Power for LEDs

LED Circuit: Making Light with Electronics

Components:
   LED (Light Emitting Diode)
        Resistor
        Wires
        Battery
        Protoboard

- We will now make a solid state light
- Such a light could be used to send flashing signals
- This is what traffic lights (red, yellow, green) are made from these days

The Light Emitting Diode is an electrical component. To operate it requires electricity to power it. For our experiment, we will get this electricity from a 9Volt battery

For this activity, you have a bag of parts and a protoboard. First, we will build a simple configuration that lights up an LED. The circuit we will build is discussed on an excellent website for projects. http://www.robotroom.com

resistor
470 Ω
(yellow, violet, brown)

9 V
battery

LED
any color
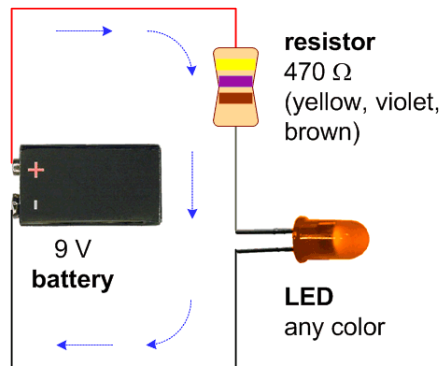
1. Using the protoboard, the LED and the current limiting resistor, build the circuit shown above. Include the wires you will use to connect to the 9V battery, but do not connect the battery.
2. Have your circuit checked. If it is OK, connect the battery to the battery wires. Your LED should light up.

If your LED does not light up, remove it and insert it in the other direction. If it does not light up, you will need some help to troubleshoot your circuit. Note the color of the light from your LED. Also measure the voltage across the LED. Repeat for all of the LEDs you have in your collection. Fill out a table like the one below. The voltage measured across the LED is called the forward voltage since it is the voltage necessary to turn the LED on. Note that there is an extra column. We will get to that in a minute.

Color (Red, Blue, etc.)	Forward Voltage (V_D)	

When you have completed your measurements, re-order the data starting with the smallest forward voltage and ending with the largest. The colors should now be ordered in the usual ROYGBIV order of the colors of the rainbow (visible light spectrum). That is because the forward voltage of an LED is determined by the band gap of the semi-conductor. Look up this very important concept in Wikipedia (http://en.wikipedia.org/wiki/Band_gap). The color of the light is also determined by the band gap. Energetic electrons jump from the conduction band (where they are free to flow throughout the material) to the valence band (where they behave like electrons in an insulator), losing energy. The energy lost comes out as a photon. High energy light is blue while low energy light is red. (In a fire, blue light is also given off by a hotter flame than for red light. On the next page is another table showing quite a wide variety of LED materials, the color and wavelength of the light, and the forward voltage necessary to turn them on. Note that this table has the order you are asked to follow in your table. Did you find that any of the LEDs you worked with do not follow this ordering? That may be because we have not really been operating the diodes in the same manner. To fully turn on an LED it is necessary to provide it with enough current, which, in

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2

turn, requires that we use the correct resistor (see the discussion below the table). We have used only one resistor so the currents are probably all over the place. To see this, calculate the current drawn by each of your LEDs, which can be done by dividing the voltage across the resistor by the resistance value. The formula is $I = \dfrac{9 - V_D}{R}$. Put the current you calculate into the third column.

Color	Material	Wavelength (nm)	V-forward
Super Red	GaAlAs	660	1.8
Green	GaP	565	2
Red	GaAsP	645	2
Red	AlInGaP	646	2
Orange	AlInGaP	610	2
Yellow	AlInGaP	590	2
Amber	GaAsP	605	2.1
Red	GaP	700	2.1
Green	GaP	555	2.1
Green	AlInGaP	574	2.2
Blue	SiC	430	3.5
Green	InGaN	505	3.5
Blue	InGaN	470	3.5
White	InGaN		3.5
Green	InGaN	525	3.7
Green	InGaN	525	4
Blue	SiC	430	4.5

3. To achieve optimal operation, we must set up its driving circuit so that the current is specified to meet conditions set by the manufacturer. The current can vary a bit from LED to LED, but for simplicity, let us assume that it is always 20mA, since that is a typical value except for very high brightness LEDs. You can do a simple calculation to determine the value of the resistor needed to obtain the desired current for each of the LEDs. The formula is easily obtained from Ohm's Law as $R = \dfrac{V_S - V_D}{I} = \dfrac{9 - V_D}{.02}$. Since this is such a common calculation, there are many examples of online of calculators to do this for us. One of the best sources of information on LEDs (LED Center, a project of Rob 'linear' Arnold) has one at http://led.linear1.org/1led.wiz. You should do at least one calculation by hand and then check it with Rob's calculator, but you can get the rest of the numbers from the calculator. From your list of LEDs, find the one for which the resistor should differ the most from the 470Ω we have used so far. Obtain this resistor and rebuild the circuit with it. You should see a significant increase in light output.

