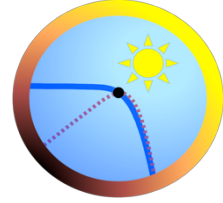


IV Swinger 2

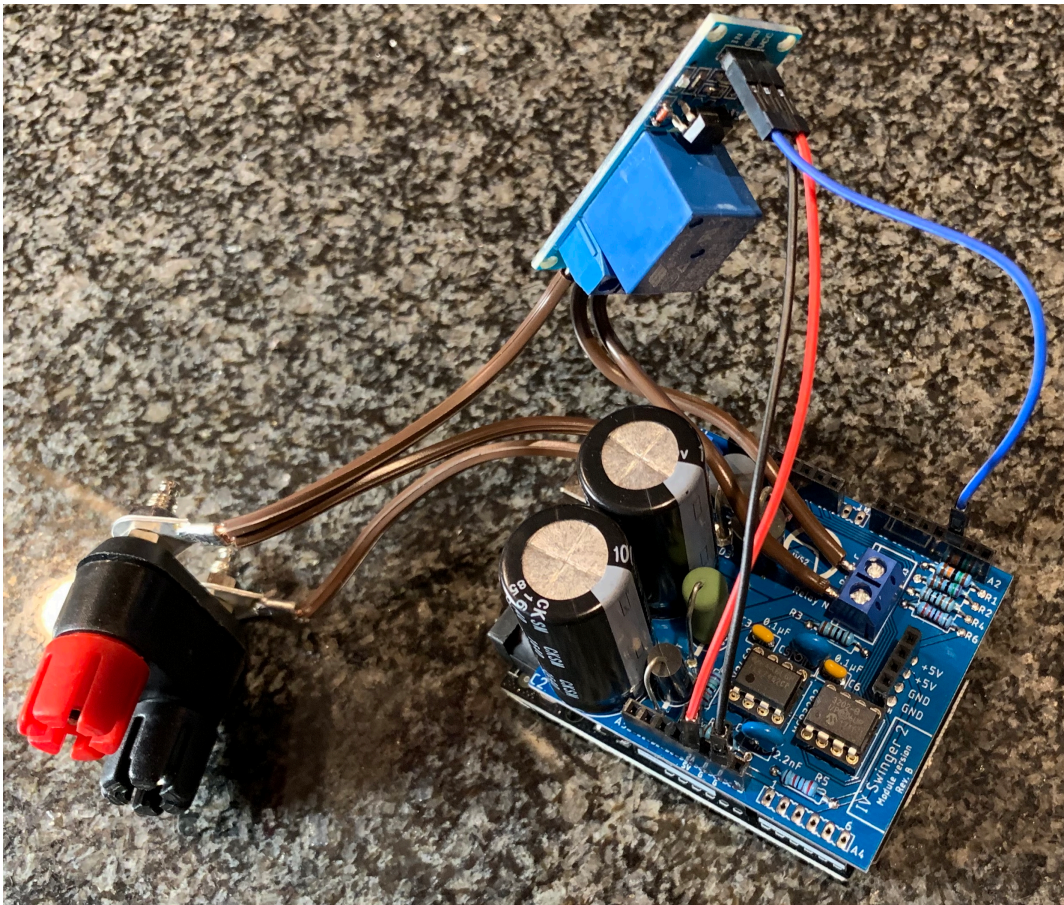


*Step-by-step Construction:
Arduino Shield PCB Designs*

*****EMR module version*****

Document Revision: 1.00 (02-Feb, 2019)

Chris Satterlee



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IV Swinger and IV Swinger 2 are open source hardware and software projects.

Permission to use the hardware design is granted under the terms of the TAPR Open Hardware License Version 1.0 (May 25, 2007) - <http://www.tapr.org/OHL>

Permission to use the software is granted under the terms of the GNU General Public License v3 - <http://www.gnu.org/licenses>.

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

https://github.com/csatt/IV_Swinger

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Intro

IV Swinger 2 is an IV curve tracer for photovoltaic (PV) solar panels (modules). There is also a version that works with PV cells.

The total cost of materials can be as low \$50 (for the least expensive version) but may be more to build a single IV Swinger 2 since that assumes some items are purchased in larger quantities. It also does not include tools to build it or the Windows/Mac laptop that is required to use it.

This is a successor to IV Swinger, which was used for Gil Masters' CEE176B class at Stanford in 2015 and 2016. IV Swinger 2 has been used for that class since 2017. It is my sincere hope that IV Swinger 2 will be used at other colleges and universities that teach PV principles. For that matter, it can be very useful for anyone wanting to learn about the effects of insolation/irradiance, temperature, and especially shading on the power production of a single PV module. While the software does support calibration, there are no guarantees as to the device's precision or accuracy.

The following two YouTube videos demonstrate IV Swinger 2 in action:

[Part I: https://youtu.be/WhnTWciINNo](https://youtu.be/WhnTWciINNo) (7:02)

[Part II: https://youtu.be/9iPq5AsuU_U](https://youtu.be/9iPq5AsuU_U) (6:48)

The hardware and software designs and documentation for IV Swinger 2 (and the original IV Swinger) are on GitHub:

https://github.com/csatt/IV_Swinger

I also want to acknowledge Jason Alderman (whom I have never met or even corresponded with). I stumbled on his wireless IV curve tracer design (<http://jalderman.org/?p=57>), and that was the "Aha!" moment without which IV Swinger 2 might not have happened.

