User Manual

Dr. Wattson Energy Monitoring Board & Enclosure

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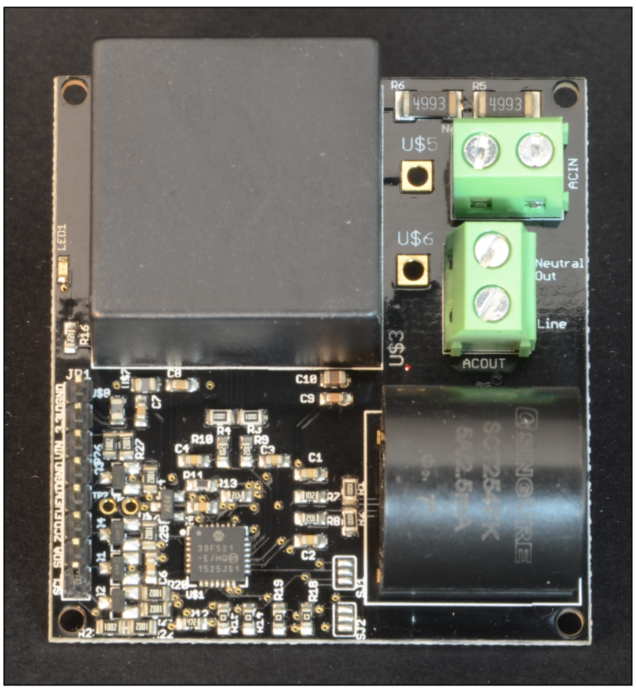

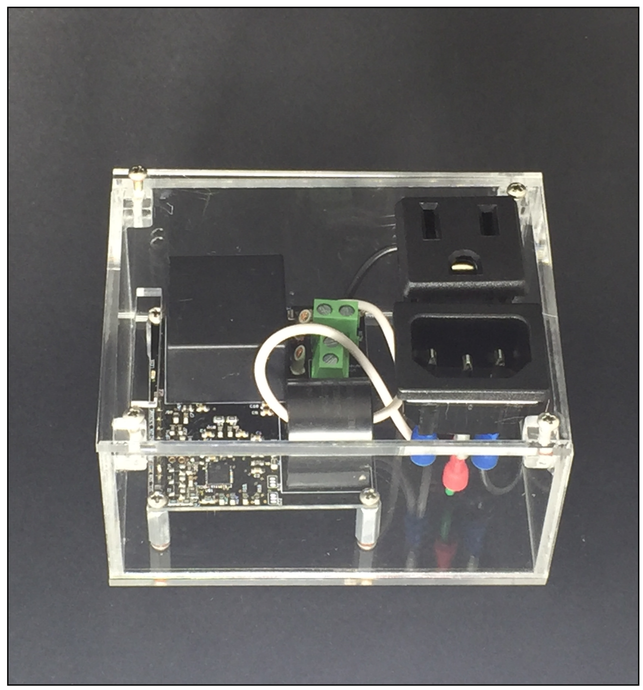

1. Introduction

Thank you for purchasing the Dr. Wattson Energy Monitoring Board! You can now easily incorporate energy monitoring into your next Arduino or Raspberry Pi project.

This manual is to help you get started with the necessary setup. In order to provide a safe platform for dealing with high voltage components while still being able to access the energy data easily, Dr. Wattson comes with an optional enclosure. This document will tell you how to wire up your Dr. Wattson, and place it in the enclosure.

1.1. Disclaimer

Dr. Wattson is designed to be safe with built-in isolation using current and voltage transformers, and also has an enclosure available to shield you from high voltages. You will, however, still need to do the wiring for your particular application. Please use common sense and caution, and if necessary, please get help from someone knowledgable and qualified!

Incorrect or improper handling could result in:

- Serious injuries or death
- Physical damage of the product
- Creating dangerous hazards

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Safety is a primary concern with high voltage circuits! Do not attempt unless you know what you are doing!

