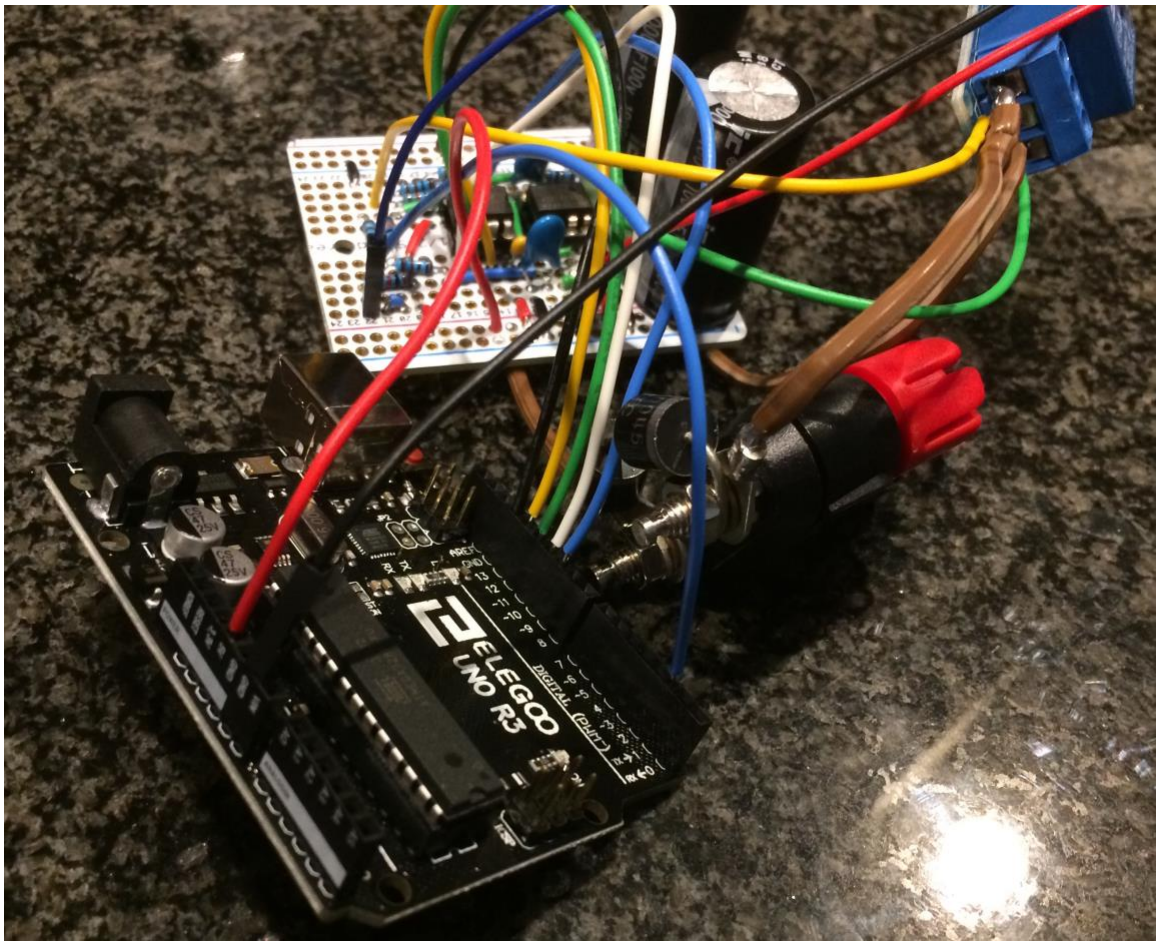
IV Swinger 2

Step-by-step Construction

Document Revision: 1.04 (03-Feb, 2022) 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, Fritzing file (hardware description), and software can be found at:

https://github.com/csatt/IV_Swinger

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.

In 2017, the total cost of materials was about $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 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 was used for that class from 2017 until Gil's retirement in 2020. 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 (7:02)

Part II: 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 an Adafruit "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) or field-effect transistors (FETs) 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.

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:

https://www.instructables.com/id/IV-Swinger-2-a-50-IV-Curve-Tracer

Step 1: Understand the HW design / Choose Variant

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 seven design variants.

Perma-Proto:

- PV module version, electromechanical relay (EMR)
- PV cell version, electromechanical relay (EMR)

PCB:

- PV module version, electromechanical relay (EMR)
- PV module version, solid-state relays (SSR)
- PV module version, field-effect transistors (FET)
- PV cell version, electromechanical relays (EMR)
- PV cell version, solid-state relays (SSR)

The GitHub repository (https://github.com/csatt/IV_Swinger) contains Fritzing design files for the Perma-Proto module and cell IV Swinger 2 designs. Images of the Breadboard View and Schematic View (module only) are attached to this

step in the Instructable. The repository also 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. Even if you are building a PCB-based IV Swinger 2, 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 is described in detail in the document titled "IV Swinger 2: Design and Theory of Operation" (file name IV_Swinger2_Design.pdf), available in the GitHub repository under docs/IV_Swinger2.

Choose Variant:

Deciding which variant to build comes down to three choices:

- Perma-Proto vs PCB
- PV module vs PV cell
- EMR vs SSR vs FET

As mentioned earlier, it is recommended that from now on, everyone should choose PCB over Perma-Proto. This is especially true if you need to build the cell version, since there is no Instructable and no step-by-step instruction document for the Perma-Proto cell version.

If you need to trace IV curves for high-power 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"
- Are trickier to calibrate
- Are not necessary at all for low-power cells, which can be accommodated with a "scaled-down" module version (please read the document titled "IV Swinger 2: Hardware Scaling", filename: IV_Swinger2_Scaling.pdf to determine whether your cells will work with a scaled module version and what component values to use to accomplish that.)

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, solid-state relay (SSR) versions and field-effect transistor (FET) version comes down to:

- Cost: the EMR versions are the least expensive to build. The FET version (module only) is next, and the SSR versions are the most expensive.
- Availability: The EMR modules are very common and available from many sources. The SSRs are a very specific part that has been nearly impossible to find during the global semiconductor shortages of 2021 and 2022. The FET version was developed specifically to address the unavailability of the SSR parts, but also requires a part (CPC1596) that could encounter similar shortages.
- Simplicity: the SSR and FET versions have fewer external wires to connect and no EMR to mount in the case.
- High voltage tolerance: The SSR and FET versions can handle PV modules with a Voc up to 80 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 and FETs 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 and FETs are silent.
- Isc accuracy: The first measurement that the SSR and FET versions capture is at a voltage closer to zero than the EMR version, so the (extrapolated) value of Isc is more accurate.
- Current calibration: The SSR and FET versions support an advanced method of calibrating the current measurements which is more accurate than the method for the EMR versions.
- Track record: the EMR and SSR versions have been built many times and are known to work well. The FET version is new (as of Feb 2022).