This document contains step-by-step instructions to build an IV Swinger 2.

The original IV Swinger 2 designs (for PV modules and PV cells) use a "Perma-Proto" board and hand-cut, hand-stripped, hand-soldered hookup wires for all of the connections between the resistors, capacitors, ICs, and power/ground rails. Hookup wire is also used for the connections between the Perma-Proto and the Arduino.

Now there are printed circuit boards (PCBs) available that provide all of these connections, making the construction much simpler, faster, and more mistake-proof. Furthermore, there are versions of the PCBs that support on-board solid-state relays (SSRs) instead of the off-board electromagnetic relays (EMRs).

It is still possible to build an IV Swinger 2 using a Perma-Proto; the documentation still exists and the software doesn't care. However, it is recommended that moving forward, all IV Swinger 2 constructions use the PCB-based designs. **This document is specific to the PCB-based designs.**

These are the same instructions that are on www.instructables.com but do not include any of the photos or videos. The purpose of this document is primarily so you can print it out and check off completed steps and make other notes as you work on the project. You should use the Instructable to take advantage of the visual aids.

Step 1: Understand the hardware design

Although it is possible to build an IV Swinger 2 without understanding how the hardware works, you will get more out of it if you do and will have a better chance of being able to diagnose any problems.

The IV Swinger 2 hardware consists of the following:

- Load:
 - Capacitors
 - Bleed resistor
 - Relay
- Ammeter and voltmeter:
 - Shunt resistor
 - Voltage divider
 - Op amp circuits
- Arduino UNO

The following YouTube video gives a high-level description of how a capacitor load is used to trace an IV curve:

<https://youtu.be/eTSCVlSTUP4> (6:00)

There are four PCB variants:

- PV module version, electromechanical relay (EMR)
- PV module version, solid-state relays (SSR)
- PV cell version, electromechanical relays (EMR)
- PV cell version, solid-state relays (SSR)

These PCBs are Arduino “shields”, which means they plug right onto the top of the Arduino board.

The first one is the direct mapping of the original Perma-Proto-based design, and is the easiest to understand. Start with understanding that one even if you plan building one of the others.

The GitHub repository (https://github.com/csatt/IV_Swinger) contains the PCB designs that were created with the EAGLE tool (free version). Each PCB has a PDF folder that contains the schematic of the circuit design. These schematics are for the PCB only. It is still useful to look at the schematic created with the Fritzing tool for the original design, since it includes the external components

(Arduino, relay, binding posts) and it shows the internal op amps in the TLV2462 IC. The circuit design will be described in detail in a yet-to-be-written design document, but anyone with a moderate level of electronics knowledge should be able to understand it without further explanation.

https://github.com/csatt/IV_Swinger/raw/master/Fritzing/IV_Swinger2_schem.pdf

https://github.com/csatt/IV_Swinger/raw/master/PCB/IV_Swinger_2_module/PDF/IV_Swinger_2_module_sch.pdf

Images of both schematics are attached to this step in the Instructable.

Step 2: Choose variant

As mentioned in the previous section, there are four PCB variants. Deciding which one to build comes down to two choices:

- PV module vs PV cell
- EMR vs SSR

If you need to trace IV curves for PV cells, one of the cell versions must be chosen. You should know, however, that the cell versions:

- Are more expensive and difficult to build
- Require an external "bias battery" for high power cells
- Are trickier to calibrate

From an educational standpoint, more can be learned from IV curves for PV modules since they show the effects of module-level electronics (namely bypass diodes).

Choosing between the electromechanical relay (EMR) versions and the solid-state relay (SSR) versions comes down to:

- Cost: the EMR versions are less expensive to build
- Availability: The EMR modules are very common and available from many sources. The SSRs are a very specific part that may go out of stock at some point.
- Simplicity: the SSR versions have fewer external wires to connect and no EMR to mount in the case

- High voltage tolerance: The SSR version can handle PV modules with a Voc up to 100 volts. The EMR version will wear out quickly at voltages over about 40V and may even burn out immediately with a Voc higher than some (unknown) voltage.
- Lifespan: An EMR has moving parts and will eventually wear out, even at lower voltages.
- Repairability: The EMR is easy to replace if it goes bad. The SSRs are difficult to replace (but shouldn't go bad, so this point may be moot).
- Sound: An EMR clicks when it switches. This can be a nice audible cue that an IV curve was swung. The SSRs are silent.

If cost isn't a big concern, the SSR versions are probably a better choice.

The remainder of this document assumes that you have chosen the following variant:

PV module version, electromechanical relay (EMR)

https://github.com/csatt/IV_Swinger/raw/master/PCB/IV_Swinger_2_module/PDF/IV_Swinger_2_module_sch.pdf

If this is not correct, please find the step-by-step construction document for the version you did choose. **Many of the steps are similar, but the details differ, so you need to use the correct document.**

Step 3: Install software

Before spending time building the hardware, install the Arduino software and the IV Swinger 2 application on the laptop that you'll be using.