2. Introduction to Dr. Wattson

Dr. Wattson is an Energy Monitoring Building Block for your project. You can very easily incorporate it into your design and start to get quality energy data, and focus your attention on building other aspects of your project!

Here are some of the main features of Dr. Wattson

- Based on Microchip MCP39F521, which is capable of accuracy of 0.1% across a 4000:1 dynamic range
- Tolerant of 5v and 3.3v systems with bi-directional level shifting
- Arduino and Python library (for boards like Raspberry Pi and BeagleBone Black) designed for easy usage, but provides advanced capabilities like calibration as well
- I2C interface with configurable addressing - use up to 4 devices with one MCU
- Isolated design by the use of CT/VT
- Small footprint
- Ready to use (no extra parts like CT/VT, etc.)
- Quality construction with 2 oz copper and wide traces, and ENIG finish

2.1. What can you do with Dr. Wattson?

- Get basic metrics on demand - V_{RMS}, I_{RMS}, Active/Reactive/Apparent Power, Power Factor, Line Frequency - all with a simple call with the Dr. Wattson library

- Start/stop energy accumulation and set thresholds

  If you want to measure energy over time, you can let Dr. Wattson handle the hard work by turning on energy accumulation. Your micro-controller can go to sleep or do other work in the meantime. You can set a no-load threshold if you want to measure energy over a certain threshold - for example, non-standby power usage. Get the accumulated energy data with a simple call with the Dr. Wattson library.

- Register and get notifications for events of interest (e.g., Voltage Surge/Sag, Over-Current, Over-Power) and Zero-cross detection

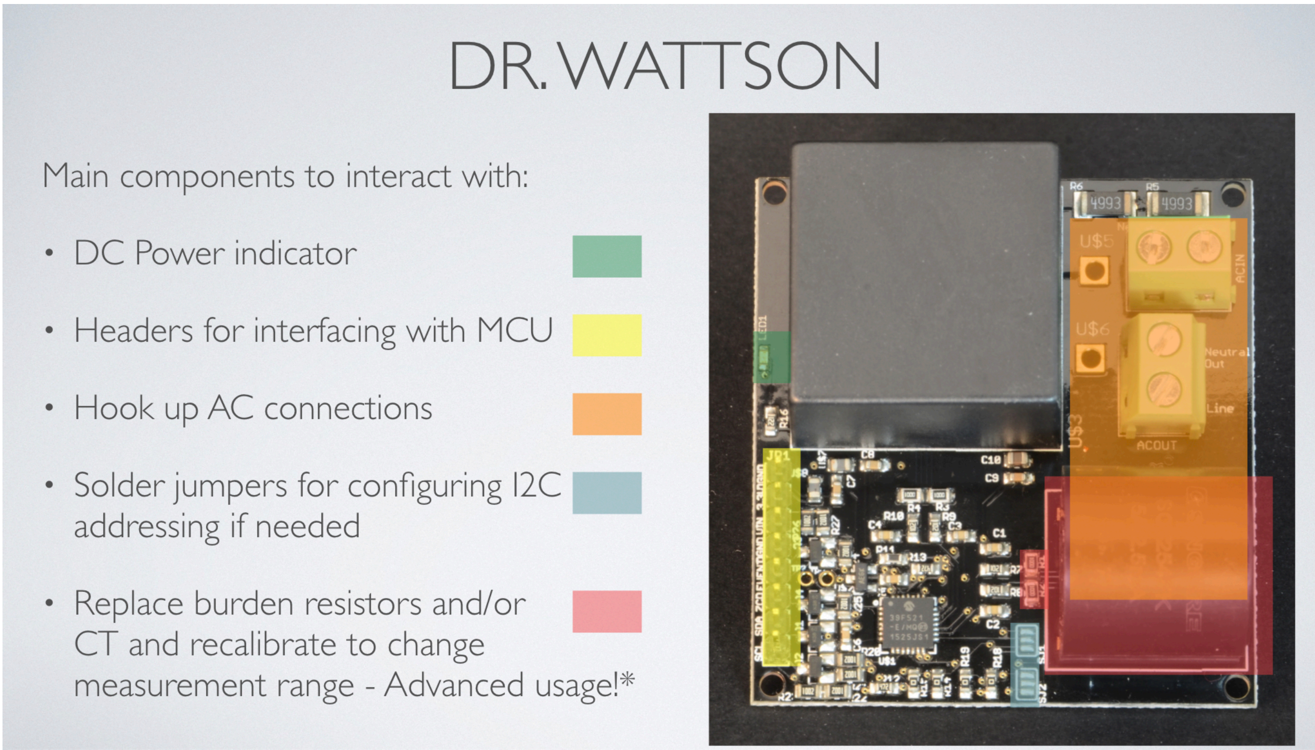
  You can set Over-Current Limit, Over-Power Limit, Voltage Surge Limit and Voltage Sag Limit, which represent the thresholds beyond which the corresponding events are triggered.