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

The step-by-step construction documents for the PCB-based designs can be found in the GitHub repository:

docs/IV_Swinger2/PCB_construction/

IV_Swinger2_EMR_mod_PCB_Step_by_Step.docx
IV_Swinger2_SSR_mod_PCB_Step_by_Step.docx
IV_Swinger2_FET_mod_PCB_Step_by_Step.docx
IV_Swinger2_EMR_cell_PCB_Step_by_Step.docx
IV_Swinger2_SSR_cell_PCB_Step_by_Step.docx

PDFs of those documents are in the same place. Please switch now to the one that corresponds to your choice unless you have decided to build the original (deprecated) Perma-Proto design for PV modules.

The remainder of this document is for the original Perma-Proto design for PV modules.

Step 2: 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 3: Buy parts

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

The Amazon link below is a "wish list" that can be used to populate your cart. Most 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. NOTE: any part that has ALT_n (e.g., ALT_1, ALT_2) in the "Customer Reference field should be ordered only if the primary version of the same part is marked as "backorder".

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. Occasionally I check the lists and modify them myself, but not very often. Send

me a message if you are uncertain about identifying a substitute part.

Alternately, the following CSV file may be used to order from Digi-Key, Mouser or possibly other suppliers that support uploading a BOM spreadsheet. It includes the manufacturer, manufacturer's part number, Digi-Key part number, and Mouser part number:

https://github.com/csatt/IV_Swinger/raw/master/PCB/BOM/DigiKeyMouser/PermaProto_Digikey_Mouser.csv

https://github.com/csatt/IV_Swinger/raw/master/PCB/BOM/DigiKeyMouser/PermaProto_Digikey_Mouser.csv

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.

- **Amazon:**
  http://a.co/8RzkH2P

- **Digi-Key:**
  https://www.digikey.com/short/q99cnzz1

- **Donate to Arduino.cc:**
  https://www.arduino.cc/en/Main/Contribute

Step 4: 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:

    - Utility knife
    - Coping saw (or hacksaw)
    - Wire cutter (flush cut)
    - Wire stripper
- Drilling:
    - Drill
    - 1/16" bit (pilot for 9/64")
    - 1/8" bit (Perma-Proto)
    - 9/64" bit (standoffs)
    - 11/64" bit (pilot for 13/64")
    - 13/64" bit (binding posts)
    - 3/8" Forstner bit (preferred - USB cable hole)
- Other:
    - Digital Multimeter (DMM)
    - Small Phillips screwdriver
    - 9V battery
    - Sharpie
    - Ruler
    - Water spray bottle

Step 5: Modify Perma-Proto

The 1/2-size Perma-Proto is just a bit too long to fit in the baseball display case.

- **Cut Perma-Proto to length:**
    - 6.5cm (cut between row 24 and 25) _____
    - Score with knife on both sides, and then break off end
- **Drill new mounting hole in cut-off end of Perma-Proto:**
    - 1/8" bit, ~5.5cm between hole centers _____

Step 6: Manually test the relay module

This will confirm that your relay module is the correct type 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 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 _____

Step 7: Prepare for Soldering

- **Soldering NOTES:**
    - Order is important:
        - Avoids earlier steps obstructing later steps
        - Avoids melting insulation of already-soldered wires
        - Minimizes time by batching as many solder joints as possible into a single "step"
    - If you don't have a lot of soldering experience, read this:

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

    - If you need practice soldering, use the scrap end of the Perma-Proto
    - Solder bridges between holes in different numbered rows (e.g. hole 16H to hole 17H) or between the power and ground rails must be removed with a solder sucker or solder wick and/or X-acto knife.
    - Solder bridges are ok between holes in the same numbered row (e.g. holes 10B and 10C). However, if an empty hole is plugged, it may block a wire/lead/pin that comes in a later step and will have to be cleared with a solder sucker or solder wick.
    - Don't skip the incremental testing steps. Mistakes found now are easy to identify and fix, but will be very difficult or impossible if you wait until the whole thing is built.

- **Wire cutting NOTES:**

- Print the following page to help cut wires to their correct lengths and to strip them properly