This may not appear to happen for a variety of reasons, but usually it can be easily observed.

4. Rob also answers the question "How many LEDs can I drive in series?" at http://led.linear1.org/how-many-leds-can-i-drive-in-series/. From the LEDs you have, select as many as possible whose total forward voltage adds up to less than 9V. Wire them in series and add a small resistor if necessary to limit the current to 20mA. For four LEDs, the calculation is $R = \dfrac{9 - V_{D1} - V_{D2} - V_{D3} - V_{D4}}{.02}$. Wire this circuit up to verify that it indeed does work.

5. LEDs only permit current to flow in one direction because they are diodes. Diodes work like a flapper valve which only allows water to flow in one direction. There is a flapper valve in the bottom of the tank that feeds water to a toilet, for example. Incandescent bulbs are not diodes, but are just resistors that get sufficiently hot to give off light. This makes them quite inefficient. If some small, low voltage incandescent bulbs are available, you can show that they can also work with a 9V battery and in both directions. (The availability of these bulbs is limited, so you may not be able to do this.) Since the alternating current (AC) power provided to these bulbs has voltages that alternate between voltages somewhere between +20V and -20V 60 time per second, this shows that an incandescent bulb will stay on essentially all of the time. If they were diodes they would only be on when the current flows in the right direction. The circuit symbol for a diode and an LED are quite similar.
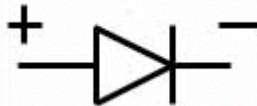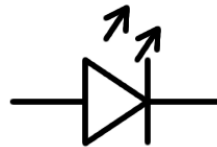
Diode: LED:

Note that the current flows to the right in both cases. The small arrows on the LED indicate that light is emitted when the diode is on.

6. Also, you can connect LEDs in parallel, but it does not work consistently well. Try each pair of LEDs from your collection. When do they both light up? If they do, is one brighter than the other? When does only one of the LEDs light up? As noted above, if you look over the descriptions of LEDs on Wikipedia http://en.wikipedia.org/wiki/Light-emitting_diode you will find that it generally takes a higher voltage to turn on LEDs at the blue end of the visible light spectrum than at the red end of the spectrum. This is because the blue end is higher energy than the red end. Thus, when you connect two diodes in parallel, the lower energy LED should be brighter, sometimes to the point of keeping the other one off completely.

7. Now we will return to using a single LED and add a potentiometer to the circuit so that the intensity of the light can be controlled. Disconnect the diode from the resistor, place the diode across one half of the potentiometer and then connect things as shown below. Your LED should light up again. If not, turn the knob and it should. This configuration shows us one way to control the intensity of the light from the LED. Unfortunately, it is not a very efficient way of doing this, just simple and inexpensive. The potentiometer lets us dim the output of the LED. There is a better way to do this, as described in item #8. One can also just use a variable voltage source (which can be provided by the Mobile Studio using the analog output. However, that is also not very efficient.)
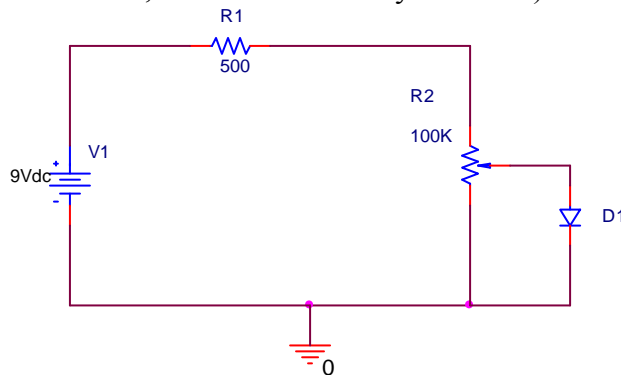
Pulse Width Modulation – How we fool our eyes into seeing different brightness while turning an LED on with exactly the same intensity, also, how to mix colors to make a new color.
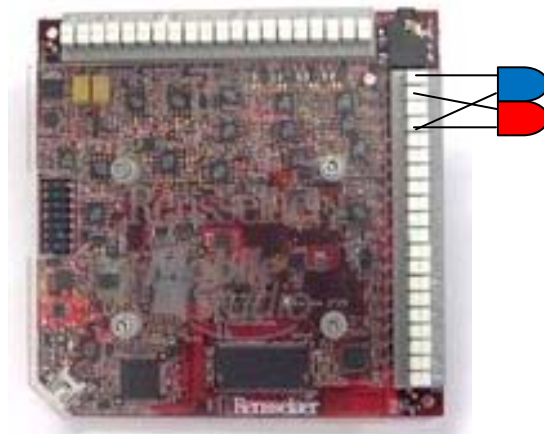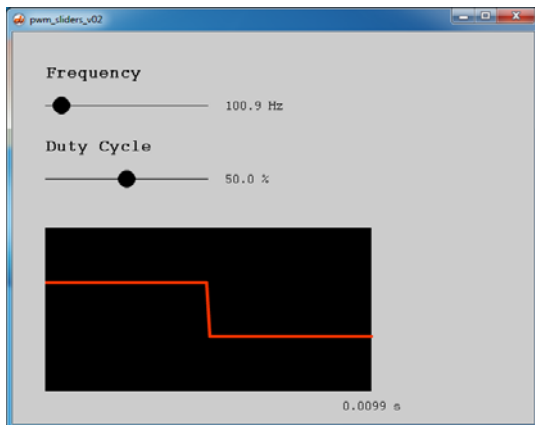

