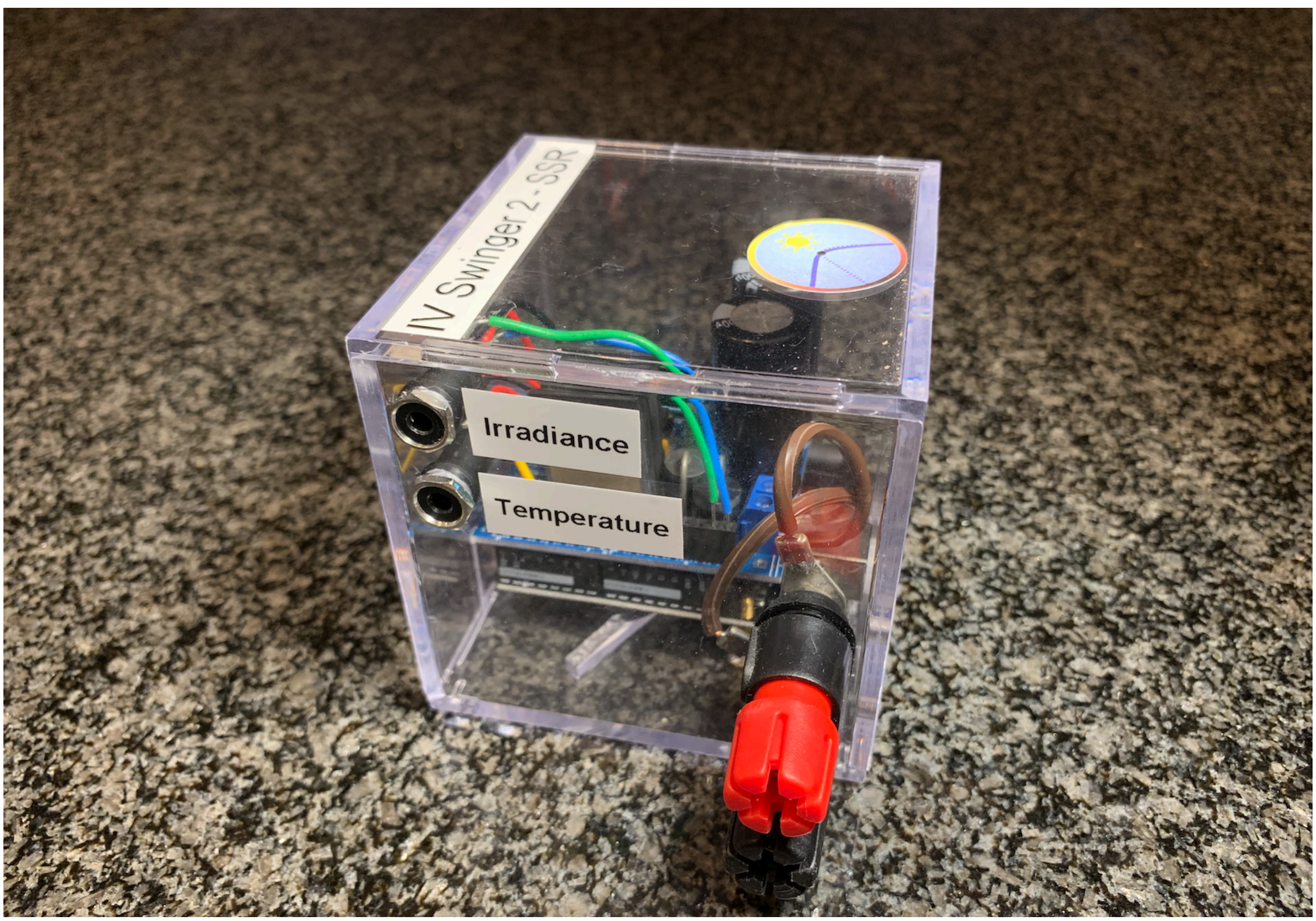
IV Swinger 2

Hardware Scaling

Document Revision: 1.00 (03-Aug, 2020)

Chris Satterlee



Current versions of the license files, documentation, hardware design files, and software can be found at:

https://github.com/csatt/IV_Swinger

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1 Introduction

1.1 What is Hardware Scaling?

The hardware components used in the standard IV Swinger 2 design are chosen to work well for a fairly wide range of commercial rooftop PV modules. It is possible, however, to choose different components that work for PV modules (or cells) that are outside this range. For example, a scaled-down version of IV Swinger 2 has been built to measure IV curves for very tiny PV modules used on CubeSat miniature satellites. There are also PV modules coming to market that generate higher voltages and/or currents than the standard design can handle.