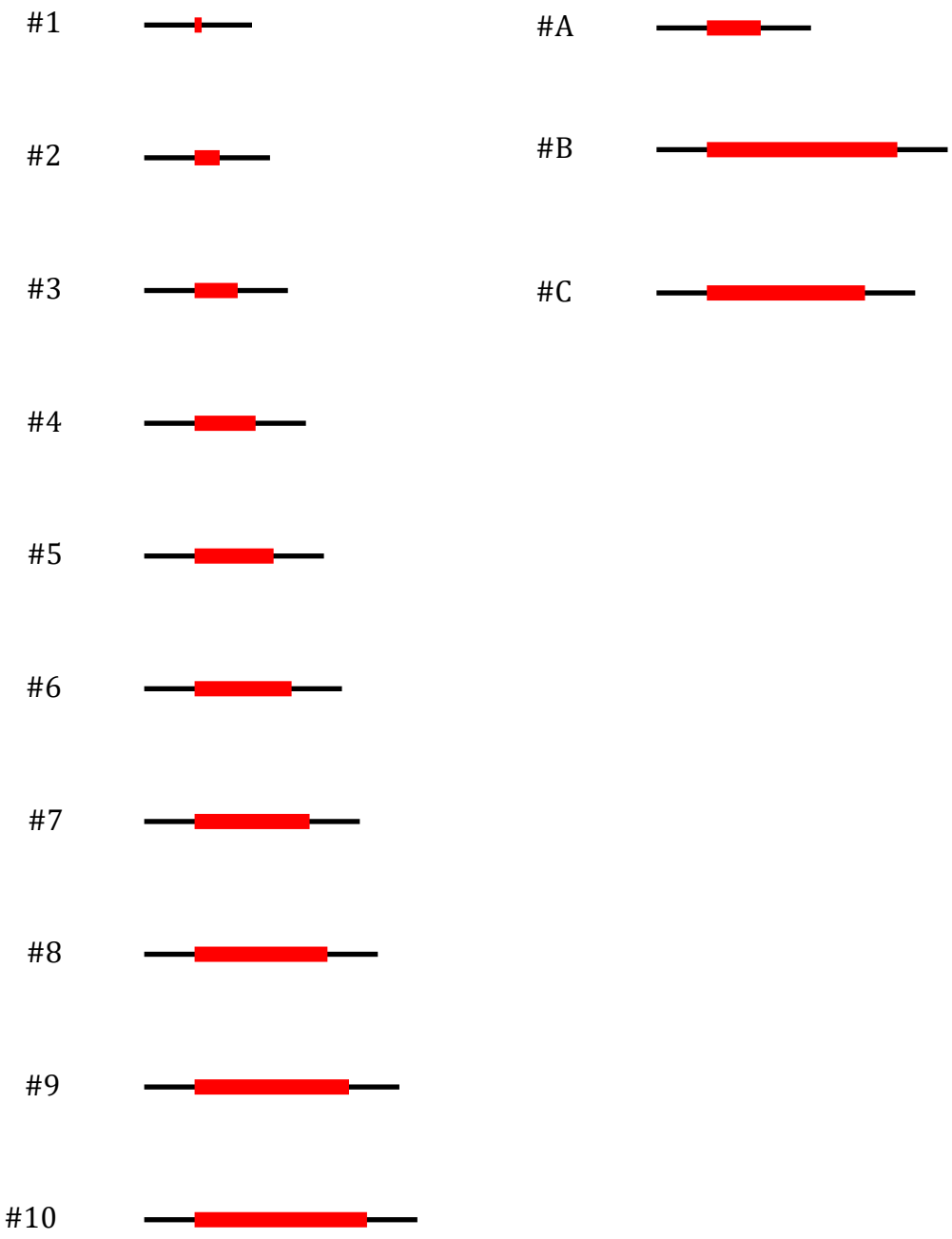
- Measure #10 – it should be 38.0mm if your printer prints to scale

- The numbered templates are named for the number of hole gaps spanned for purely vertical or horizontal wires (e.g. adjacent holes use #1)

- The lettered templates are for a few wires that are diagonal or not routed directly between two holes

- To use:
  - Lay the uncut wire over the template, with the end aligned to the right end of the template
  - Use wire cutters to gently dent the insulation at the positions of the two ends of the insulation and the left end of the wire
  - Use wire strippers to strip the right end at the rightmost dent
  - Cut the wire to length at the leftmost dent
  - Hold the wire by the insulation with needle nosed pliers
  - Use wire strippers to strip the left end at the first dent

- Total counts for each color and length:
  - BLACK:
    - #2: 2
    - #3: 4
    - #4: 2
  - RED:
    - #2: 3
    - #A: 1
  - BLUE:
    - #1: 1
    - #6: 1
  - GREEN:
    - #1: 1
    - #B: 2
  - WHITE:
    - #C: 1



Wire cutting and stripping templates

Step 8: BLACK (ground) wires

- **Solder BLACK (ground) wires to Perma-Proto (16 joints):**
    - Only the ones with both ends connecting to Perma-Proto holes
    - Insert all wires before soldering. Tape down on front to hold in place. Lengths (total/insulation template#) and holes:
        - 20.0/6.0mm (#3) 7J - upper ground rail (blue stripe), hole 7 _____
        - 20.0/6.0mm (#3) 12J - upper ground rail (blue stripe), hole 12 _____
        - 20.0/6.0mm (#3) 7F - 7E _____
        - 20.0/6.0mm (#3) 12F - 12E _____
        - 22.5/8.5mm (#4) 7D - 11D _____
        - 22.5/8.5mm (#4) 12D - 16D _____
        - 17.5/3.5mm (#2) 12A - lower ground rail (blue stripe), hole 12 _____
        - 17.5/3.5mm (#2) 21A - lower ground rail (blue stripe), hole 21 _____
    - Flip board upside down and hold with vise or 3rd hand tool. Solder all 16 joints _____
    - Inspect with magnifying glass to make sure all joints are good and there are no solder bridges _____
    - Trim all 16 leads _____

- **Test ground plane:**
  - Test continuity:
    - Upper ground rail to lower ground rail _____
    - Upper ground rail to all holes in row 7 _____
    - Upper ground rail to holes A-E in row 11 _____
    - Upper ground rail to all holes in row 12 _____
    - Upper ground rail to holes A-E in row 16 _____
    - Upper ground rail to holes A-E in row 21 _____
  - Test NON-continuity:
    - Upper ground rail to upper/lower power rail _____
    - Upper ground rail to holes:
      - 6J _____
      - 8J _____
      - 11J _____
      - 13J _____
      - 6E _____
      - 8E _____
      - 10E _____
      - 13E _____
      - 14E _____
      - 15E _____
      - 17E _____
      - 20E _____

- 22E _____

Step 9: RED (+5V) wires

- **Solder RED (+5V) wires to Perma-Proto (8 joints):**
  - Only the ones with both ends connecting to Perma-Proto holes
  - Insert all wires before soldering. Tape down on front to hold in place. Lengths (total/insulation template#) and holes:
    - 17.5/3.5mm (#2) 8J - upper power rail (red stripe), hole 8 _____
    - 17.5/3.5mm (#2) 13J - upper power rail (red stripe), hole 13 _____
    - 17.5/3.5mm (#2) 19J - upper power rail (red stripe), hole 19 _____
    - 21.5/7.5mm (#A) 17E - 19F _____
  - Flip board upside down and hold with vise or 3rd hand tool. Solder all 8 joints
    _____
  - Inspect with magnifying glass to make sure all joints are good and there are no solder bridges
    _____
  - Trim all 8 leads _____

- **Test power plane:**
  - Test continuity:
    - Upper power rail to holes F-J in row 8 _____
    - Upper power rail to holes F-J in row 13 _____

- Upper power rail to holes F-J in row 19 _____
- Upper power rail to holes A-E in row 17 _____

o Test NON-continuity:

- Upper power rail to upper/lower ground rail _____
- Upper power rail to holes:
  - 9J _____
  - 14J _____
  - 18J _____
  - 20J _____
  - 18D _____

Step 10: BLUE (and one GREEN) wires

- **Solder BLUE (and ONE GREEN) wires to Perma-Proto (6 joints):**

o Only the BLUE ones with both ends connecting to Perma-Proto holes

o Only the very short GREEN one

o Insert all wires before soldering. Tape down on front to hold in place. Lengths (total/insulation template#) and holes:

- 27.5/13.5mm (#6) 11H - 17H (BLUE) _____
- 15.0/1.0mm (#1) 20J - 21J (BLUE insulation optional) _____
- 15.0/1.0mm (#1) 9I - 10I (GREEN insulation optional) _____

- Flip board upside down and hold with vise or 3rd hand tool. Solder all 6 joints.