Note that in this activity, the ground is the digital ground, which is the first pin next to the earphone jack on the digital side of the board. This is labeled on the RED2 board but not on the plastic cover. It is best not to mix the digital and analog grounds on the Mobile Studio Board.

In this activity we see how we can flash an LED on and off to make it look bright and dim. The light is pulsed rather than steady. The longer the on pulse and the shorter the off pulse, the brighter the light. We will try different pulse widths to see this effect. Also, if the light flashes more than 30 times per second (30Hz) we cannot see the light flash. Our eyes do not respond fast enough. To see the light flash, we will slow it down to 10Hz or less (1Hz is best) and you will see the light does indeed flash. Also, you will see that the two LEDs flash alternately so that when one gets brighter the other gets dimmer.

Movies and television images appear to move smoothly because they flash faster than we can see.

8. If the PWM Slider executable is not already installed on your computer, download it from http://mobilestudio.rpi.edu/Downloads.aspx You will find it at the bottom of the page.

   Build the two LED circuit on your protoboard rather than connecting the LEDs directly to the Mobile Studio Board as shown in the figure above. You will need two LEDs and two current limiting resistors (the ones you used in earlier activities). You will also need 4 jumper wires. In this circuit, D2 will turn on whenever the PWM1 voltage is high and D1 will turn on whenever the PWM1 voltage is low. Thus, the LEDs will alternate being on and will have complementary duty cycles. When the duty cycle for PWM1 is large, the duty cycle experienced by D1 will be small.
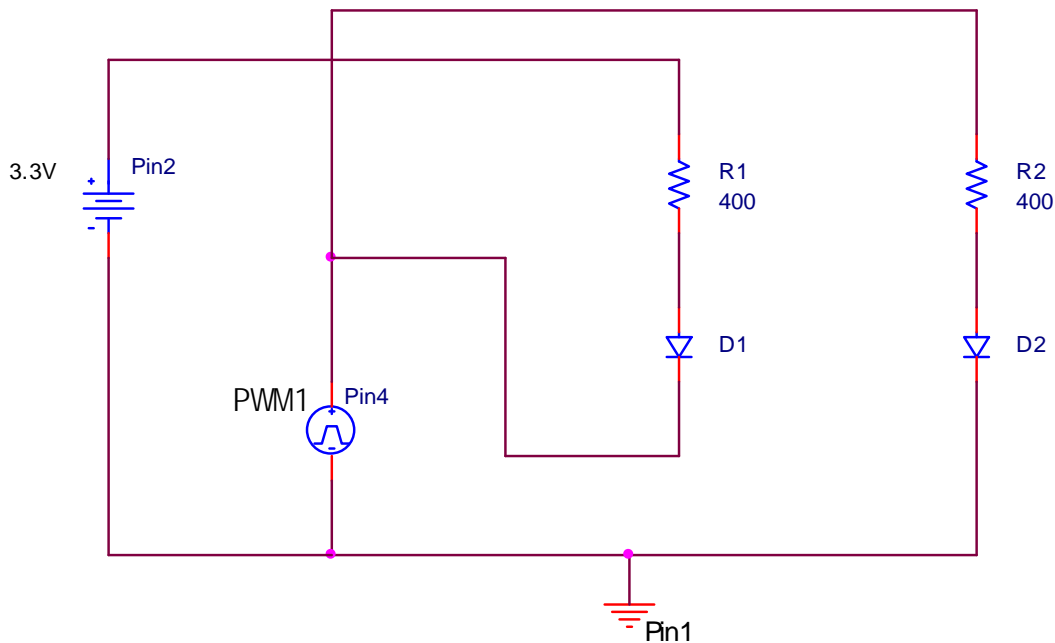
a. Verify the information provided above by trying different frequencies and duty cycles. You should be able to observe that that this is an effective way of mixing colors.