- Store and read data from EEPROM

  The MCP39F521 has 256 16-bit words of EEPROM that is organized into 32 pages for a total of 512 bytes. You can easily read and write pages of data with simple calls using the Dr. Wattson library.

2.2. Main Components of Dr. Wattson

The following represent the main components that you can interact with in Dr. Wattson:



* Beyond the scope of this document and not supported. But this product is for the Maker/Hacker, so it would be remiss to not point this out. The board changes coupled with the MCP39F521 calibration and configuration routines that are supported by the Arduino and Python libraries means you can modify it to suit your needs. You will need to get familiar with the MCP39F521 and its calibration. Please refer to Chapter 10: <u>Changing the Measurement Range</u> for more information.

3. Dr. Wattson Specifications

Dr. Wattson is based on MCP39F521, a single-phase energy monitoring chip from Microchip.that is capable of 0.1 % accuracy over a 4000:1 Dynamic range.

Dr. Wattson is itself designed to measure currents from about 1 mA to 4 A. This thus enables you to measure really small currents, which is suitable if you want to study, for example, the standby power consumption of your devices.

It is possible for you to reconfigure the board to measure a different range - for instance, you can measure from about 4 mA to 15 A (15A / 4000 = 0.00375A, or 3.75mA). The changes required to the board are discussed in Chapter 10: Changing the Measurement Range.

Dr. Wattson is made with 2 oz copper, and the traces are designed to be wide and allow for 10 amps of current @120v with a 10˚C rise, or 15 amps of current @120v with a 25˚C rise. The terminal connectors are themselves rated for 300v and 12 amps. Please note these limits when connecting your Dr. Wattson to your AC load for measurements.

There are 2 ways by which you can hook up connections, one where high current does not pass through the board directly, and the other where the high current AC does pass through the Dr. Wattson board. In the second case, please be careful of Dr. Wattson's limits as specified above. For more information, please refer to Chapter 5: Instructions for Wiring Dr. Wattson Instructions for Wiring Dr. Wattson and Chapter 6: Instructions for Alternate Wiring of Dr. Wattson.

On the DC side, Dr. Wattson is itself powered by 3.3v. It is, however, tolerant of 5v and 3.3v logic levels by the use of bi-directional level shifting. See Chapter 8: Hooking Up Dr. Wattson to your MCU - Low Voltage Wiring for more information.