- **Install Arduino IDE:**
<https://www.arduino.cc/en/Main/Software>
- **Install IV Swinger 2 app:**
https://github.com/csatt/IV_Swinger/releases
- **Make sure both of the above come up before proceeding. If necessary, upgrade the OS on your computer**

Step 4: Order PCB

Currently the PCB must be purchased from a manufacturing house that will actually fabricate it for your order. The downside of this is that you'll probably have to buy more than you need. I have used the following two:

OSH Park:

<https://oshpark.com>

Made in USA

Cost: \$25 for 3 PCBs (includes shipping)

Time: < 12 days to ship

PCBWay:

<https://www.pcbway.com>

Made in China

Cost: \$5 for 10 PCBs + shipping (\$16 DHL to CA)

Time: < 5 days to ship

Amazingly, I have put orders in to PCBWay on a Monday and had the boards in my hands in California on Friday.

I have shared this PCB design on PCBWay, and you can order it directly using the following link:

****To be added****

Alternately, you can order PCBs from OSH Park (or anywhere else) by uploading the ZIP archive of the Gerber files, which are found in the GitHub repository:

IV_Swinger/PCB/IV_Swinger_2_module/Gerber/*.zip

Soon, I hope to find someone who wants to sell individual PCBs on EBay (possibly in kits, that include all the other parts too).

Step 5: Buy other parts

The other necessary parts to build an IV Swinger 2 can all be purchased online from Amazon and Digi-Key.

EMR PV module version BOM:

https://github.com/csatt/IV_Swinger/raw/master/PCB/BOM/emr_mod_BOM.pdf

The BOM has an Amazon link and a Digi-Key link at the bottom. The Amazon link is a "wish list" that can be used to populate your cart. Some of the items come in quantities larger (in some cases much larger) than needed to build a single IV Swinger 2. You may of course choose to find equivalents that are offered in smaller quantities. Also, many of the items are things that you may already have, so don't necessarily just blindly order everything on the list.

The Digi-Key link is a pre-populated shopping cart. Again, you'll want to check if you already have any of the items before ordering.

In both cases, it is possible (or probable) that certain items will go out of stock or be discontinued, so you'll have to find suitable substitutions. Note that there are some of the Digi-Key items have *ALTERNATE* in the "Customer Reference field. These should only be ordered if the primary version of the same part is marked as "backorder".

Also included below is the link to donate to the original Arduino developers. I donate \$5 for each \$10 Arduino clone that I buy. This is your choice, but I think it is the right thing to do.

Donate to Arduino.cc:

<https://www.arduino.cc/en/Main/Contribute>

Step 6: Gather / buy tools

- **Holding:**
 - Vise
 - 3rd hand tool with magnifying glass
 - Tape (preferably Kapton, but Scotch ok)
 - Long/needle-nosed pliers
- **Soldering:**
 - Soldering iron (preferably temp controlled solder station)
 - Tip cleaner
 - Rosin core solder
 - Solder sucker or solder wick

- Cutting:
 - Wire cutter (flush cut)
 - Wire stripper
- Drilling:
 - Drill
 - 1/16" bit (pilot for 9/64")
 - 9/64" bit (standoffs)
 - 11/64" bit (pilot for 13/64")
 - 13/64" bit (binding posts)
 - 3/8" Forstner bit (preferred - USB cable hole)
 - Alternate: 1/8", 3/16", 7/32", 1/4", 9/32", 5/16", 11/32", 3/8", and 25/64" normal bits
- Other:
 - Digital Multimeter (DMM)
 - Small Phillips screwdriver
 - 9V battery
 - Sharpie
 - Ruler
 - Water spray bottle

Step 7: Manually test the relay module

This will confirm that your relay module is the correct type (active-low trigger) and that it is functional.

- With Arduino powered off:
 - Connect relay module GND to Arduino GND with female-to-male jumper _____
 - Connect relay module VCC to Arduino 5V with female-to-male jumper _____
 - Connect female-to-male jumper to relay module IN (male end not connected) _____
- Connect Arduino to laptop with USB cable:
 - Arduino: green LED should be on _____
 - Arduino: yellow LED should be blinking once per second (assuming fresh-out-of box Arduino, running the default "Blink" sketch) _____

- Relay module: red power LED should be on, green LED should be off _____
- Relay module: C (middle) terminal should have continuity with NC (bottom) terminal and no continuity with NO (top) terminal _____
- Connect the male end of the jumper from the relay module IN pin to the GND socket near the blinking yellow LED on the Arduino _____
 - Relay module: should click and green LED should come on _____
 - Relay module: C (middle) terminal should have continuity with NO (top) terminal and no continuity with NC (bottom) terminal _____
- Connect the male end of the jumper from the relay module IN pin to the "13" socket near the blinking yellow LED on the Arduino _____
 - Relay module: should click once per second _____
 - Relay module: green LED should blink exactly opposite from the Arduino's yellow LED _____

NOTE: If your relay module behaves in the opposite manner to that described in each of the above three steps, that indicates that it is the wrong type, i.e. it has an active-high trigger instead of an active-low trigger. Your relay module may have a jumper that selects active-high/low, in which case you should change the jumper and try again. Otherwise, don't despair – there is a configuration setting in the software Preferences that will allow you to use your active-high relay.