  _____

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

  _____

- Trim all 6 leads _____

- **Test BLUE (and ONE GREEN) wire soldering:**

  - Test continuity:
    - Hole 9F to hole 10F _____
    - Hole 11F to hole 17F _____
    - Hole 20F to hole 21F _____
  - Test NON-continuity:
    - Hole 8F to hole 9F _____
    - Hole 10F to hole 11F _____
    - Hole 11F to hole 12G _____
    - Hole 16F to hole 17F _____
    - Hole 17F to hole 18F _____
    - Hole 19G to hole 20G _____
    - Hole 21F to hole 22F _____

Step 11: 1/4W resistors

- **Solder 1/4W resistors to Perma-Proto (16 solder joints):**

  - Insert all resistors before soldering. Tape down on front to hold in place.
    - R1 (150k): 20F - 20D _____
    - R2 (7.5k): 21F - 21D _____
    - R3 (1k): 6B - 10B _____
    - R4 (1k): 17G - 21G _____
    - R5 (22k): 13A - 17A _____
    - R6 (22k): 19H - 22H _____
    - Rf (75k): 15C - 19C _____
    - Rg (1k): 16B - 19B _____
  - Flip board upside down and hold with vise or 3rd hand tool. Solder all 16 joints
    _____
  - Inspect with magnifying glass to make sure all joints are good and there are no solder bridges
    _____
  - Trim all 16 leads _____

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

  Measuring between the specified Perma-Proto holes listed below also verifies the soldering.

- R1 (150k): 20I - 20A _____
- R2 (7.5k): 21I - 21B _____
- R3 (1k): 6E – 10A _____
- R4 (1k): 17J - 21I _____
- R5 (22k): 13E - 17D _____
- R6 (22k): 19I - 22G _____
- Rf (75k): 15E – 19D _____
- Rg (1k): 16E – 19D _____

The measured values of R1, R2, Rf, and Rg could be useful, so keep this record. All values should be within the tolerance of the resistors if the soldering was done correctly.

- **Additional tests of resistor soldering:**

  o Test NON-continuity:

  - Hole 6A to hole 7C _____
  - Hole 9A to hole 10A _____
  - Hole 10A to hole 11A _____
  - Hole 12B to hole 13B _____
  - Hole 13B to hole 14B _____
  - Hole 14E to hole 15E _____
  - Hole 15E to hole 16E _____
  - Hole 16E to hole 17D _____
  - Hole 19A to hole 20A _____
  - Hole 20B to hole 21B _____

- Hole 16J to hole 17J _____
- Hole 19I to hole 20I _____
- Hole 21I to hole 22I _____

Step 12: IC sockets

- **Solder IC sockets to Perma-Proto (16 joints):**
  - Insert both sockets before soldering. Tape down on front to hold in place.
  - Make sure notch is on the left end
  - TLV2462 (left) socket:
    - Pin 1: hole 8E _____
    - Pin 5: hole 11F _____
  - MCP3202 (right) socket:
    - Pin 1: hole 13E _____
    - Pin 5: hole 16F _____
  - Flip board upside down and hold with vise or 3rd hand tool and solder all 16 joints
    _____
  - Inspect with magnifying glass to make sure all joints are good
    _____

- **Test socket soldering:**
  - Test continuity:
    - TLV2462 (left) socket hole 1 (lower left) to Perma-Proto hole 8C _____

- TLV2462 (left) socket hole 2 to Perma-Proto hole 9C _____
- TLV2462 (left) socket hole 3 to Perma-Proto hole 10C _____
- TLV2462 (left) socket hole 4 to Perma-Proto ground rails _____
- TLV2462 (left) socket hole 5 (upper right) to Perma-Proto hole 11J _____
- TLV2462 (left) socket hole 6 to socket hole 7 _____
- TLV2462 (left) socket hole 7 to Perma-Proto hole 9G _____
- TLV2462 (left) socket hole 8 to Perma-Proto upper power rail _____
- MCP3202 (right) socket hole 1 (lower left) to Perma-Proto hole 13B _____
- MCP3202 (right) socket hole 2 to Perma-Proto hole 14B _____
- MCP3202 (right) socket hole 3 to Perma-Proto hole 15B _____
- MCP3202 (right) socket hole 4 to Perma-Proto ground rails _____
- MCP3202 (right) socket hole 5 (upper right) to Perma-Proto hole 16G _____
- MCP3202 (right) socket hole 6 to Perma-Proto hole 15J _____
- MCP3202 (right) socket hole 7 to Perma-Proto hole 14J _____
- MCP3202 (right) socket hole 8 to Perma-Proto upper power rail _____

o Test NON-continuity:

- TLV2462 socket hole 1 to Perma-Proto ground rails
  _____
- TLV2462 socket hole 1 to socket hole 2
  _____
- TLV2462 socket hole 2 to socket hole 3
  _____
- TLV2462 socket hole 3 to socket hole 4
  _____
- TLV2462 socket hole 5 to Perma-Proto ground rails
  _____
- TLV2462 socket hole 5 to socket hole 6
  _____
- TLV2462 socket hole 7 to socket hole 8
  _____
- TLV2462 socket hole 8 to Perma-Proto ground rails
  _____
- MCP3202 socket hole 1 to Perma-Proto ground rails
  _____
- MCP3202 socket hole 1 to socket hole 2
  _____
- MCP3202 socket hole 2 to socket hole 3
  _____
- MCP3202 socket hole 3 to socket hole 4
  _____
- MCP3202 socket hole 4 to Perma-Proto hole 17D
  _____
- MCP3202 socket hole 5 to Perma-Proto hole 17J
  _____
- MCP3202 socket hole 5 to socket hole 6
  _____

- MCP3202 socket hole 6 to socket hole 7
  _____
- MCP3202 socket hole 7 to socket hole 8
  _____
- MCP3202 socket hole 8 to Perma-Proto ground rails
  _____

Step 13: Filter capacitors

- **Solder 0.1uF capacitors to Perma-Proto (4 joints):**
  - Insert both capacitors before soldering. Bend leads on back to hold in place.
    - C3: 7G - 8G _____
    - C6: 12G - 13G _____
  - Flip board upside down and hold with vise or 3rd hand tool and solder both joints
    _____
  - Inspect with magnifying glass to make sure joints are good and there are no solder bridges
    _____
  - Trim all 4 leads _____

- **Solder 2.2nF capacitors to Perma-Proto (4 joints):**
  - Insert both capacitors before soldering. Bend leads on back to hold in place.
    - C4: 10C - 11C _____
    - C5: 11I - 12I _____

- Flip board upside down and hold with vise or 3rd hand tool and solder both joints

  _____

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

  _____

- Trim all 4 leads _____

- **Test capacitor soldering**

  - Test continuity:

    - C3 left leg (7G) to Perma-Proto ground rails

      _____

    - C3 right leg (8G) to Perma-Proto upper power rail

      _____

    - C6 left leg (12G) to Perma-Proto ground rail

      _____

    - C6 right leg (13G) to Perma-Proto upper power rails

      _____

    - C4 left leg (10C) to Perma-Proto TLV2462 socket hole 3 _____

    - C4 right leg (11C) to Perma-Proto ground rails

      _____

    - C5 left leg (11I) to Perma-Proto TLV2462 socket hole 5 _____

    - C5 right leg (12I) to Perma-Proto ground rails

      _____

  - Test NON-continuity:

    - C3 left leg (7G) to Perma-Proto hole 6G

      _____

    - C3 left leg (7G) to C3 right leg (8G)

      _____

- C3 right leg (8G) to Perma-Proto hole 9G
  _____
- C6 left leg (12G) to Perma-Proto hole 11G
  _____
- C6 left leg (12G) to C6 right leg (13G)
  _____
- C6 right leg (13G) to Perma-Proto hole 14G
  _____
- C4 left leg (10C) to Perma-Proto hole 9C
  _____
- C4 left leg (10C) to C4 right leg (11C)
  _____
- C5 left leg (11I) to Perma-Proto hole 10I
  _____
- C5 left leg (11I) to C5 right leg (12I)
  _____
- C5 right leg (12I) to Perma-Proto hole 13I
  _____

Step 14: Two more GREEN wires, one WHITE wire

- **Solder one more GREEN wire to Perma-Proto (2 joints):**

  o Insert wire and tape down on front to hold in place. Length (total/insulation template#) and holes:

  - 40.5/26.5mm (#B) 9G - 14C _____

  Bend and route between the IC sockets in a Z (on top of black wires)

- Flip board upside down and hold with vise or 3rd hand tool and solder both joints

  _____

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

  _____

- Trim both leads _____

- **Solder one more GREEN wire to Perma-Proto (2 joints):**

  - Insert wire and tape down on front to hold in place. Length (total/insulation template#) and holes:

    - 40.5/26.5mm (#B) 9C - 19D _____

    Route around capacitor C4 and over the top of the previous green wire

  - Flip board upside down and hold with vise or 3rd hand tool and solder both joints

    _____

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

    _____

  - Trim both leads _____

- **Solder one WHITE wire to Perma-Proto (2 joints):**

  - Insert wire and tape down on front to hold in place. Length(total/insulation template#) and holes:

    - 36.0/22.0mm (#C) 8A - 15B _____

    This wire should NOT lie flat, but should be a small "arch" to leave clearance for the blue wire to connect to hole 13B

- Flip board upside down and hold with vise or 3rd hand tool and solder both joints

  _____

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

  _____

- Trim both leads _____

- **Test GREEN and WHITE wire soldering:**

  - Test continuity:

    - TLV2462 socket hole 1 to MCP3202 socket hole 3

      _____

    - TLV2462 socket hole 2 to Perma-Proto hole 19A

      _____

    - TLV2462 socket hole 7 to MCP3202 socket hole 2

      _____

  - Test NON-continuity:

    - TLV2462 socket hole 1 to Perma-Proto ground rails

      _____

    - TLV2462 socket hole 1 to socket hole 2

      _____

    - TLV2462 socket hole 2 to socket hole 3

      _____

    - TLV2462 socket hole 7 to socket hole 8

      _____

    - MCP3202 socket hole 1 to socket hole 2

      _____

    - MCP3202 socket hole 2 to socket hole 3

      _____

- Perma-Proto hole 18A to hole 19A
  _____

- Perma-Proto hole 19A to hole 20A
  _____

Step 15: Insert bleed resistor

- **Insert 47ohm bleed resistor Rb:**
  - Tape down on front to hold in place, but don't solder yet
    - 6H - 6C _____

Step 16: Insert load capacitors

- **Insert 1000uF load capacitors:**
  - Tape down on front to hold in place, but don't solder yet
    - 1J - 4J (shorter lead / stripe side (-) on the right (4J), IMPORTANT!) _____
    - 1A - 4A (shorter lead / stripe side (-) on the right (4A), IMPORTANT!) _____

Step 17: Solder bleed resistor

- **Solder 47ohm bleed resistor Rb leads (2 joints):**
  - DO NOT TRIM LEADS

- Note that the resistor may have to be raised slightly to fit
- Leads are thick so they take a longer time to heat up enough to melt solder
- Solder to holes 6H and 6C with leads straight through holes (i.e. not bent)

  _____

Step 18: Shunt resistor

- **Solder .005 ohm shunt resistor to *BACK* of Perma-Proto (2 joints):**
  - Bend leads at right angle so resistor is CENTERED between bends and the lead ends are 27.5mm apart

    _____
  - Insert shunt resistor leads into the following holes FROM THE BACK of the Perma-Proto:
    - 4E - lower ground rail (blue stripe), hole 13

      _____
  - Tape down on back to hold in place _____
  - Flip board face-up and hold with vise or 3rd hand tool and solder both joints (long heavy leads will take time to heat)

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

    _____
  - Trim both leads _____

Step 19: Prepare load circuit zip cord

- **Prepare load circuit zip cord:**

- 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.