b. Once you have explored the various operating conditions with the PWM Slider executable, repeat using the Mobile Studio Desktop. That is, close the PWM, open the Mobile Studio Desktop and click on the Digital I/O option. You should see a display that looks like that shown below. Click on 'Start All Channels' and then adjust the parameters of the pulse width modulation. You will have much more precise control of conditions this way so you should be able to better determine how fast you can see the LEDs flash, for example.
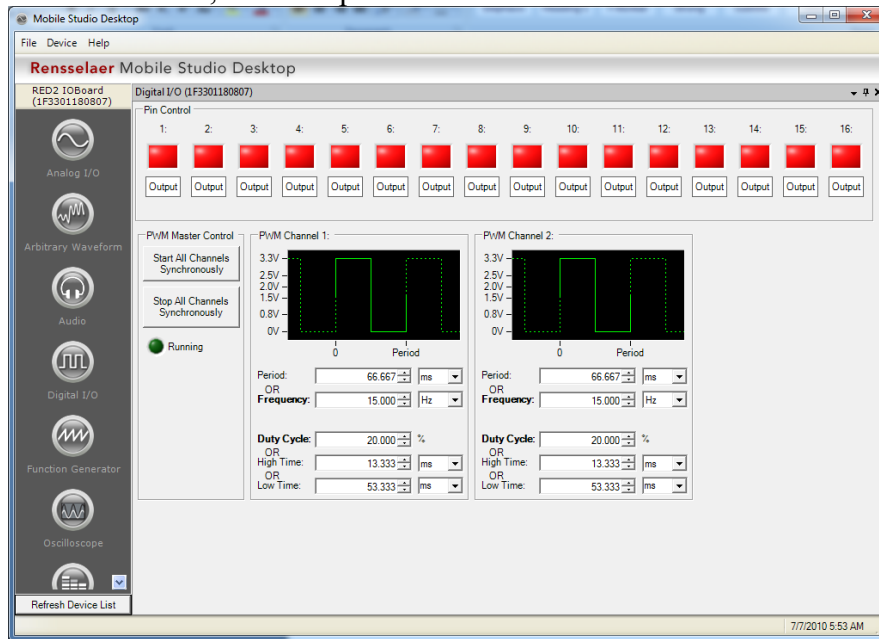
9. If you have time, you can connect an LED with its current limiting resistor to one of the digital I/O pins and to the digital ground. Then you can turn the LED on and off by clicking the corresponding button (green is on). Note that digital I/O ports on a board like the Mobile Studio can function in either input or output mode. We can select either mode by clicking on where it says either input or output. We are using them in output mode here, so be sure that you have selected output. In effect we are creating a really complicated switch, so this does not seem very impressive. However, remember that all of these conditions can be switched by software based on input signals from various sensors. Thus, this can all be done automatically. There is a simple example of this in another activity on lighting control.

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7

Note: The parts distributed to you this week are yours to keep. We need the protoboard returned to us, but you will still be able to make the LED light up at home by following the instructions found below.

First, connect the LED and the resistor, by twisting the wires together.
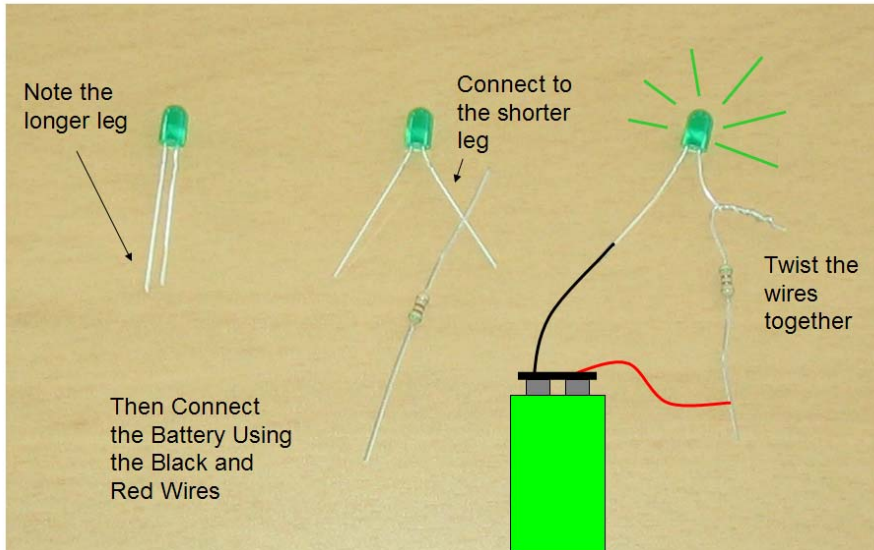
To light the LED, touch the metal ends of the black and red wires to the resistor and diode. This should cause the light to turn on. Again, if the LED does not turn on, try connecting the wires in the other direction.