Step 8: Prepare for Soldering

- Soldering NOTES:

- If you don't have a lot of soldering experience, read this:

<https://learn.adafruit.com/adafruit-guide-excellent-soldering/common-problems>

- Soldering components to the PCB is pretty mistake-proof, but doing it in the order described is recommended (shortest -> tallest).
- Some components have a correct and an incorrect orientation and some don't matter. Pay attention to the instructions.
- I highly recommend using 63/37 0.031" (or 0.8mm) rosin core solder. Yes, it is 37% lead, but it is not a health risk for you (really), and environmentally insignificant when used by hobbyists. You'll solder like a pro.

Step 9: 1/4W resistors

Resistors can be inserted in either orientation. It is very important to use the correct value for each, however.

- Solder 1/4W resistors to PCB:

- Insert all resistors before soldering. Tape down on front to hold in place OR bend leads slightly on back.

PV module version (EMR) – 16 joints:

- R1 (150k): _____
- R2 (7.5k): _____
- R3 (1k): _____
- R4 (1k): _____
- R5 (22k): _____
- R6 (22k): _____
- RF (75k): _____
- RG (1k): _____

- Flip board upside down and hold with vise or 3rd hand tool OR tape board to work surface. Solder all 16 leads _____

- Inspect with magnifying glass to make sure all joints are good and there are no solder bridges

NOTE: A solder bridge is ok between the ends of RF and RG

- Trim all leads _____

- **Use multimeter to measure exact resistances of soldered resistors:**

With the PCB still upside down, measure the resistances with a DMM. The resistances (but unfortunately not the names) are marked on the back. Record the exact values of the ones marked with an asterisk (*) below – these values will be used later (“Step 29: Apply resistor calibration”). The others should just be close to their specified value (should be 1%, but don’t worry as long as it is < 10%) – the main point is to catch any mistakes you might have made.

PV module version (EMR):

- R1 (150k): _____ *
- R2 (7.5k): _____ *
- R3 (1k): _____
- R4 (1k): _____
- R5 (22k): _____
- R6 (22k): _____
- RF (75k): _____ *
- RG (1k): _____ *

Step 10: IC sockets

- Solder IC sockets to PCB – 16 joints:

- Insert both sockets before soldering. Tape down on front to hold in place.
- Make sure notch is on the left end as marked on the PCB
- Flip board upside down and hold with vise or 3rd hand tool OR tape board to work surface and solder all 16 pins _____
- Inspect with magnifying glass to make sure all joints are good

If you have opted not to use sockets, solder the ICs directly to the PCB instead of the sockets. Make sure dot is on the left end of the TLV2462 (pin 1). Make sure notch and dot are on the left end of the MCP3202 (pin 1).

Step 11: Stacking connectors and female header

- Solder stacking connectors and female header to PCB – 30 joints:

- Insert stacking connectors A1, A2, and A3 and female header FH. These connectors are symmetrical, so there's no "backwards". Tape down to hold in place.
 - A1 (10 pin): _____
 - A2 (8 pin): _____
 - A3 (8 pin): _____
 - FH (4 pin): _____

NOTES: Stacking connector A4 is not needed. Stacking connector A1 can be 8-pin (pins 9 and 10 are not used).

- Flip board upside down and hold with vise or 3rd hand tool OR tape board to work surface and solder all pins
-

NOTE: the pins on A1, A2, and A3 that are actually used on the PCB are circled on the back of the PCB. Soldering the others provides physical support only.

- Inspect with magnifying glass to make sure joints are good and there are no solder bridges
-

Step 12: Screw terminal blocks

- Solder screw terminal blocks to PCB – 4 joints:

- Insert screw terminal blocks with the openings facing left. Tape down to hold in place.

- J1: _____

- J2: _____

NOTE 1: The screw terminal blocks may be 2-pin or 3-pin. If 2-pin blocks are used, insert them in the lower two holes and leave the top hole open.

NOTE 2: The screw terminal blocks may be omitted entirely, soldering the 18ga wire directly to the holes in the PCB (later).

- Flip board upside down and hold with vise or 3rd hand tool OR tape board to work surface and solder all joints
-

- Inspect with magnifying glass to make sure joints are good and there are no solder bridges
-

Step 13: Filter capacitors

The small filter capacitors are not polarized, so it doesn't matter which lead goes in which hole.

- Solder 0.1uF capacitors to PCB - 4 joints:

- Insert both capacitors before soldering. Bend leads on back to hold in place.
 - C3: _____
 - C6: _____
- Flip board upside down and hold with vise or 3rd hand tool and solder all four joints

- Inspect with magnifying glass to make sure joints are good and there are no solder bridges

- Trim all 4 leads _____

- Solder 2.2nF (2200pF) capacitors to PCB - 4 joints:

- Insert both capacitors before soldering. Bend leads on back to hold in place.
 - C4: _____
 - C5: _____
- Flip board upside down and hold with vise or 3rd hand tool and solder all four joints

- Inspect with magnifying glass to make sure joints are good and there are no solder bridges

- Trim all 4 leads _____

Step 14: Bypass diode(s)

The purpose of the bypass diode(s) is to protect the electronics in case the PV is connected to the IV Swinger 2 backwards.

The PCBs were designed for 15A, 45V bypass diodes (15SQ045). The module versions require two of these in series.