4. Tools Needed

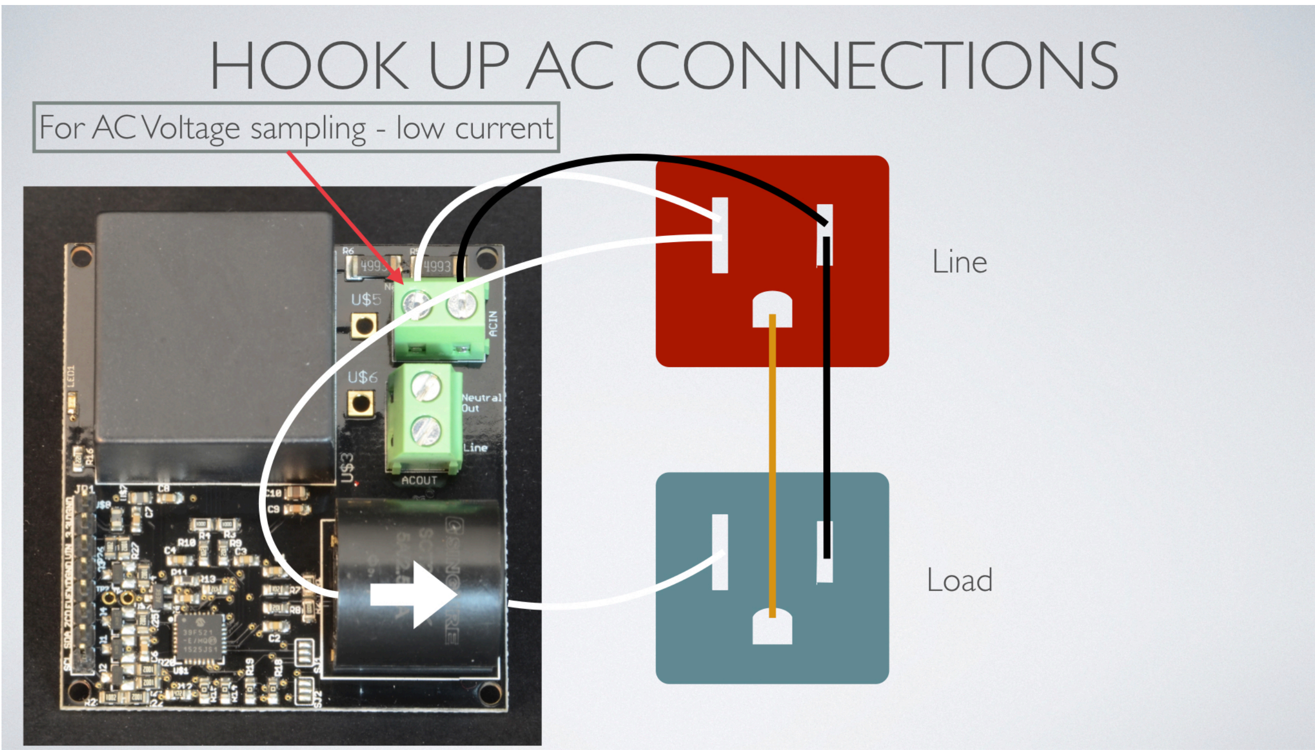
You will need the following tools to assemble Dr. Wattson in your enclosure.

1. #5 Phillips screwdriver to tighten the 2-56 screws
2. Crimper to crimp the spade connectors with your wire (such as this one https://www.homedepot.com/p/Gardner-Bender-Terminal-and-Crimping-Tool-Kit-GS-67K/202518592)
3. Wiring: 16 gauge or better recommended. Please select suitable wiring gauge for your given maximum load as per your design
4. Wire cutter/stripper to cut and strip the appropriate gauge wiring for your AC (16 gauge or better is recommended)

5. Instructions for Wiring Dr. Wattson

Dr. Wattson needs to be connected to the high voltage wiring so that it can measure the current, voltage, power etc. There are two ways by which it can be hooked up - the first way does not route high current though the board. It is the ***preferred*** method, and is described below.

Please also refer to Section 7.3 Step 3 - High Voltage Wiring for additional details of wiring in relation to the Dr. Wattson enclosure, such as the AC/IEC receptacles and spade connectors used.



5.1. Step 1a

Connect wires from Line to Terminal Connector AC IN to neutral and load. This provides connections to the Voltage Transformer and draws a small amount of current for the purpose of AC Voltage sampling.