This document describes how to select appropriate components for such "scaled" versions of IV Swinger 2. This is constrained to components that are physically compatible with the existing PCB and enclosure designs. This scaling is limited to V_{OC} values 100 V or less and to I_{SC} values 30 A or less.

The IV Swinger 2 application software has a simulation feature that helps to choose appropriate component values for scaled IV Swinger 2 designs. This document describes how to use that feature, and how to configure the software to work with the scaled hardware once it has been built.

1.2 Scaling Components

The components that affect the voltage and current ranges are: R1, R2, Shunt, Rf, Rg, C1/C2, Rb and the relay(s). Here are very brief qualitative descriptions of the effects of these components.

1.2.1 Voltmeter Resistors - R1 and R2

The voltage divider is needed to reduce the voltage generated by the PV to the range of 0-5V that the analog-to-digital converter (ADC) can handle. A large voltage divider ratio provides a higher upper limit for the supported PV voltage, but this is at the expense of resolution for PVs that have a low V_{OC}. The standard R1 and R2 values divide the voltage by 21, which supports V_{OC} values over 100 V. But a PV with a V_{OC} of only 4 V, for example, would produce a very low-resolution IV curve with this ratio. This is because only a small part of the 12-bit ADC range is utilized. IV Swinger 2 designs targeted exclusively for very low voltage PVs should have a much lower voltage divider ratio. This improves the voltage measurement resolution, but reduces the maximum voltage that can be measured. Note that the lowest possible ratio is 1:1 (R1=0).

1.2.2 Ammeter Resistors - Shunt, Rf and Rg

The ammeter circuit measures the voltage across the shunt resistor. This voltage is small, so it needs to be multiplied before being measured by the ADC. The values of Rf and Rg determine the multiplication ratio. The value of the shunt itself determines the ratio between the current and the pre-multiplied voltage to the ADC. The standard components can handle a current up to approximately 13.2 A. A PV with an I_{SC} of 100 mA, for example, would produce a very low-resolution IV curve with the standard components. IV Swinger 2 designs targeted exclusively for very low current PVs should have a higher resistance shunt and/or lower multiplication ratio (Rf, Rg). This improves the current measurement resolution, but reduces the maximum current that can be measured.

1.2.3 Load Capacitors and Bleed Resistor - C1, C2 and Rb

The load capacitors affect the ranges in two ways. First, they have a maximum voltage rating. Exceeding this rating will destroy them. The standard load capacitors are rated at 100 V, but exceeding 80 V is risky. The capacitance also affects both the current and voltage ranges in an interrelated way. A higher capacitance slows down the sweep time. That produces better resolution, but for very low currents can cause the sweep time to be excessive. Also, higher capacitance means a lower maximum voltage rating (assuming the same physical size). In general, the capacitance should be higher for PVs with a high I_{SC}:V_{OC} ratio. But the voltage rating must be high enough such that the maximum V_{OC} does not exceed 80% of the rating.

The bleed resistor's resistance and its power rating are directly related to the load capacitor capacitance and the maximum V_{OC} value. It must be able to dissipate the energy stored in the load capacitors and its resistance determines how long the load capacitors take to drain, which determines how soon the next IV curve can be measured.

1.2.4 Relay(s) - EMR or SSRs

The relay type affects the maximum current and voltage. The EMR is rated for only 30 V, but experience has shown that they can handle higher voltages given the infrequent and brief use that is typical of IV Swinger 2 usage. The current guesstimate of the upper limit is 60 V for EMR-based IV Swinger 2s. They also have a current limit of 10 A. The SSRs are rated at 100V and can handle up to 30 A, given the very brief time they are active.

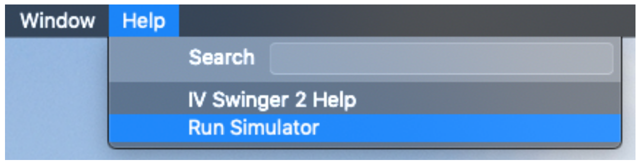
1.2.5 Choosing Optimal Components

In some cases, the choice of components is based on hard constraints such as the voltage ratings of the load capacitors and relay(s). In others, it is more subjective (e.g. resolution). Choosing components manually for a scaled IV Swinger 2 can be tricky and requires much more detail than given above. The simulator feature in the application software makes it relatively easy, and even allows for subjective judgement because the user can see a very close approximation of what the IV curve will look like for a given I_{SC} and V_{OC} when specified values of the components are used. It also has a button to automatically choose optimal components for a given I_{SC} and V_{OC}. That set of components can then be tested for different I_{SC} and V_{OC} combinations

2 Running the IV Swinger 2 Simulator

The IV Swinger 2 hardware simulator is built into the application software. Refer to the IV Swinger 2 User Guide for instructions on how to download and install the application on a Windows or Mac computer.