There is a 15A, 100V part (15SQ100) that may be used in place of the two 45V parts in the module versions (preferred).

- **Solder bypass diode(s) to PCB – 2 or 4 joints:**

- Bend lead on striped end of diode around the diode so that it points in the same direction as the other lead.
- 100V diode (1x 15SQ100). Insert leads as follows:
 - Pad D1, striped end (top): _____
 - Pad D4, non-striped end (bottom): _____

-OR-

- 45V diodes (2x 15SQ045). Insert leads as follows:
 - Pad D1, striped end (top): _____
 - Pad D2, non-striped end (bottom): _____
 - Pad D3, striped end (top): _____
 - Pad D4, non-striped end (bottom): _____
- Flip board upside down and hold with vise or 3rd hand tool and solder both (or all four) leads

- Trim leads _____
- Re-flow/add solder on both/all leads _____

(This is because leads are thick, and may not have heated well before trimming)
- Inspect with magnifying glass to make sure joints are good

Step 15: Vertical shunt resistor

The shunt resistor is oriented vertically on the PCB and should be soldered on at this point.

- Solder vertical shunt resistor to PCB – 2 joints:

- Bend one lead (either one) of the $5\text{m}\Omega$ shunt resistor around the resistor so that it points in the same direction as the other lead: _____
- Insert bent lead in lower hole and unbent lead in upper hole. Tape in place.

- SHUNT: _____

- Flip board upside down and hold with vise or 3rd hand tool and solder both leads _____
- Trim both leads _____
- Re-flow/add solder on both leads _____

(This is because leads are thick, and may not have heated well before trimming)

- Inspect with magnifying glass to make sure joints are good

Step 16: Vertical bleed resistor

The bleed resistor is oriented vertically on the PCB and should be soldered on at this point.

- Solder vertical bleed resistor to PCB – 2 joints:

- Bend one lead (either one) of the 47Ω bleed resistor around the resistor so that it points in the same direction as the other lead: _____
- Insert bent lead in lower hole and unbent lead in upper hole. Tape in place.

- RB: _____

- Flip board upside down and hold with vise or 3rd hand tool and solder both leads _____
- Trim both leads _____
- Re-flow/add solder on both leads _____
(This is because leads are thick, and may not have heated well before trimming)
- Inspect with magnifying glass to make sure joints are good

Step 17: Load capacitors

- Solder load capacitors to PCB:

Module versions use 1000 μ F, 100V load capacitors.

These are polarized electrolytic capacitors, so orientation is important.

- Insert load capacitors in position. **Stripe side (shorter lead) goes to the right – this is the negative lead.** Tape to hold in place.
 - C1 _____
 - C2 _____
- Flip board upside down and hold with vise or 3rd hand tool _____
- Solder all 4 leads _____
- Trim all 4 leads _____
- Re-flow/add solder on all 4 leads _____
(This is because leads are thick, and may not have heated well before trimming)

- Inspect with magnifying glass to make sure joints are good
-

Step 18: Optionally clean flux residue from PCB

Some people think it is important to clean off the flux residue from the PCB after soldering. It makes it look nicer, but since the PCB sits on top of the Arduino, you don't see the back anyway.

Functionally, it shouldn't matter. The solder manufacturer Kester says this:

"Rosin flux residues are non-conductive and non-corrosive. Under normal circumstances they do not have to be removed from a printed circuit assembly. Rosin residue removal would be for cosmetic considerations. In an environment where the working temperature of the assembly will exceed 200°F the rosin residues will melt and become conductive, in these situations flux removal is required."

If you do want to clean it off, see this Instructable:
<https://www.instructables.com/id/Cleaning-up-your-PCB/>

Step 19: Check for shorts

Using the digital multimeter (DMM) set on the continuity check (beep), check that there is no continuity between the following:

Power to ground (mandatory):

- Left IC socket, pin 8 to pin 4
- OR
- Right IC socket, pin 8 to pin 4

Other (recommended):

- All "neighbor" pins or solder joints. None should indicate continuity, except the pairs circled in the pictures.
- The idea is to find solder bridges that you didn't see visually

Step 20: Insert ICs

Static electricity can destroy ICs. Take off your shoes and touch something metal connected to ground before handling them, if possible.

- **Insert TLV2462 in left socket** _____
 - o Make sure dot is on the left end (pin 1)
 - o Legs may have to be bent inward slightly
- **Insert MCP3202 in right socket** _____
 - o Make sure notch and dot are on the left end (pin 1)
 - o Legs may have to be bent inward slightly

Step 21: Prepare load circuit wires

- **Prepare load circuit wires:**
 - o NOTE: This can be any stranded AWG 18 or AWG 16 insulated wire such as from a typical household extension/lamp cord or heavier speaker wire. **AWG 18 solid core is fine too. If solid core is used, ignore the instructions to twist and "tin" the strands.**
 - o **"PV-":** PV- (black) binding post to PV- screw terminal on PCB (J1)
 - Cut to length: 9 cm

 - Strip 1 cm on each end and twist strands

 - Crimp cable ring connector on one end using pliers (or vise / ViseGrips / crimping tool)

- Heat crimp with the soldering iron and flow solder into strands

- Heat the strands of the other twisted end and flow solder into the strands (i.e. "tin" it)

- **"PV+":** PV+ (red) binding post to relay module NO terminal and to PV+ screw terminal on PCB (J1)

This is a "Y" with a cable ring connector in the middle.