5.2. Step 2a

Thread the Neutral wire from Line through the Current Transformer on Dr. Wattson (note orientation of wire), and connect to Neutral on your Load side. This enables the AC Current sampling through the Current Transformer.

5.3. Step 3a

Connect "hot" wire (load) from Line to Load.

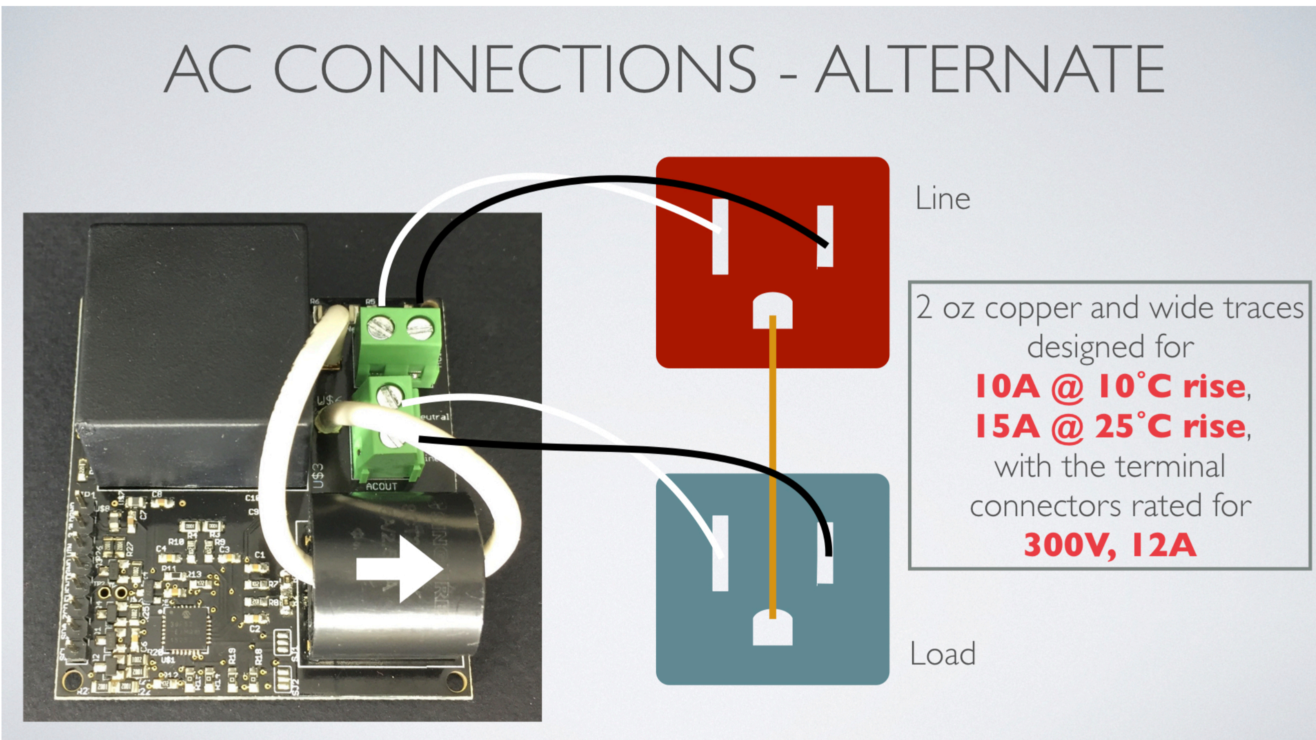
5.4. Step 4b

Connect Earth wire from Line to Load as appropriate.

6. Instructions for Alternate Wiring of Dr. Wattson

There is a second way to do the high voltage wiring. In this configuration, thread a suitable gauge wire through the Current Transformer and solder it into the corresponding connectors on the PCB. The high voltage wiring is then a little simplified - you can connect from Line to AC IN and from AC OUT to Load as shown in the figure below.

