ENGR 40M Project 1: Solar-powered USB charger

Prelab due 24 hours before your section, July 3–6, 2017

Lab due before your section, July 11–14, 2017

1 Objectives

In this project, we'll build a solar-powered USB charger. In this charger, a solar panel charges a battery, which in turn powers a USB port that can charge a cellphone, iPod or tablet. But USB chargers must output 5 V, and the battery only provides about 3.7 V, so we'll need a small converter circuit to get the 5 V output. We'll use this to explore the concepts of voltage, current, and power.

By completing this lab, you will:

- Use your multimeter to measure voltage, current and resistance
- Use wire cutters and strippers to prepare wire
- Use a soldering iron to make reliable solder joints
- Describe, qualitatively and quantitatively, where power is produced or absorbed in a circuit

2 Parts and equipment

2.1 Lithium-polymer batteries

We will use a rechargeable lithium-polymer (LiPo) battery to store energy from the solar panel. The battery has a nominal potential of 3.7 V, but it may be as high as 4.2 V when fully charged. When the voltage drops below 3.7 V, the battery is nearly dead and you should recharge it.

LiPo batteries are flammable. (Incidentally, this is why they're banned in checked baggage on aircraft.) Because of this, nearly all LiPo batteries have built-in protection circuitry to prevent overcharging, short circuits and other accidents. This circuitry disconnects one of the terminals when the current or voltage of the battery go outside a safe range. If you ever find that your battery's voltage is zero, this might be why. Nonetheless, you should still ensure that the charging current is less than 1 A and check periodically that the battery isn't getting too hot.

You also need to protect the battery physically from puncture. For this purpose, we're giving you two pieces of plastic to fully cover the battery. A fair warning: Not using the plastic is dangerous. Because we care, failing to cover the battery will be very heavily penalized.

2.2 DC-DC voltage converter

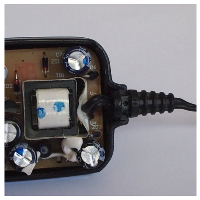
We won't go deep into how the voltage converter works in this course. Its job is to take an input of between 2.5 V and 5 V and provides a 5 V output on the USB port. It is important to remember that the voltage converter doesn't contain any energy sources (sometimes called a passive circuit), so the power it provides at its output must always be less than the power it draws from its input. The goal of any converter is to be energy efficient, that is, to transfer the highest possible percentage of the input power to the output. In this lab we will measure how efficient the converter really is.

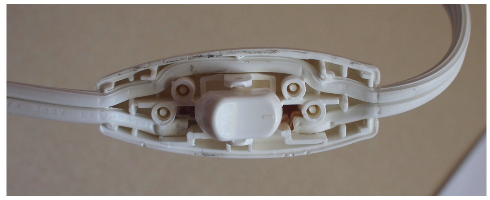
2.3 Soldering

Solder is a metal alloy used to bond metal pieces together. It melts when heated with a *soldering iron*, and solidifies as it cools to create a permanent connection. Solder is often used to make permanent electrical connections. The process of applying solder is called *soldering*.

One important note about solder is that, while it's very electrically conductive, mechanically it's quite weak. If there will be any mechanical force applied to the joint, it is a good idea to have a parallel mechanical path for the stress. Observe in the pictures below how mechanical support is built into the plastic housings, so that there is no stress on the solder joint.

Read the soldering page from Sparkfun, and watch both videos: https://learn.sparkfun.com/tutorials/how-to-solder---through-hole-soldering/all





3 Prelab

Each lab assignment in ENGR 40M will have a prelab section, which you must submit 24 hours before your lab start time. We'll sometimes do parts of prelabs as in-class exercises.

Prelab logistics: You must submit your prelab on Gradescope 24 hours before your lab section. Your TA will grade it before your lab starts.

Prelabs are graded on a coarse, four-point scale. In order to achieve full credit, you must get everything right. You should feel free to use office hours and Piazza as much as you wish in order to achieve this. It's very important that you understand the prelab thoroughly—our experience is that students who don't take much longer to do the lab.

If you switch sections for just one week, the due date is either 24 hours before your usual section, or 24 hours before the lab you will attend, **whichever is the earlier**.

P1: Check that you have all the pieces in your lab kit. Compare what's in your lab kit to the inventory sheet. Use the space below to record any missing parts, and report them to your TA when you come to lab.

Also, bring your phone and charging cable when you come to lab; you'll need them to test the charger.

P2: Given what you know about the solar panel, diodes, battery, and power converter, draw a diagram showing how you can connect them to build the solar charger. The battery must charge when the solar panel is exposed to the sun, and not discharge when it's in the dark. The voltage converter should always be able to draw power, regardless of whether the device is in the sun or not.

3.1 Characterizing your solar cell in light

In the lab you will solder wires to your solar panel, but for now, you should use two of your clip leads to connect to the panel. Clip one onto the silver-colored positive connection on the back of the panel, and the other onto the negative connection.

P3: On a sunny day, the sun is about 1000 times brighter than indoor lighting, so it's best to characterize your solar cell in the sun. Go outside when the sun is shining (you're in California, so no excuses about not having a chance to), and use your multimeter to measure the *short-circuit current* and the *open-circuit voltage* of the solar cell. Remember to orient the solar cell to catch as much light as possible, *i.e.*, cast the largest shadow possible.

P4: From these measurements, can you estimate an upper bound on the amount of power the solar panel can provide? *Hint: Have a look at the V–I characteristic of a solar cell. How can you represent the power* $P = VI$ *provided by the solar panel at some given voltage and current, graphically?*

If you look carefully at your solar cell (bright light is best) you will see it is not one monolithic piece, but rather a large number of strips, each about 10 mm wide. So far we have characterized the solar panel when the same light falls on all the different solar cells diodes that make up the panel. Now we're going see what happens when some cells are blocked.

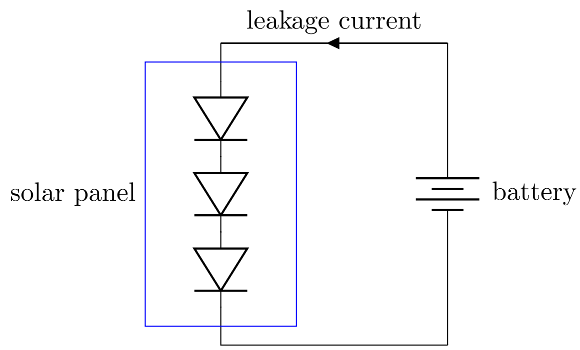
P5: A silicon diode has a forward voltage of about 0.6 V. Given the panel voltage you measured, how many diodes must it contain?

P6: Measure the short-circuit current if you block the sun from one of these strips using a finger or a piece of dark tape. For bonus points, explain your results using the model of the solar cell as a stack of current sources in parallel with diodes.

P7: Extra credit: Find a way to measure the solar panel at points other than open-circuit voltage and short-circuit current, and use this to produce an experimental I-V characteristic plot for the solar cell. (If you do this, submit the plot on a separate sheet. Feel free to use a computer to do the plot, if you like.)

3.2 Characterizing the solar cell in the dark

So far we have looked at the current through the solar cell when light is shining on the cell. However, if we are going to connect the solar cell to the battery to charge it, we also need to consider what will happen if the battery remains connected and the sun is no longer shining. When the sun is not shining on the solar panel, it behaves like any other stack of diodes. If the panel is connected directly to the battery, current can flow from the battery through the solar panel.



P8: Measure this *leakage current* by measuring the current through the cell when it is connected directly to your battery.

P9: Your LiPo battery can store up to 2800 mAh (milliamp-hour) of charge, or 10.08 kC. Using your measured leakage current, how long would it take for your battery to fully discharge, if it started full and you stored the circuit above in the dark?

4 Lab procedure

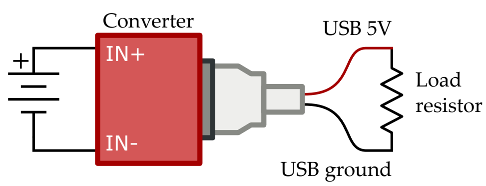
4.1 Characterizing the converter

You will need:

- 1 kΩ and 100 Ω resistors
- Two 27 Ω power resistors
- Converter board (small red circuit board with a USB port)
- LiPo battery
- One of your USB A to USB mini-B cables

L1: Connect the power converter to your battery using crocodile/alligator clips: the battery's red lead to `IN+` and its black lead to `IN-`. How much current does the converter board draw from the battery when nothing is connected to the USB port?

Our next objective is to study the efficiency of the converter board. We will use the following circuit.



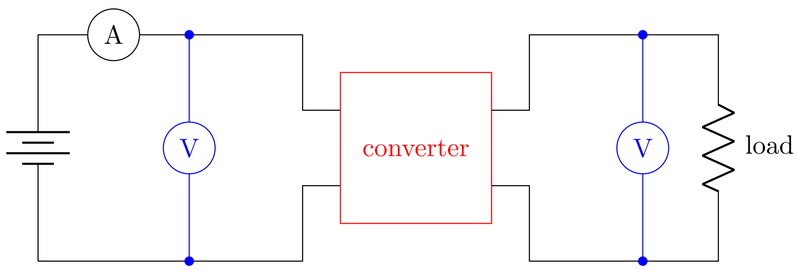
So that you can connect load resistors to the USB port, prepare a USB cable as follows: Cut the USB cable in half, and strip back the outer jacket on the USB-A (big connector) side. Strip about 1/4" of the 5 V and ground wires (red and black respectively), and tin the ends by melting a small bit of solder onto the wire.

To measure its efficiency, we need to measure the input and output power of the converter. We'll do so using the following procedure, for each of four different load resistors:

1. Measure the resistance of the resistor. Note that this might be quite different from its nominal value: they have a tolerance of ±5%.
2. Measure the current going from the battery into the converter board. You may need to use the 10A scale (and the associated jack) on your meter.

   Leave this current meter connected during both of the following voltage measurements. The current meter isn't ideal and its presence affects the circuit's behavior. Leaving it in the circuit ensures that all measurements are taken under the same conditions.
3. With the current meter still connected, use a *second* meter to measure the voltage across the converter board input (*after* the current meter). Using this and the measured current, calculate how much power the battery is supplying to the converter board, *i.e.*, the converter's input power.
4. Measure the voltage across the load resistor. Using this and the measured resistance, calculate how much power the converter is supplying to the resistor, *i.e.*, the converter's output power.

When the load resistor is connected, your circuit (with both meters) should look like this. The ammeter should always be in the circuit; the voltmeters can be disconnected so that you can use a single multimeter to measure each voltage in turn. *Tip:* If you have a third multimeter available (there's one on your lab bench, which is a lot fancier than the ones in your lab kit), you might find it convenient to use it so that you never have to move any of the multimeters.



L2: Carry out the measurements above for each of the following resistors. Use two 27 Ω resistors in parallel to get 13.5 Ω.

	Battery			Resistor			
	Voltage	Current	Power	Voltage	Resistance	Power	Efficiency
1kΩ							
100Ω							
27Ω							
13.5Ω							

Efficiency is defined to be the ratio of output power divided by input power. The website for the converter board says the efficiency is 96%.

L3: Of the measurements you made, what was the maximum efficiency your converter achieved? Does this get close to the advertised efficiency?

Now, grab your phone charging cable, and connect your phone to the converter board. Check that your phone begins charging when you plug it in.

L4: Determine how much current your phone is drawing. (You might not be able to measure this current directly.) Show your work and briefly explain what you measured.

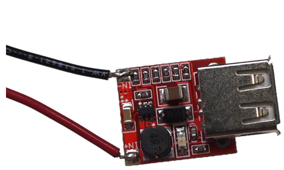
4.2 Assembly

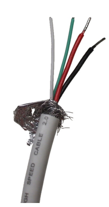
Now it's time to assemble the charger. It's up to you to figure out how to wire it up, so talk with a TA if you aren't sure about the schematic you drew for the prelab.

You will need:

- LiPo battery
- Converter board
- Solar panel
- Diode
- Plastic sheet, and double-sided tape

1. Solder wires for ground and V_{in} onto your converter board. Make sure your wires are at least as long as you think they'll need to be when you assemble your charger—it's a lot easier to make wires shorter than longer. It is convention in electronics to use a black wire for the ground connection, and a red wire (or other light color) for V_{in}. Please follow this convention, so that others can quickly understand your circuit.



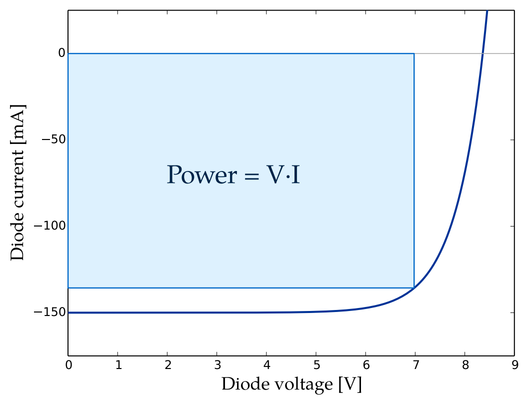


2. Solder the charger together according to the circuit you designed in the prelab.
3. Use double-sided tape to stick the components to the solar panel. Make sure to insulate any exposed contacts that might cause a short circuit.
4. When you're done, test your charger by plugging in your phone.

The package we've provided provides decent protection for the circuit, but it's not particularly pretty. We encourage you to experiment and build a better one that is more aesthetically pleasing or more solid. Just make sure that you can still get the converter board out for a later lab—don't glue everything together just yet!

5 Analysis

Our solar cells are rated to produce 1W in direct sunlight. But to produce this much power, the panel voltage must be about 7V:



However, we are charging the battery by connecting it directly to the solar panel, which forces the panel voltage to be 3.7V.

A1: In this setup, how much power is being delivered to the battery?

A2: We could collect more power from our solar panel if we used a battery of a different voltage. What battery voltage should we choose to get the most power from the solar panel?

A3: Bonus: LiPo batteries only come in multiples of 3.7V, so we can only use 3.7 V, 7.4 V, 11.2 V, etc. Since our options for changing the battery voltage are limited, what else could we do to increase the amount of power we get from our solar panel?

6 Reflection

Individually, answer the questions below. Two to four sentences for each question is sufficient. Answers that demonstrate little thought or effort will not receive credit!

R1: What was the most valuable thing you learned, and why?

R2: What skills or concepts are you still struggling with? What will you do to learn or practice these concepts?

R3: If this lab took longer than the regular 3-hour allotment: what part of the lab took you the most time? What could you do in the future to improve this?

7 Build quality rubric

Build quality will be graded on a scale from "+" to "−". We expect that most projects will be in the check to "+" range initially, with the majority of the class reaching "+" by the end of the quarter.

Plus

- All solder joints are clean
- Wires are color coded and about the right length
- Connections between components are well-planned
- Package is robust, and all components are firmly held together

Check

- One or two solder joints could be improved
- Wires are color coded, but some wires are longer than necessary
- One connection between wires could have been avoided with better planning
- Package holds everything in place, but some parts may be loose or spilling out

Minus

- Many solder joints are dirty or use too much solder
- Many wires are too long, or some are much too long
- Wires are color coded using a non-standard scheme (e.g., red for ground)
- Multiple unnecessary connections between wires
- Wires are prone to short-circuiting