- "A": PV- binding post to lower ground rail and shunt

  - Cut to length: 9cm

    _____

  - Strip 1cm 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)

    _____

- "B": PV+ binding post to relay module NO terminal

  - Cut to length: 9cm

    _____

  - Strip 1cm 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)

    _____

- "C": Load capacitors (+) side to relay module C terminal
  - Cut to length: 11cm

    _____
  - Strip 1cm on each end and twist strands

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

    _____

Step 20: Load capacitor (+) leads

- **Solder (+) load capacitor leads to each other and to zip cord "C"(1 large joint):**
  - DON'T COVER UP MOUNTING HOLE!
  - Leave enough room for standoff, but don't put standoff in hole when soldering; it will suck heat and wires won't get hot enough to flow solder
  - Bend lead from hole 1A so it lies flat and in the correct direction and contacts lead from hole 1J. See photo.

    _____
  - Solder leads to their holes (1J and 1A)

    _____
  - Solder capacitor leads to each other

    _____
  - Tack on zip cord "C" so it extends toward the top of the board, parallel to the end. Heat up tinned end of wire and capacitor leads enough to completely reflow the solder (add more solder if needed). See photo.

    _____
  - Make sure there is no solder bridging to any of the row 4 holes (rows 1, 2, and 3 are ok)

    _____

Step 21: Load capacitor (-) leads

- **Solder (-) load capacitor leads to each other, shunt resistor, and lead of 47ohm bleed resistor Rb that comes through hole 6C (1 large joint):**

  - Use needle-nosed pliers to wrap Rb lead around shunt resistor lead between its body and hole (may also need to cut off some of Rb lead)

    _____

  - Bend capacitor (-) leads to contact shunt resistor lead at E4. See photo.

    _____

  - Solder leads to their holes (4J and 4A)

    _____

  - Solder capacitor (-) leads to each other and to shunt resistor lead at E4, and also make sure solder flows to Rb lead that is wrapped around shunt resistor lead

    _____

  - Trim other Rb lead

    _____

Step 22: Zip cord "A"

- **Solder zip cord "A" to shunt/ground**

  - Tack zip cord "A" onto the end of the shunt resistor that is connected to the lower ground rail. Orient it so it extends toward the top of the board. Heat up tinned end of wire and shunt lead enough to completely reflow the solder (add more solder if needed). See photo.

    _____

Step 23: Test previous 8 steps

- **Test bleed resistor, shunt resistor, and load capacitor soldering:**
  - Measure capacitance between Perma-Proto holes 1F and 4F. It should be between 1600uF and 2400uF (most likely on the smaller end)

    _____
  - Use multimeter to measure resistance between Perma-Proto holes:
    - Rb (47ohms): 6J - 6A _____
    - Shunt: 6A - ground rails _____

    NOTE: Shunt is only .005 ohms, which is below the resolution of the multimeter. Measured value should be approximately the same as shorting the probes together.
  - Test NON-continuity:
    - Capacitor (-) leads to capacitor (+) leads on back

      _____
    - Hole 6J to ground rails

      _____ (47Ω)

Step 24: 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** _____
  - Make sure dot is on the left end (pin 1)
  - Legs may have to be bent inward slightly
- **Insert MCP3202 in right socket** _____

- Make sure notch and dot are on the left end (pin 1)
- Legs may have to be bent inward slightly

Step 25: Off-Perma-Proto hookup wires

- **Solder off-Perma-Proto hookup wires to Perma-Proto:**
  - Cut all wires to length, with 7mm insulation stripped from each end:
    - BLUE, 8.5cm _____
    - BLUE, 8.5cm _____
    - YELLOW, 7.0cm _____
    - YELLOW, 15.0cm _____
    - GREEN, 7.0cm _____
    - GREEN, 13.0cm _____
    - WHITE, 7.0cm _____
    - RED, 11.0cm _____
    - BLACK, 7.0cm _____
  - Use 3rd hand tool to hold wire in hole and perpendicular to the board while soldering
  - Solder BLUE wires (2 joints):
    - Perma-Proto hole 13B (8.5cm) _____
    - Perma-Proto hole 22I (8.5cm) _____
  - Solder YELLOW wires (2 joints):
    - Perma-Proto hole 14G (7.0cm) _____

    - Perma-Proto hole 20C (15.0cm) _____
  - Solder GREEN wires (2 joints):
    - Perma-Proto hole 6I (13.0cm) _____
    - Perma-Proto hole 15G (7.0cm) _____
  - Solder WHITE wire (1 joint):
    - Perma-Proto hole 16G _____
  - Solder RED wire (1 joint):
    - Perma-Proto upper power rail (red stripe), hole 15 _____
  - Solder BLACK wire (1 joint):
    - Perma-Proto lower ground rail (blue stripe), hole 15 _____
  - Inspect with magnifying glass to make sure joints are good and there are no solder bridges _____
  - Trim all 9 leads _____

- **Test off-Perma-Proto hookup wire soldering:**
  - Test continuity:
    - Lower BLUE wire (stripped end) to MCP3202 pin 1 _____
    - Upper BLUE wire (stripped end) to Perma-Proto hole 22F _____
    - Lower YELLOW wire (stripped end) to Perma-Proto hole 20A _____
    - Upper YELLOW wire (stripped end) to MCP3202 pin 7 _____

- Left GREEN wire (stripped end) to Perma-Proto hole 6J _____
- Right GREEN wire (stripped end) to MCP3202 pin 6 _____
- WHITE wire (stripped end) to MCP3202 pin 5 _____
- RED wire (stripped end) to Perma-Proto hole 19I _____
- BLACK wire (stripped end) to Perma-Proto hole 7I _____

o Test NON-continuity:

- Lower BLUE wire (stripped end) to Perma-Proto hole 7I _____
- Lower BLUE wire (stripped end) to Perma-Proto hole 9J _____
- Upper BLUE wire (stripped end) to Perma-Proto hole 21I _____
- Lower YELLOW wire (stripped end) to Perma-Proto hole 19A _____
- Lower YELLOW wire (stripped end) to Perma-Proto hole 21B _____
- Upper YELLOW wire (stripped end) to Perma-Proto hole 13I _____
- Upper YELLOW wire (stripped end) to Perma-Proto hole 15I _____
- Left GREEN wire (stripped end) to Perma-Proto hole 7I _____ (47Ω)
- Right GREEN wire (stripped end) to Perma-Proto hole 14I _____

- Right GREEN wire (stripped end) to Perma-Proto hole 16I _____
- WHITE wire (stripped end) to Perma-Proto hole 15I _____
- WHITE wire (stripped end) to Perma-Proto hole 17I _____
- RED wire (stripped end) to Perma-Proto hole 7I _____
- BLACK wire (stripped end) to Perma-Proto hole 19I _____

Step 26: Solder Male-Female relay jumpers to Perma-Proto

- **Solder Male-Female relay module power/control jumper wires to Perma-Proto:**
  - This assumes the relay module has jumper pins on the power and control inputs (some have screw terminals, like the load side)
  - Solder BLUE jumper (cut pin off) (1 joint):
    - This one needs to have its pin cut off and that end stripped. This is because the pin and its plastic housing are too tall to fit next to the Arduino in the case.
    - Solder stripped end to Perma-Proto hole 22J _____
  - Solder RED jumper pin (1 joint):
    - Perma-Proto upper power rail (red stripe), hole 10 _____

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

  _____

- Trim lead of BLUE jumper (don't trim pin from RED jumper)

  _____

- **Test soldering of Male-Female relay module power/control jumper wires to Perma-Proto:**

  - Test continuity:

    - Need to insert a wire into female end for these
    - BLUE jumper to Perma-Proto hole 22F

      _____
    - RED jumper to Perma-Proto hole 19I

      _____

  - Test NON-continuity:

    - BLUE jumper to Perma-Proto hole 21I

      _____
    - RED jumper to Perma-Proto hole 7I

      _____

Step 27: Solder bypass diodes in series (NO LONGER NEEDED)

NOTE: The original design called for two 15A, 45V bypass diodes (15SQ045), but this was a design error. A single 15A, 100V diode must be used.

Step 28: Make binding post connections

- **Make binding post connections:**
  - Remove outer nuts and washers from threaded post

    _____
  - Insert negative (black side) threaded post through the cable ring connector on zip cord "A" (other end is attached to shunt resistor and ground rail on bottom of Perma-Proto)

    _____
  - Insert positive (red side) threaded post through the cable ring connector on zip cord "B"

    _____
  - Bend 100V diode leads into loops that will fit onto the threaded posts (NOTE: photos show two 45V diodes)

    _____
  - Slide looped ends of the diode leads onto the threaded posts with the STRIPED END OF THE DIODE TOWARD THE RED SIDE

    _____
  - Put washers back on, over the diode lead loops

    _____
  - Put nuts on and tighten (not too tight – they'll be coming off again later)

    _____

Step 29: Make relay switching side connections

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

  - Twist end of zip cord "B" (from red side of binding posts) to end of yellow wire that comes from Perma-Proto hole 20C, and solder them together

    _____

  - Loosen screw and insert the twisted/soldered end into the top ("Normally Open" - NO) screw terminal hole on the relay module and tighten down the screw. Tug the wires gently to make sure they are securely connected.

    _____

  - Loosen screw and insert the end of zip cord "C" (other end is attached to capacitor + leads on back of Perma-Proto) into the center ("Common" - C) screw terminal hole on the relay module and tighten down the screw.

    _____

  - Loosen screw and insert the end of the green wire that comes from Perma-Proto hole 6I into the bottom ("Normally Closed – NC) screw terminal hole on the relay module and tighten down the screw.

    _____

Step 30: Make relay power/control side connections

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

  - Connect the BLUE jumper (from Perma-Proto hole 22J) to the IN pin on the relay module

    _____

  - Connect the RED jumper (from Perma-Proto upper power rail hole 10) to the VCC pin on the relay module

_____

- Connect the BLACK jumper from the GND pin on the relay module to the GND pin on the Arduino ("Power" side)

_____

Step 31: Make other Arduino connections

- **Make other Arduino connections:**

  - Connect the BLUE wire from Perma-Proto hole 22I to Arduino pin 2

    _____

  - Connect the BLUE wire from Perma-Proto hole 13B to Arduino pin 10

    _____

  - Connect the WHITE wire from Perma-Proto hole 16G to Arduino pin 11

    _____

  - Connect the GREEN wire from Perma-Proto hole 15G to Arduino pin 12

    _____

  - Connect the YELLOW wire from Perma-Proto hole 14G to Arduino pin 13

    _____

  - Connect the RED wire from Perma-Proto upper power rail (red stripe), hole 15 to Arduino +5V pin

    _____

  - Connect the BLACK wire from Perma-Proto lower ground rail (blue stripe), hole 15 to Arduino GND (near pin 13)

    _____

Step 32: Test system connections

- **Test system connections:**

  - Test continuity:

    - RED binding post to Perma-Proto hole 20A

      _____

    - BLACK binding post to Arduino GND pin (on back)

      _____

    - Relay module "NC" terminal (on back) to Perma-Proto hole 6J (or resistor Rb lead)

      _____

    - Relay module IN pin (on back) to Arduino pin 2 (on back) _____

    - Relay module GND pin (on back) to Perma-Proto upper ground rail

      _____

    - Relay module VCC pin (on back) to Perma-Proto upper power rail

      _____

    - MCP3202 pin 1 to Arduino pin 10 (on back)

      _____

    - MCP3202 pin 5 to Arduino pin 11 (on back)

      _____

    - MCP3202 pin 6 to Arduino pin 12 (on back)

      _____

    - MCP3202 pin 7 to Arduino pin 13 (on back)

      _____

    - Perma-Proto upper ground rail to Arduino GND pin (on back)

      _____

- Perma-Proto upper power rail to Arduino 5V pin (on back)

  _____

- Test NON-continuity:

  NOTE: temporarily disconnect the RED wire from the Arduino 5V pin for these tests (OR expect ~1.5kΩ resistance between VCC and GND in last test).

  - RED binding post to BLACK binding post

    _____

  - Relay module IN pin (on back) to relay module GND pin (on back)

    _____

  - Relay module IN pin (on back) to relay module VCC pin (on back)

    _____

  - Relay module GND pin (on back) to relay module VCC pin (on back)

    _____

- Measure resistance:

  - BLACK binding post to Perma-Proto hole 1F
    _____ (should be 47 ohms)

Step 33: System bench test

- **System bench test:**

  - Connect Arduino to laptop via USB

    - Check for smoke ☺ _____

    - Check that relay module red 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) _____

- 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

  - 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 "TX" LED should be blinking. This is not the same yellow LED that the Blink sketch controls.
  _____

- "Nothing connected" test

  - Open the IV Swinger 2 application _____

- Verify that "Swing!" button text changes to RED and message below it changes from "Not connected" to "Connected" (briefly, then disappears). The "TX" LED should no longer be on.

  _____

  If not, pull down the "USB Port" menu and select the correct port.

- Click the "Swing!" button. You should hear the relay click twice and see an error dialog saying "ERROR: Voc is zero volts"

  _____

o 9V battery test

- 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 9V battery snap-on connector, use that.

  _____

- Connect the wire from the RED binding post to the positive (smaller/male) terminal of a 9V battery (you can either tape it or hold it with your thumb)

  _____

- Connect the wire from the BLACK binding post to the negative (larger/female) terminal of the same 9V battery (tape it or hold it with the same thumb as the other)

  _____

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

Step 34: 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, and the "fins" on the bottom need to be trimmed off in order for everything to fit.

Case side definitions:

- Front: side with the USB connector
- Back: side opposite from front
- Left: side with binding posts and Perma-Proto
- Right: side with relay module
- Bottom: side with Arduino
- Top: side closest to capacitors

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”

Step 35: Cut off fins

- **Cut fins:**

  There are three fins on the bottom of the case (to cradle the baseball). Their tips need to be cut off so the Arduino clears them when it is on its standoffs. (Using longer standoffs is another possibility.)

  A coping saw or hacksaw can be used for this, among other possibilities. Just be careful not to crack or scratch the case.

Cut off as much as possible, but at least enough so standoffs are longer than the remaining height.

_____

Step 36: Mark holes for Arduino standoffs

IMPORTANT: For this step and the next three, look straight down 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 4 standoffs to Arduino:
    - Disconnect all wires from 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 37: Mark holes for Perma-Proto standoffs

- **Mark holes for Perma-Proto:**

  - Attach 2 standoffs to Perma-Proto:

    - Insert threaded/male end of each standoff through its hole in the Perma-Proto from the back. Don't worry if the one on the capacitor end touches the soldered capacitor leads.

      _____

    - Screw nuts on the threaded ends of the standoffs on the front of the Perma-Proto and tighten them

      _____

  - Place the Perma-Proto in position. Leave 2-3mm on the side near the front. Align so the capacitors are 2-3mm below the top (if they are angled up at all, make sure the ends will be low enough not to contact the lid).

    _____

  - Use Sharpie to mark the centers of the two holes

    _____

Step 38: Mark holes for relay module standoffs

- **Mark holes for relay module:**
  - Attach 4 standoffs to relay module:
    - Disconnect any remaining 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 right side of the case at the following position:
    - 1.0 cm from the left (i.e. front) edge
    - 1.5 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 39: Mark holes for binding posts

- **Mark holes for binding posts:**
  - Remove top nuts, washers, diodes, 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 rear inner edge of the case and about 1mm from the bottom.

_____

- Use Sharpie to mark the centers of the two holes

_____

Step 40: Drill 12 marked holes

- **Drill 12 marked holes:**

  - Use something pointy to make an indentation in the middle of each of the 12 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 twelve 1/16” pilot holes

_____

  - Switch to 9/64” bit and re-drill all 12 holes

_____

- **Enlarge 2 holes for binding posts:**

  - Switch to 11/64” bit and re-drill both of the binding post holes

_____

  - Switch to 13/64” bit and re-drill both of 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 41: 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 42: Install Perma-Proto

- **Install Perma-Proto in case:**

  - Insert the Perma-Proto into the case and screw down its two standoffs with two M3 screws

    _____

Step 43: Make binding post connections

- **Make connections to binding posts:**

  - Slide cable ring connector on zip cord "A" (from Perma-Proto) onto negative (BLACK side) threaded post

    _____

  - Slide cable ring connector on zip cord "B" (other end soldered to yellow wire from Perma-Proto) onto positive (RED side) threaded post

    _____

  - Put washers back on, over the cable ring connectors

    _____

  - Slide looped ends of the diode leads onto the threaded posts with the STRIPED END OF THE DIODES TOWARD THE RED SIDE

    _____

  - Put nuts on and tighten down securely

    _____

Step 44: Install Arduino

- **Install Arduino 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

    _____

Step 45: Connect Perma-Proto to Arduino

- **Connect the 7 wires from the Perma-Proto to the Arduino:**

  You may need to use needle nosed pliers for this unless you have small hands

  - Connect the BLUE wire from Perma-Proto hole 22I to Arduino pin 2

    _____

  - Connect the BLUE wire from Perma-Proto hole 13B to Arduino pin 10

    _____

  - Connect the WHITE wire from Perma-Proto hole 16G to Arduino pin 11

    _____

  - Connect the GREEN wire from Perma-Proto hole 15G to Arduino pin 12

    _____

  - Connect the YELLOW wire from Perma-Proto hole 14G to Arduino pin 13

    _____

  - Connect the BLACK wire from Perma-Proto ground rail, hole 15 to Arduino GND

    _____

  - Connect the RED wire from Perma-Proto power rail, hole 15 to Arduino +5V pin

    _____

Step 46: Connect screw-down side of relay module

- **Connect 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.

- Insert the twisted/soldered end of zip cord "B" (from RED binding post) and yellow wire (from Perma-Proto) into the top ("Normally Open" - NO) screw terminal hole on the relay module and tighten down the screw. Tug the wires gently to make sure they are securely connected.

  _____

- Insert the end of zip cord "C" (from back of Perma-Proto) into the center ("Common" - C) screw terminal hole on the relay module and tighten down the screw. Tug gently to test.

  _____

- Insert the end of the green wire that comes from Perma-Proto hole 6I into the bottom ("Normally Closed – NC) screw terminal hole on the relay module and tighten down the screw. Tug gently to test.

  _____

Step 47: Install relay module

- **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.

    _____

Step 48: Connect relay module jumpers

- **Connect wires to jumper side of relay module:**

  - Connect the BLUE jumper (from Perma-Proto hole 22J) to the IN pin on the relay module

    _____

  - Connect the BLACK jumper from the GND pin on the relay module to the GND pin on the Arduino

_____

- Connect the RED jumper (from Perma-Proto upper power rail hole 10) to the VCC pin on the relay module

_____

Step 49: 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", 1/4", 5/16", 3/8" (untested – may need even smaller (1/32") steps)

    _____

  - 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 50: 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 zip cord 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 diodes between the binding posts 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 51: 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 some amount of 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.