- Cut two wires to length: 9cm each
1: _____
2: _____
- Strip 1 cm on each end of both and twist strands
1: _____
2: _____
- Insert one end of each into the cable ring connector and crimp cable ring connector using pliers (or vise / ViseGrips / crimping tool)

- Heat crimp with the soldering iron and flow solder into strands

- Heat the strands of the other twisted ends and flow solder into the strands (i.e. "tin" them)

- **"Relay C":** Relay module C terminal to Relay C screw terminal on PCB (J2)

"Relay NC": Relay module NC terminal to Relay NC screw terminal on PCB (J2)

- Cut two wires to length: 9 cm each
Relay C: _____
Relay NC: _____
- Strip 1 cm on each end of each and twist strands
Relay C: _____
Relay NC: _____

- Heat the strands of both ends of each and flow solder into the strands (i.e. "tin" them)

Relay C: _____

Relay NC: _____

Step 22: Make load circuit connections

Refer to the drawing of off-PCB connections for this step. These connections use the load circuit wires that were prepared in the previous step.

- Make binding post connections:

- Remove outer nuts and washers from threaded posts

- Insert threaded post of black side through the cable ring connector on load circuit wire:
"PV-"

- Insert threaded post of red side through the cable ring connector on load circuit wire:
"PV+"

- Put washers back on

- Put nuts on and tighten

- Make PCB connections:

- Loosen screw and insert the twisted/soldered end of the load circuit wire from the black binding post into the lower hole of screw terminal J1 and tighten down the screw.
"PV-"

Loosen screw and insert the twisted/soldered end of the load circuit wire from the red binding post into the adjacent hole of screw terminal J1 and tighten down the screw.

"PV+"

- Loosen screw and insert one twisted/soldered end of the "RELAY NC" load circuit wire into the upper hole of screw terminal J2 and tighten down the screw.

"RELAY NC"

- Loosen screw and insert one twisted/soldered end of the "RELAY C" load circuit wire into the lower hole of screw terminal J2 and tighten down the screw.

"RELAY C"

- **Make relay module switching side (screw-down) connections:**

- Loosen screw and insert the twisted/soldered end of the "PV+" load circuit wire into the top ("Normally Open" - NO) screw terminal hole on the relay module and tighten down the screw.

"PV+"

- Loosen screw and insert the end of the "RELAY C" load circuit wire into the center ("Common" - C) screw terminal hole on the relay module and tighten down the screw.

"RELAY C"

- Loosen screw and insert the end of the zip "RELAY NC" load circuit wire into the bottom ("Normally Closed - NC) screw terminal hole on the relay module and tighten down the screw.

"RELAY NC"

Step 23: Make relay power/control side connections

Refer to the drawings of off-PCB connections for this step. These connections use the 4-inch male-to-female jumpers.

- Make relay module control/power side (jumper) connections:

- Connect the BLUE jumper from PCB connector A2, pin 6 (Arduino pin D2) to the IN pin on the relay module (IN1 pin on 2-relay module)

- Connect the BLACK jumper from PCB connector A3, pin 7 (Arduino, GND) to the GND pin on the relay module

- Connect the RED jumper from PCB connector A3, pin 5 (Arduino, +5V) to the VCC pin on the relay module

Step 24: Check all off-PCB connections

- Check all off-PCB connections:

- Use the drawing of off-PCB connections and double-check that all connections match the drawing.

- Tug all wires connected to screw-terminal blocks gently to make sure they are securely connected.

Step 25: Mate PCB with Arduino

- Mate PCB with Arduino:

- Put tape on metal USB connector housing where PCB will touch it

- Line up stacking connector pins on bottom of the PCB with the corresponding connectors on the top of the Arduino and press the boards together, taking care not to bend any of the pins.

Step 26: Smoke test

- Smoke test:

- Connect Arduino to laptop via USB
 - Check for smoke ☺ _____
 - Check that relay module red power LED is on and green LED is off

 - Check that Arduino yellow LED is blinking once per second (assuming that it's still loaded with "Blink" sketch) _____

Step 27: Load Arduino sketch

- Load IV Swinger 2 Arduino sketch:

- Open Arduino application on your computer

- Find where the Arduino software looks for sketches:

Arduino->Preferences->Sketchbook location

- Use your browser to go to:
https://raw.githubusercontent.com/csatt/IV_Swinger/master/Arduino/IV_Swinger2/IV_Swinger2.ino

https://raw.githubusercontent.com/csatt/IV_Swinger/master/Arduino/IV_Swinger2/IV_Swinger2.ino

- Right-click and use "Save As" to save IV_Swinger.ino to the Arduino sketchbook folder found above (make sure your browser doesn't add an extension like .txt to the file name)
- Go back to the Arduino application and find the IV_swinger2.ino sketch using:

File->Open

The Arduino application will inform you that IV_Swinger2.ino must be in a folder named IV_Swinger2 and it will offer to do that for you. Accept its kind offer.

- Click on arrow button or select "Upload" from "Sketch" menu

- Check Arduino LEDs: Yellow LED should be blinking. This is not the same yellow LED that the Blink sketch controls.

Step 28: Connect via IV Swinger 2 app

- Connect via IV Swinger 2 application:

- Open the IV Swinger 2 application _____
- Verify that "Swing!" button text changes to RED and the message below it changes from "Not connected" to "Connected" (briefly, then disappears). The yellow LED should no longer be on.

If not, pull down the "USB Port" menu and select the correct port. If it isn't obvious which one to select:

- Close the IV Swinger 2 application and disconnect the IV Swinger 2 USB cable from the laptop
- Re-open the IV Swinger 2 application (leave the cable disconnected)
- Pull down the USB Port menu and take note of the listed ports
- Connect the USB cable from the IV Swinger 2 hardware to the laptop
- Pull down the USB Port menu and select the port that is new to the list

Step 29: Apply resistor calibration

- Apply resistor calibration:

- In the IV Swinger 2 app, select "Resistors" from the "Calibrate" menu _____
- Enter the values you measured and recorded in "Step 9: 1/4W resistors" above.
 - Values are in ohms

Step 30: Sanity tests

- Sanity tests:

- "Nothing connected" test
 - Click the "Swing!" button. You should hear the relay click twice and see an error dialog saying "ERROR: Voc is zero volts"

- Battery test

Use 9V battery

- Strip both ends of two wires and screw one end of each into the side holes of the binding posts. If you happen to have a battery connector or holder with wires, use that.

- Connect the wire from the RED binding post to the positive terminal of the battery (you can either tape it or hold it with your thumb/finger)

- Connect the wire from the BLACK binding post to the negative terminal of the same battery

- Click the "Swing!" button. You should get an IV curve that looks like the photo.

- If you get an error dialog that says: "ERROR: Voc is zero volts" check that you don't have the battery backwards and that the wires are making good contact with the terminals.
- If you get an error dialog that says: "ERROR: Timed out polling for stable Isc"
 - Click on Preferences, click on Arduino tab, change value of "Isc stable ADC" to 500, click OK
 - Retry the battery test; it should work
 - Click on Preferences, click on Arduino tab, click on "Restore Defaults", click OK

Step 31: Prepare for case and final assembly

The acrylic baseball display case used for the IV Swinger 2 enclosure needs to have several holes drilled through it for attachments.

Case side definitions (see photo):

- Front: side with the USB connector
- Back: side opposite from front
- Left: side with binding posts and relay module
- Right: side opposite from left
- Bottom: side with Arduino
- Top: side above PCB

The case comes in two U-shaped halves:

- Base: Left / Bottom (with fins) / Right
- Lid: Front / Top / Back

All the attachments are made to the base half. The lid half has nothing attached to it, but does need a 3/8" hole in the front for the USB cable.

Care must be taken when drilling acrylic or else it will crack:

- Use a drill press if you have one
- Use vise (with rubber guards) to hold case
- Position so that the hole being drilled is close to the vise jaw
- Start with 1/16" pilot for all holes
- Drill slowly with light pressure
- Spray water on hole as it is being drilled to cool
- Use a Forstner bit to drill the 3/8" hole for the USB cable. Otherwise, you'll have to start with 1/16" pilot and drill incrementally larger holes until you get to 3/8" (actually 25/64")

Step 32: Mark holes for Arduino standoffs

IMPORTANT: For this step and the next three, look straight down with one eye when making the Sharpie dots (the plastic distorts/refracts if you look at an angle, and you'll miss the mark).

- **Mark holes for Arduino standoffs:**

- Attach four 15mm standoffs to Arduino:
 - Unplug the USB cable from the Arduino

 - Carefully remove the PCB from the Arduino

 - Insert threaded/male end of each standoff through its hole in the Arduino from the back

 - Screw nuts onto the threaded ends of the standoffs on the front of the Arduino – hold the nut with your finger and turn the standoff to tighten it. Use pliers to tighten more.

NOTE: The hole nearest the Arduino reset button doesn't have room for a nut

- Place the Arduino in position, standing on its standoffs (including the one without a nut). The Arduino should be touching the right side of the case, with the USB connector facing the front. The single fin should be facing toward you so the fins look like a "Y". See photo.

- PUT LID ON THE CASE. This is important because the fit is very tight!

- Turn the case over and look at it from the bottom. The Arduino will probably stay in place, but you can make sure by squeezing the front and back together with the hand you're holding it with. Use a Sharpie to mark the centers of the four holes.

- Remove the lid from the case and remove the Arduino

Step 33: Mark holes for relay module standoffs

- Mark holes for relay module:

- Attach 4 standoffs to relay module:
 - Disconnect all wires from relay module

 - Insert threaded/male end of each standoff through its hole in the relay module from the back

 - Screw nut on the threaded end on the front of the relay module and tighten it

- Use the Sharpie to make a dot on the left side of the case at the following position:
 - 0.5 cm from the left (i.e. back) edge
 - 0.5 cm from the top edge

- Hold the relay in position inside the case, with the hole of the upper left standoff aligned with the Sharpie dot. You can hold it with one hand and mark with the other – or use a small clamp to hold it in place.

- Use Sharpie to mark the centers of the other three holes

Step 34: Mark holes for binding posts

- Mark holes for binding posts:

- Remove top nuts, washers, cable rings, and bottom nuts from the binding posts. Remove the black plastic backing plate.