To run the simulator, choose Run Simulator from the Help menu.



That will bring up the dialog window shown Figure 2-1 below.

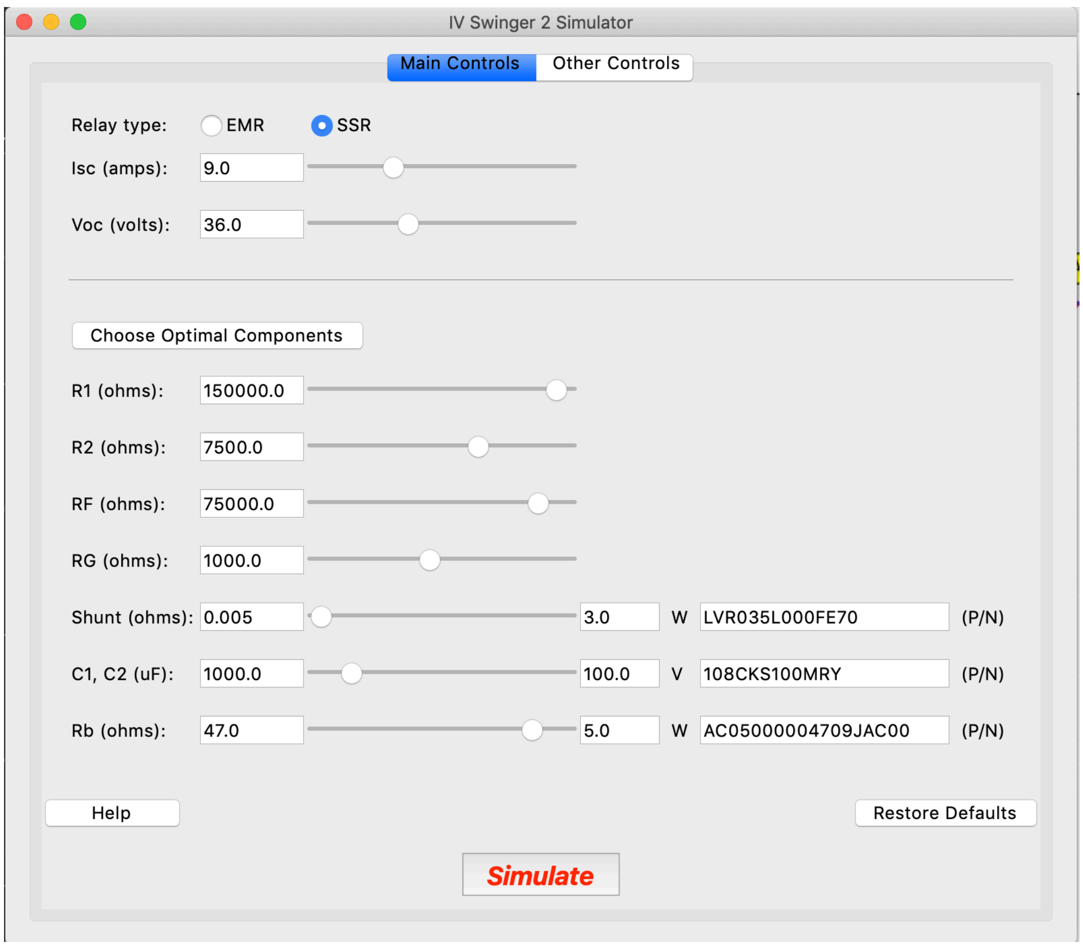


Figure 2-1: Simulator Dialog

2.1 Main Controls Tab

The Main Controls tab is selected by default. Start by clicking on the Simulate button. This will run a simulation using the default components with nominal values for I_{SC} and V_{OC}. The simulated IV curve is displayed and quantitative results are listed on the Results tab (see Section 2.3 on page 8).

Now you can start changing things to see the effects. Try setting the I_{SC} and V_{OC} values to the maximum expected values for the PV modules you are interested in and run the simulation. Then try clicking on the Choose Optimal Components button and re-run the simulation; you should be able to see the improvement. Now, with the new component values you can try I_{SC} and V_{OC} values for different PV modules or irradiance or temperature conditions. You may need to re-run the component optimization with different I_{SC} and V_{OC} values to find components that work acceptably for all cases you are interested in. You may also discover that you need to build more than one IV Swinger 2 to meet your needs.