Please also refer to Section 7.3 Step 3 - High Voltage Wiring for additional details of wiring in relation to the Dr. Wattson enclosure, such as the AC/IEC receptacles and spade connectors used.



However, in this configuration, the high voltage current now flows through the Dr. Wattson board. Dr. Wattson is made with 2 oz copper, and the traces are designed to be wide and allow for 10 amps of current @120v with a 10˚C rise, or 15 amps of current @120v with a 25˚C rise. The terminal connectors are themselves rated for 300v and 12 amps. Please note these limits when connecting the Load. Also note that Dr. Wattson itself is designed to measure from about 1 mA to 4 A, so anything in excess of that cannot be measured.

It is possible for you to reconfigure the board to measure a different range - for instance, you can measure from about 4 mA to 15 A (15A /4000 (the dynamic range of MCP39F521) =

0.00375A, or 3.75mA). The changes required to the board are discussed in Chapter 10: Changing the Measurement Range.

6.1. Step 1b

Thread a suitable Neutral wire (with the appropriate gauge to handle the current for your design) through the Current Transformer of Dr. Wattson, and solder it to the through-hole connectors on the board as shown above.

6.2. Step 2b

Connect suitable gauge wires from Line to Terminal Connector AC IN, to Neutral and Load. This provides connections to the Voltage Transformer and draws a small amount of current for the purpose of AC Voltage sampling. This also provides Neutral and Load connections to the AC OUT Terminal connector. In this case, note that the AC load current is passing through the PCB, so please be mindful of its limits.

6.3. Step 3b

Connect suitable wires from the Terminal Connector AC OUT to your Load. This finishes the circuit. In this case, note that the AC load current is passing through the PCB, so please be mindful of its limits.

6.4. Step 4b

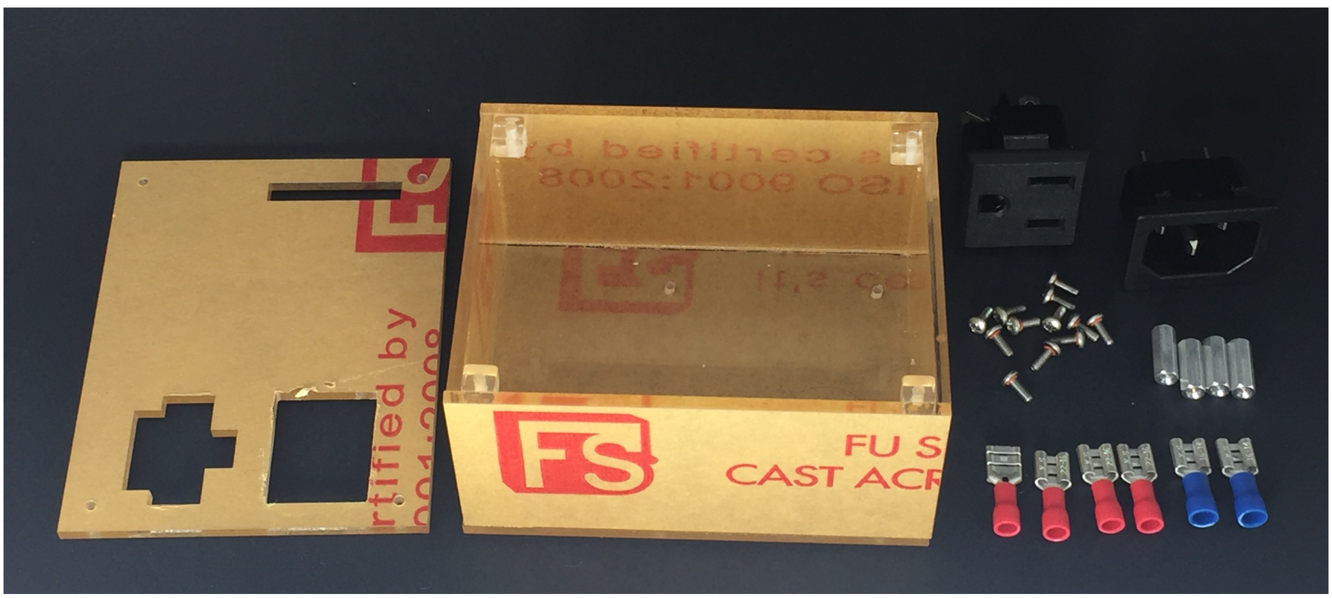
Connect Earth wire from Line to Load as appropriate.