- Hold the plastic backing plate in position on the inside of the left side of the case. It should be about 1mm from the front inner edge of the case and about 1mm from the bottom.
-

- Use Sharpie to mark the centers of the two holes
-

Step 35: Drill marked holes

- **Drill 10 marked holes:**

- Use something pointy to make an indentation in the middle of each of the Sharpie marks. The tip of the Forstner bit is perfect for this, but you can also use a needle or the tip of an X-acto blade (poke and twirl). This will keep the drill bit centered when you start drilling the hole.
-

- Drill 1/16" pilot holes
-

- Switch to 9/64" bit and re-drill all holes
-

- **Enlarge holes for binding posts:**

- Switch to 11/64" bit and re-drill the binding post holes
-

- Switch to 13/64" bit and re-drill the binding post holes one more time
-

- **Clean up case:**

- Remove burrs around holes with X-acto knife or your fingernails
-

- Wash case off and dry
-

Step 36: Install binding posts

- Install binding posts:

- Insert the binding posts through their holes with the RED terminal toward the TOP of the case
-
- Slide backing plate over the posts on the inside of the case
-
- Thread nuts on the posts and tighten down
-

Step 37: Install Arduino and PCB

- Install Arduino (without PCB) in case:

- Attach the one Arduino standoff that won't have a nut onto the bottom of the case with an M3 screw
-
- Insert the Arduino, put the lid on the case, and screw down the other three standoffs with M3 screws. TIP: start all screws before tightening any of them.
-
- Remove the lid
-

- Mate PCB back onto Arduino:

- Load circuit wires should still be screwed to PCB. If not, insert them back to into their correct screw terminal block openings and tighten them down.
-

- Line up stacking connector pins on bottom of the PCB with the corresponding connectors on the top of the Arduino and press the boards together, taking care not to bend any of the pins.
-

Step 38: Install relay module

- Reconnect wires to screw-down side of relay module:

This needs to be done BEFORE the relay module is attached to the case, while you still have screwdriver access.

- Restore connections as before, following the off-PCB connections drawing.
-

- Install relay module in case:

- Insert the relay module into the case and screw down its standoffs with four M3 screws. TIP: start all screws before tightening any of them.
-

- Restore relay module control/power side (jumper) connections:

- Restore connections as before, following the off-PCB connections drawing.
-

Step 39: Restore binding post connections

- Restore connections to binding posts:

- Restore connections as before, following the off-PCB connections drawing. Tighten nuts securely.
-

Step 40: Drill USB connector hole

- Drill USB connector hole:

- Put the lid on the case

- Make indentation in the exact center of the USB connector using the tip of the Forstner bit (or whatever pointy thing you used for the other drill-starting indentations). **NOTE: it is very important that this hole is precisely centered.** You need to look at it from all four directions before making the indentation since the refraction through the plastic distorts the apparent position (you'll see what I mean as soon as you turn it 90 degrees).

- Use 3/8" Forstner bit to drill the hole
 - Drill slowly, spraying with water often
 - Reduce pressure when hole is getting close to "punching through"
 - Alternative to Forstner bit is to use following succession of normal bits:
 - 1/16", 1/8", 3/16", 7/32", 1/4", 9/32", 5/16", 11/32", 3/8", 25/64"

- Clean up the edge of the hole with X-acto knife or your fingernail

- Wash lid off and dry _____
- Put lid on and insert the USB cable to make sure it fits _____
 - If it doesn't, try loosening the Arduino standoff screws. This might give you enough "play" to get the connector in. Then, with the connector still in, re-tighten the screws
 - If that isn't enough, you may have to enlarge the hole with a round file or some other way

Step 41: Make PV cables

- Make PV cables:

To connect to a standard PV module, you need cables with MC4 connectors.

It is not necessary to use the same heavy gauge cable that is used in a rooftop solar installation (and on the modules themselves), assuming you only need them to be a few feet long. The nice thing about the binding posts is that you can easily swap cables with longer or shorter ones depending on the situation. The main reason for longer cables would be so the laptop and IV Swinger 2 can be in a shady spot away from the panel. These instructions intentionally do not specify the length or type of the PV cables because it is so dependent on the usage.

If you decide that shorter cables are OK, you can just use the same load circuit wire that you used for the internal load connections. The only tricky part is that crimping the MC4 connectors onto smaller wire gauge doesn't really work - you need to solder them on. You also should use solder to tin the bare ends that insert into the binding posts so they are more durable.

The downside to the binding posts is that it is possible to connect the wrong cable to the wrong post. The bypass diode(s) protect against this, but it's still a good idea to make it as foolproof as possible. Put some red tape around the one that connects to the red binding post and some black tape around the one that connects to the black binding post.

The cable with the female MC4 connector connects to the RED binding post.

The cable with the male MC4 connector connects to the BLACK binding post.

Step 42: Final test

Your IV Swinger 2 is now complete!

Repeat the tests you did for the "system bench test" to make sure everything got hooked back up correctly.

You may now test it with a real PV module.

If accuracy is important to you, see the IV Swinger 2 User Guide for instructions on how to perform a calibration. There is also a Help dialog available from the Calibrate menu in the application.