and **direction matters**. The LED only illuminates when current is in the correct direction. The flat side of the bulb lines up with the shorter of its two lead wires. This is the negative side of the LED, or *cathode*. The round side of the bulb lines up with the longer of the two wires. This is the positive side, or *anode*. The LED must be positioned so that current is flowing *from the positive side* (*longer lead*) *to the negative side* (*shorter lead*). The longer, anode lead of the LED goes in the square pad. Also note that the "flat" side of the plastic LED housing aligns with the "flat" side of the drawing on the PC board. Install the LED into D_1 and another resistor into the slot labeled for R_4. Solder and trim.

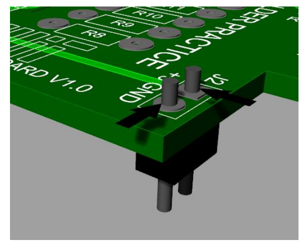
Header, Rail Pin, and Ground Clip Installation


LED Orientation - align the flat side of the LED to the flat side of the circle around section D1.

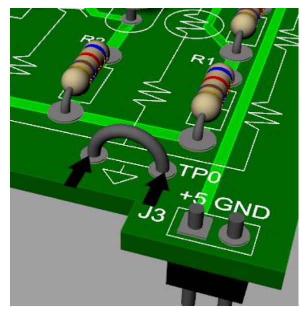
Install the 6-pin header into the **J4** pads at the top of your board for testing later. Insert the pins into the pads and make soldered joints on the underside of the board. Also install the 2-pin header rail into pads **J0, J1, J2,** and **J3**. These are installed in reverse, with the base of the pin on the underside of the board, and the location of the soldered joint on the top of the board. *BEFORE SOLDERING*, insert the bottom of the pins into your breadboard rails, place the divider board on top of the pins, and *then* make your soldered connections on the circuit board to ensure proper alignment. *Make certain that the power supply board is not on during this step.* Construct a ground clip on the pads **TP0** in the lower right corner of your divider board. Take one of the resistor wire cuttings and bend it into an arc. Insert each end into the contact points. Solder and trim.



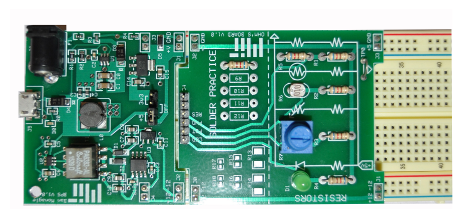
Header Pin Installation



Rail Connector Pin Installation



Ground Clip Soldering Locations


Power Supply Installation

Testing

Ensure that your divider circuit board is installed in the breadboard in line with the power supply module with pins fully inserted, and that the power cord (USB or wall wart) is fitted into the proper port on the power supply module. Look at the pictures to see how the boards nest next to one another. Check that the indicator light is illuminated on the power supply board.

1.) Set your multimeter to "DC Volts." Attach the red multimeter lead to the header pin at the top of the board labeled "RES." This is equivalent to placing the lead in between the two resistors of the voltage divider. Attach the other, black lead to the ground clip. Record V_5, the voltage drop across the resistor R_5. Now, put the red multimeter lead on the +5 volt connection (at the “top” of R_1) and the black multimeter lead at the “RES” node. This will allow you to measure and record V_1, the voltage across R_1.

2.) Remove the black multimeter lead from R_1 and re-attach it to the ground clip. Attach the red multimeter lead to the header pin labeled "PHO." Record the voltage across the photoresistor, V_{photo}, while it is exposed to the light, and record it again with your hand covering the photoresistor.

3.) Record the voltage across the photoresistor while pointing a flashlight at it, and record again with the flashlight off. Do these numbers concur with your predictions?

4.) Move one meter lead to the header pin at the top of the board labeled "POT," and leave the other connected to ground. Record the voltage across the potentiometer when the knob is fully turned all the way clockwise, and again when it is turned all the way counterclockwise. Do these numbers concur with your prediction? Is the previous estimation of tolerance reasonable?

5.) Move one meter lead to the header pin at the top of the board labeled "LED," and leave the other connected to ground. Record the voltage, V_{LED}, across the LED. Does this match the forward voltage listed on the LED specification sheet?

6.) What would the LED voltage be if you changed the input voltage to $3.3V$? If you made this change, would the LED brightness change? Why?

Test $1a$ - *Check against prediction 1*	V_1:
Test $1b$ - *Check against prediction 1*	V_5:
Test $2a$ - *Check against prediction 2*	Resistor no cover - V_{photo}:
Test $2b$ - *Check against prediction 2*	Resistor covered - V_{photo}:
Test $3a$ - *Check against prediction 3*	Flashlight On - V_{photo}:
Test $3b$ - *Check against prediction 3*	Flashlight Off - V_{photo}:
Test $4a$ - *Check against prediction 4*	Clockwise:
Test $4b$ - *Check against prediction 4*	Counterclockwise:
Test 5	V_{LED}:
Test 6	V_{LED}: