

## **P-N Junction**

P-type (ex. Silicon doped with Boron) has “holes”

N-type (ex. Silicon doped with Phosphorus) has extra electrons

Forward bias: positive terminal connected with p-type and negative with n-type

Reverse bias: positive with n-type and negative with p-type

In solar cell, if the energy of a photon is  $\geq$  the band gap then it bumps an electron into the n-type and a hole into the p-type. This generates a current that flows from the n-doped side to the p-doped side (then back around through an exterior conductor if present). A triple junction cell improves the solar panel efficiency by having three p-n junctions with different band gaps to more fully use photons that have energies lower than or much higher than the band gap of a single solar cell.

Note: the forward bias is in the reverse direction that the solar cell runs which is why there is a danger that other cells in parallel could drain backwards through a cell with lower voltage. Prof. Stauth thinks that if they were all in parallel though, there wouldn't be a large enough voltage difference to overcome the forward voltage of the solar cells (as diodes). However, initially, he said that it would be good for the solar cell voltage to be slightly higher than the voltage of the battery we want to charge (so the DC/DC converter doesn't have to do as much). Consequently, we designed a panel with 6 cells in series (and 4 of these strings in parallel) to accomplish this for a 9V battery. We are now reconsidering using all the cells in parallel with a 3.6ish volt Li-ion battery and then using a second DC/DC converter to step up the voltage to run the DNT (9V) and the Arduino (7-12V).

## **IV Curves**

The current and voltage are related, so a solar cell is neither a current source nor a voltage source. We can model a solar cell using a current source, diode, and resistors. We can use LTspice to give us the IV curve. The current source should have the same value as the solar cell's short circuit current while the diodes should have a forward voltage equal to the open circuit voltage of the solar cell. The shunt resistance affects how flat the voltage is for low currents and the series resistance affects how flat the current is for low voltages. Decreasing the shunt resistance and increasing the series resistance both reduce the solar cell's maximum power.

My Matlab model for the TASC cells seems to fit the 6x4 (4 parallel strings of 6 TASC in series) and 2x4 panel IV curves well. At least one of the 2x4 IV curves is noticeably different, but I think it is because that one had Plexiglas. It's evidence that the Plexiglas does decrease performance. I'm not sure if the coating had as much of a negative effect, but we might want to avoid it anyway since it has started peeling off the panel we put it on. Continuing with PV modeling, the Matlab model is fairly far off from the real curve for a panel with 11 cells in parallel (1x11) as well. This could be because I messed up in how I account for series and parallel panels in my equations/model or because the parallel cells we tested were jury-rigged together and may not have been working at their peak performance. It is more likely that it was a problem with the real panel (partial short) because the LTspice IV curve for a 1x11 panel matches the Matlab model well.

## **Batteries**

A NiMH cell has a voltage of 1.2 to 1.4 V. NiMH batteries can be charged with either a small constant current source for an extended period of time or a larger current source but a circuit that detects when there is a drop in voltage across the battery, which indicates that the battery is fully charged. Because they have low internal resistance, NiMH batteries are frequently used in applications where they need to supply greater 1 Amp. The

primary disadvantage of NiMH batteries is that they have a relatively high self-discharge rate.

Lithium ion batteries contain lithium ions that move to the positive electrode while charging and to the negative electrode when discharging. These batteries have a cell voltage nominally of 3.6 to 3.7 V. The advantages of Lithium ion batteries are high open circuit voltage and a low self-discharge rate. The disadvantage of lithium ion batteries is that their lifespan decreases from exposure to high temperatures and are also liable to explode at high temperatures. Charging a Lithium ion battery involves first constant current charging until each cell in the battery reaches its fully-charged voltage. Then the battery needs to be charged by applying a constant voltage, equal to the voltage of the battery until it is below a threshold (sometimes 3% of initial constant current).

The difference between Lithium ion and Lithium polymer batteries is that the Lithium ions in a Lithium ion battery exist in an organic solvent while those in a Lithium polymer battery exist in a polymer. The advantage of a Lithium polymer battery over a Lithium ion battery is that they have a longer lifespan. Like Lithium ion batteries, lithium polymer batteries are at risk of exploding or catching fire at high temperatures or if they are shorted.

Professor Stauth suggested that we use Lithium ion batteries, potentially a cellphone battery. The charge controller from Adafruit that we tested charged a Lithium ion battery. The concerns with using Lithium ion batteries are primarily the risks of explosion and a more complicated charging curve. While Lithium ion batteries are two to three times more expensive than Nickel Metal Hydride batteries, they are able to source roughly twice as much current. For example, there almost no 9V NiMH batteries that source 500 mA but many 9V Lithium ion batteries that can.

### **Charge Controllers**

A controller to charge a Li-ion battery from a solar panel needs to do a number of things to protect the solar cell and the battery. It needs to prevent reverse current (with a diode) so that the battery does not drive the solar cells backwards when they are shaded. The charge controller needs to regulate the charging curve for the batteries and make sure that they are not overcharged (using information such as battery voltage, battery temperature, and time charging). Additionally, it would be nice for a charge controller to disconnect the battery if its voltage drops to low because completely depleting a Li-ion battery can permanently damage it. Finally, it should have some sort of overload protection (too much current) in case the battery or load is shorted somehow.

Prof. Stauth suggested that we approach these requirements by having the charge controller run in multiple modes:

1. *Not charging* – when the solar panel cannot provide enough power to be useful
2. *Low voltage disconnect* – when the battery voltage is below some minimum
3. *Constant current* – when the solar panel can provide enough power to charge the battery and the battery voltage is less than some percentage of its fully-charged voltage
4. *Constant voltage* – when the solar panel can provide enough power to charge the battery and the battery voltage is near its fully-charged voltage
5. *Maximum Power Point Tracking (MPPT)* – when the solar panel cannot provide enough power to the charge the battery in its current mode, but could if the DC/DC converter switch to a different conversion ratio to find the maximum power point on the solar cell's IV curve

The plan to implement this will use two DC/DC converters (boost ones). One will regulate the power from the solar panel to the battery, then one will step the battery voltage up to 9V to power the payload and provide a steady voltage reference. Note when using a DC/DC converter: make sure that the voltage you ask it to provide does not exceed the power that the solar cell can provide (i.e.  $P_{\text{solar}} \text{ must be } \geq V_{\text{out}}^2/R_{\text{load}}$ ).

The easiest way to control the conversion ratio of the first DC/DC converter is to manipulate its feedback voltage. This can be done using the equation:  $V_{\text{out}} = V_{\text{fb,target}}(R1+R2)/R2 - V_x$  where  $V_{\text{out}}$  is the output voltage the converter will obtain,  $V_{\text{fb,target}}$  is the feedback voltage the DC/DC converter is trying to achieve,  $R1$  is the resistance separating the feedback from the output,  $R2$  is the resistance separating the feedback from  $V_x$ , and  $V_x$  is some voltage you set depending on what you want  $V_{\text{out}}$  to be.  $V_x$  can be set using an digital to analog converter. This can be achieved with a transistor, a series of resistors with switches around them, or a pulse-width-modulated digital output, smoothed out by a capacitor and inductor or resistor.

#### **Next Steps**

- Wait for DC/DC converters to arrive
- Set up converters so we can use them (mount to a board with necessary capacitors, inductors, etc)
- Test: use them to get a steady voltage out of the solar panel
- Make a digital to analog converter to be controlled by an Arduino
- Program the Arduino to do constant current/voltage charging and maximum power point tracking