You may also manually change the component values. The sliders have presets at real-world values. The R1, R2, Rf and Rg resistors are 1/4 W 1% resistors that are included in the recommended set. The shunt resistor, C1 and C2 capacitors and bleed resistor (Rb) are all components available from DigiKey and others. The manufacturer part number (P/N) is listed to facilitate ordering.

2.2 Other Controls Tab

The Other Controls Tab is shown in Figure 2-2 below.

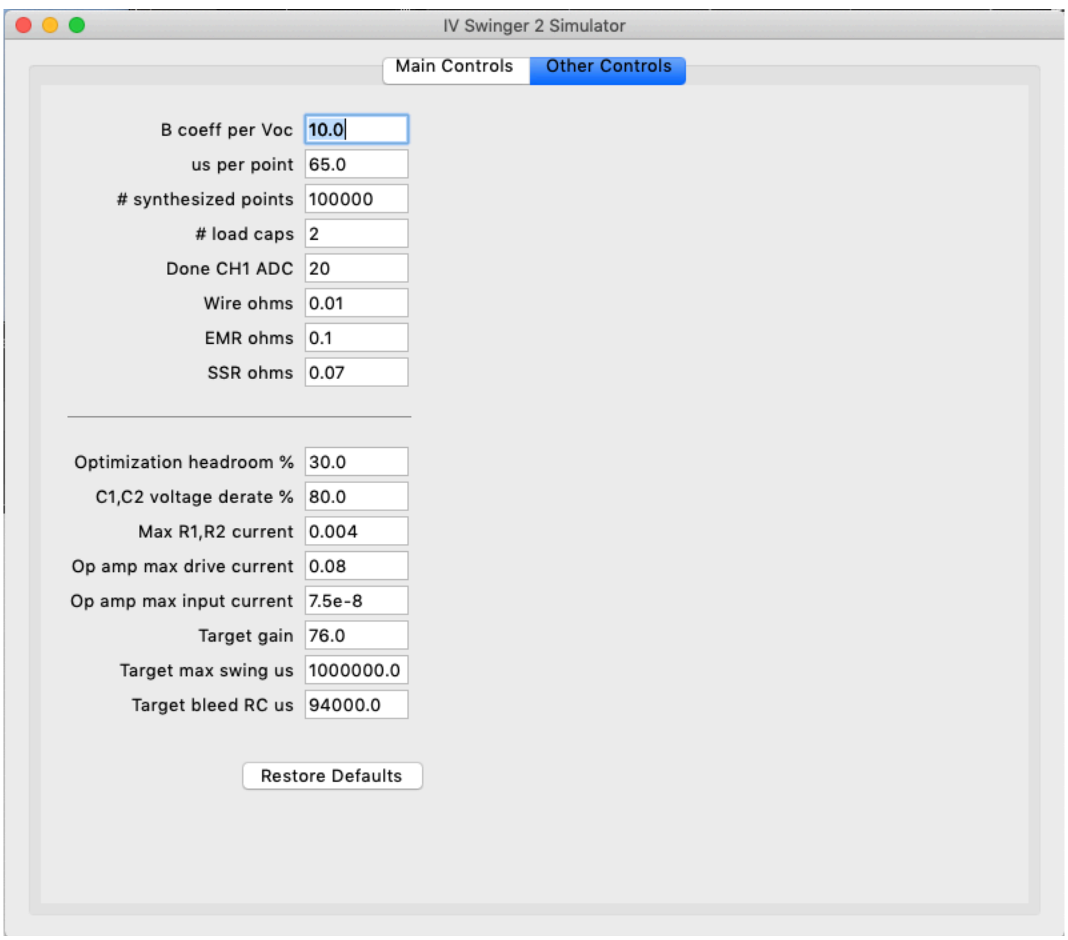


Figure 2-2: Other Controls Tab

This tab has other adjustable values used for the simulation (above the line) and optimization (below the line). You should not have to change any of these values. Their only documentation is in comments in the IV_Swinger2_sim.py Python file.

2.3 Results Tab

The Results tab is shown in Figure 2-3 below.

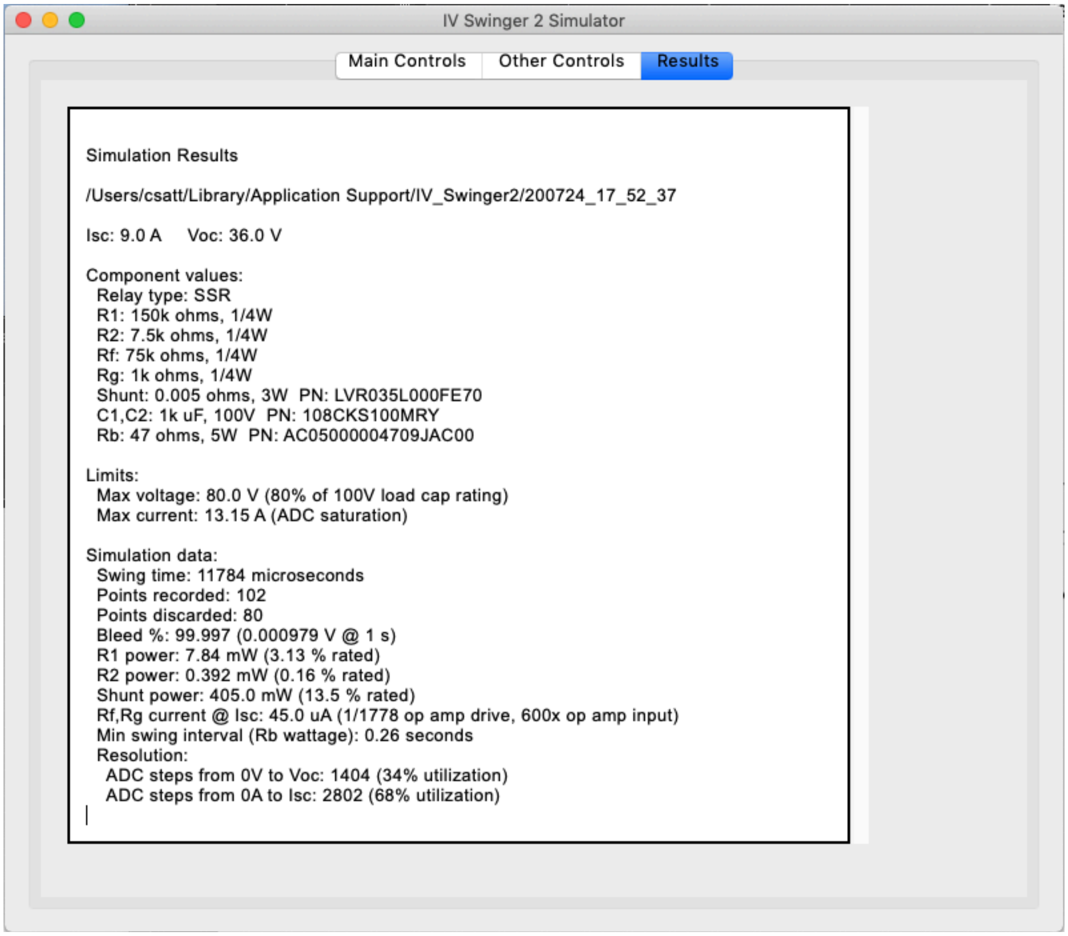


Figure 2-3: Results Tab

This tab exists only after a simulation has been run. It lists the I_{SC} and V_{OC} values, the component values used, the voltage and current limits for the configuration, and several quantitative results from the simulation. There may be annotations with warnings if any of the results are out of their desired ranges.

2.4 Simulated IV Curve

When the Simulate button is pressed, the simulated IV curve is displayed in the main window just like a measured IV curve. Figure 2-4 below shows the simulated IV curve when all controls are left at their defaults, including the I_{SC} and V_{OC} values.

The simulated IV curve is generic from the following equation:

$$I = I_{SC} - A * (e^{B*V} - 1)$$

This equation does not account for series or parallel resistance, and the A and B coefficients are chosen such that the MPP current and voltage are at a typical ratio of the I_{SC} and V_{OC}, respectively. This results in a fairly representative curve that should be adequate to predict the resolution and other characteristics of real IV curves with the given I_{SC} and V_{OC}. Of course, the exact shape of the real IV curves will differ depending on actual series and parallel resistances, temperature, etc.

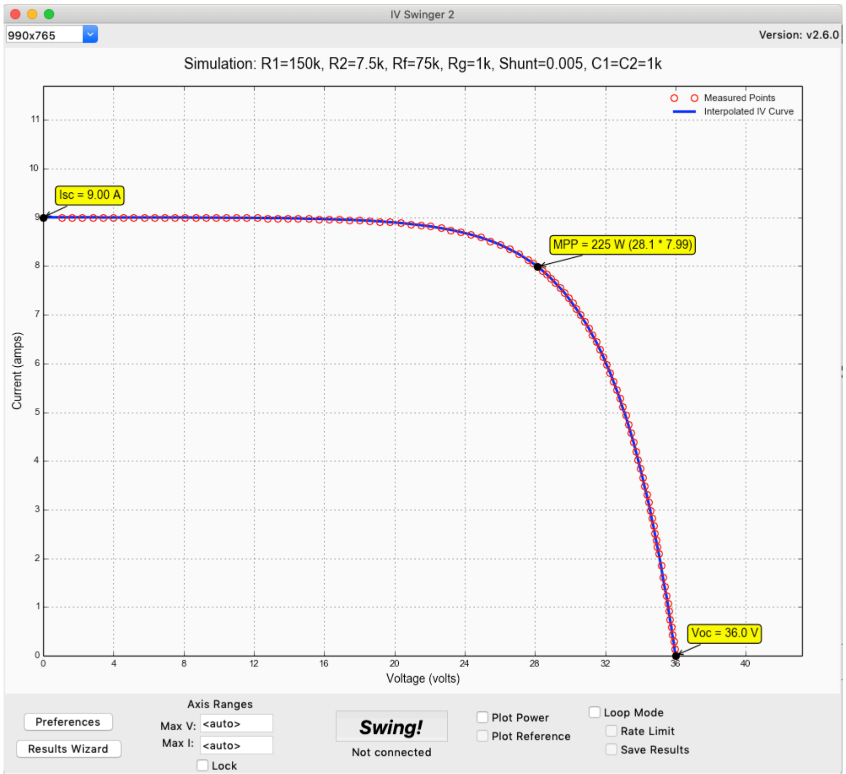


Figure 2-4: Simulated IV Curve (defaults)

The IV curve shown in Figure 2-4 is clearly "good":

- The resolution is more than adequate
- There are simulated "measured" points very close to both the I_{SC} and V_{OC} ends of the curve
- There is no truncation of the curve due to current or voltage limits

Now let's look at some examples where one or more of these is not true.

Suppose we have a small PV module whose I_{SC} and V_{OC} are 100 mA and 3.0 V respectively. First, let's simulate that with the standard components. Figure 2-5 below shows the simulated IV curve in this case, and it is clearly "bad".

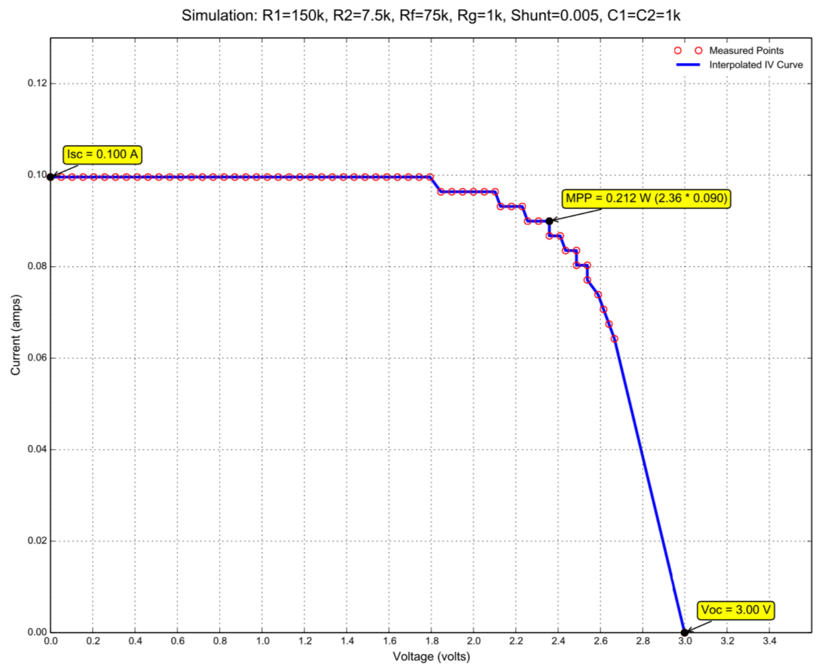


Figure 2-5: Simulated IV Curve (poor resolution)

- The voltage resolution is poor and the current resolution is terrible (aliasing)
- The last simulated "measured" point is very far from the V_{OC} end of the curve

Now let's click on the Choose Optimal Components button, and try again. Figure 2-6 below shows the resulting simulated IV curve with the chosen components (R1 and Shunt changed from defaults, as shown in title).

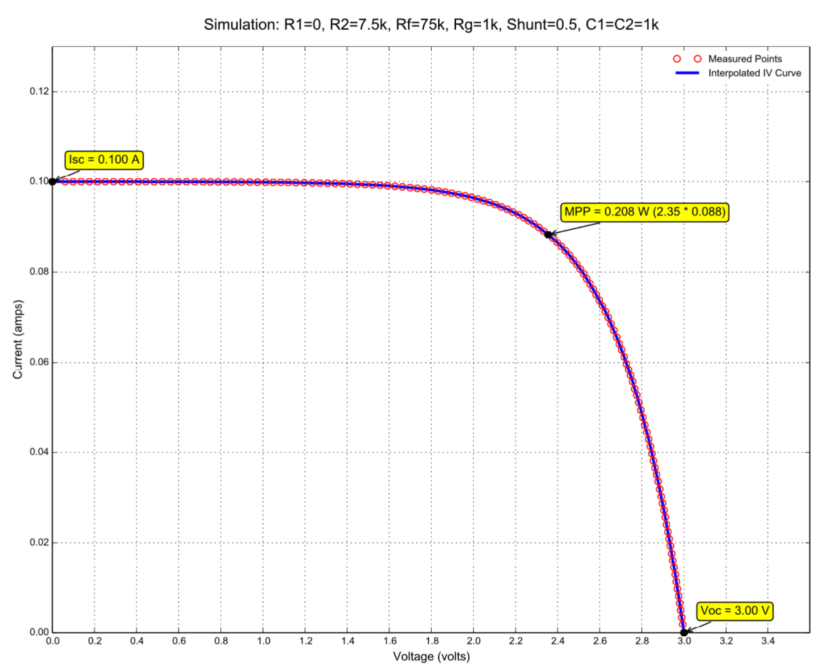


Figure 2-6: Simulated IV Curve (scaled components fix resolution)

Very nice. Now, let's keep those same component values and try the original I_{SC} and V_{OC} values (9 A, 36 V). The resulting simulated IV curve is shown in Figure 2-7 below.

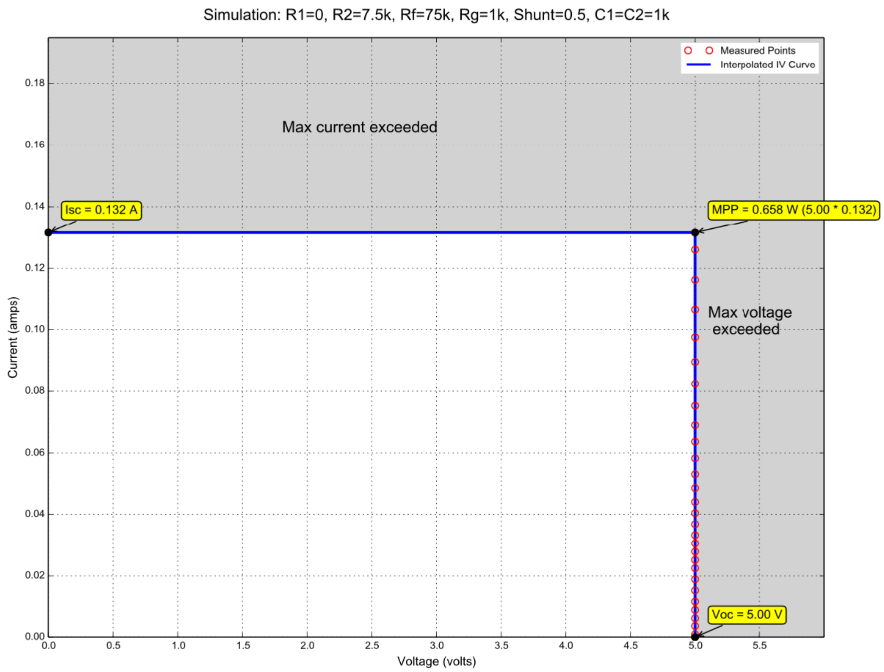


Figure 2-7: Simulated IV Curve (limits exceeded)

No good. The current measurements saturate (max out) at 0.132 A and the voltage measurements saturate at 5.0 V. So, while the changed R1 and Shunt values result in very good resolution at low currents and voltages, the trade-off is that the ability to measure high currents and voltages is completely lost.

As a final example, the simulator can be used to demonstrate why a bias battery is needed to swing IV curves of large individual PV cells such as those used in most full-size PV modules. Figure 2-8 below shows the simulated IV curve for a PV cell that has an I_{SC} of 10 A and V_{OC} of 0.7 V. The Choose Optimal Components button was used, which changed R1 to 0Ω and C1 and C2 to 22000 µF. The whole top of the curve is missing. The very first measured point is at 0.621 V and 6.74 A. This results in an incorrect extrapolation of I_{SC}. The cause of the problem is that the intrinsic resistance of the "short circuit" path is approximately 92 mΩ (0.621 V / 6.74 A). It is simply not possible to measure points whose R=V/I is less than that, so the points at the beginning of the curve are not measurable. The cell version of IV Swinger 2 supports a bias battery to add voltage to all points, which is then subtracted out to render the PV cell's IV curve.

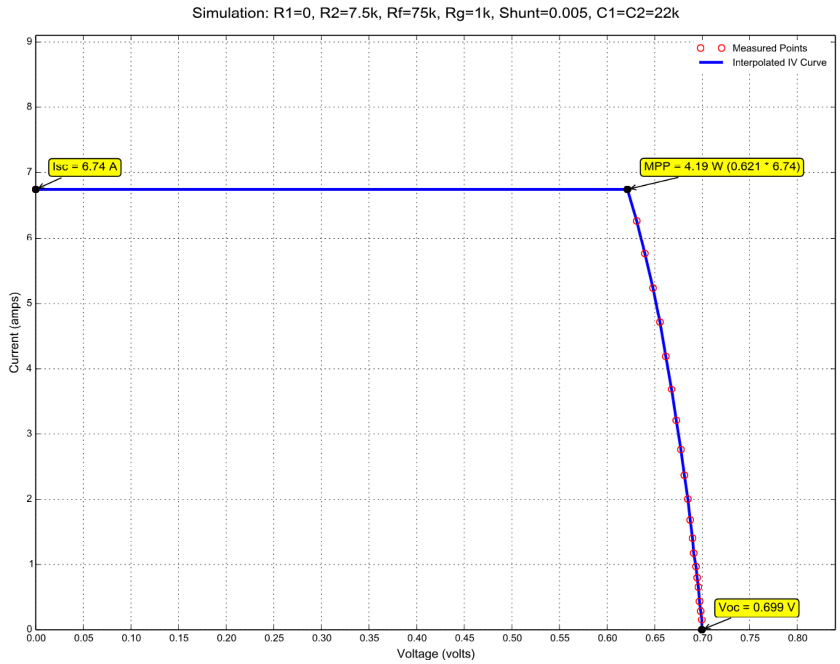


Figure 2-8: Simulated IV Curve (PV cell problem)

2.5 Changing Preferences for Simulated Curves

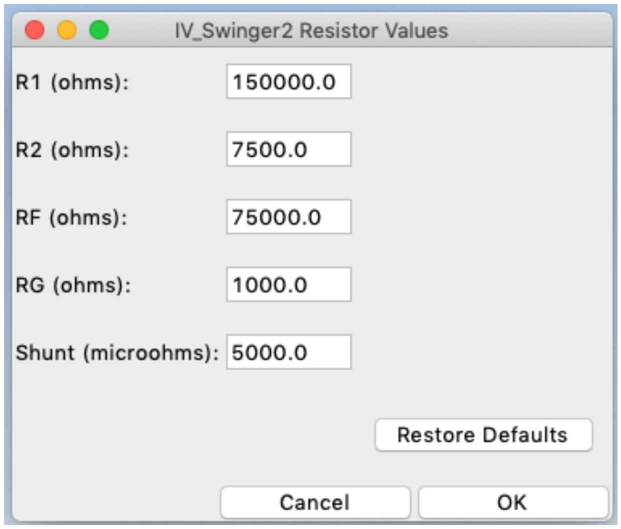
All simulations are run using default preferences regardless of what you may have changed them to. It should be noted that the simulator does not apply the ADC corrections that are enabled by default for real IV curves. This is so you can see the raw results without any of the post-processing that can hide their flaws.

After a simulation has been run (and the simulator dialog is closed), you may use the Results Wizard to change Plotting preferences for that run (including the ability to apply the ADC corrections.) With the run selected in the Results Wizard dialog, click on the Preferences button in the main GUI. Changes are visible immediately. Click on Cancel to revert to the simulation defaults (do not use the Restore Defaults button). Click on OK to save the modified results.

3 Configuring for Scaled Hardware

Once an IV Swinger 2 that uses non-standard components has been built, it needs to be configured so the software knows about some of them. It does not need to know about C1, C2, Rb or the relay type. It does need to know the R1, R2, Rf, Rg and Shunt resistances.

The values of these resistors need to be entered using the Resistors entry on the Calibrate menu.



If the precise values have been measured, use those values. Otherwise use the nominal values, and then voltage and current calibration will adjust for minor differences.

These values will be stored in the Arduino's EEPROM, so this process needs to be done only once and then the scaled IV Swinger 2 may be used with any laptop. Non-scaled or differently-scaled IV Swinger 2's may be used with the same laptop without any manual configuration when they are switched because the values are read from EEPROM when the USB is connected.