7. Instructions for Enclosure

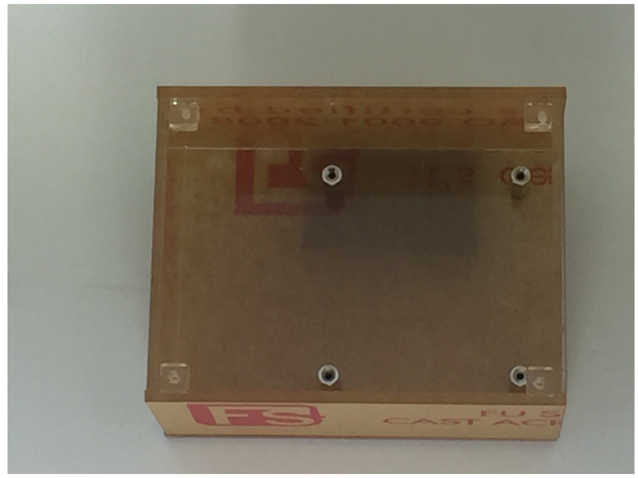
Contents:

- Acrylic enclosure
- Acrylic enclosure cover
- 2-56 standoffs (4) to mount Dr. Wattson
- 2-56 screws (8) to mount standoffs and Dr. Wattson
- 2-56 or 4-40 screws (4) to close enclosure cover
- 4 red spade connectors (for single wire)
- 2 blue spade connectors (for two wires)
- Snap-in IEC receptacle
- Snap-in AC receptacle

Note that the acrylic enclosure and enclosure cover come with the protective layer that can be peeled off.

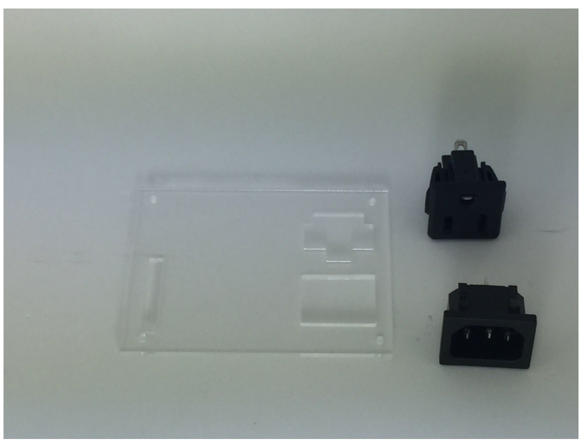
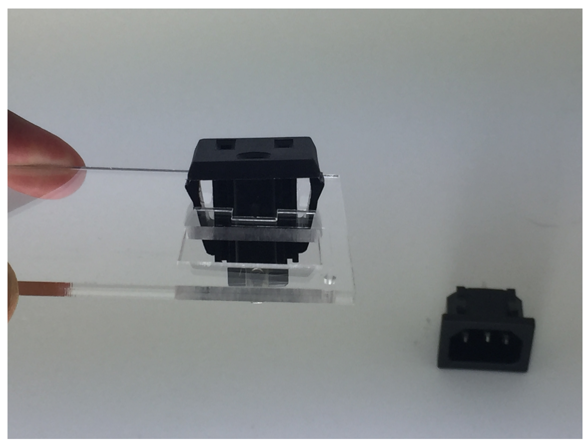


7.1. Step 1 - Install standoffs

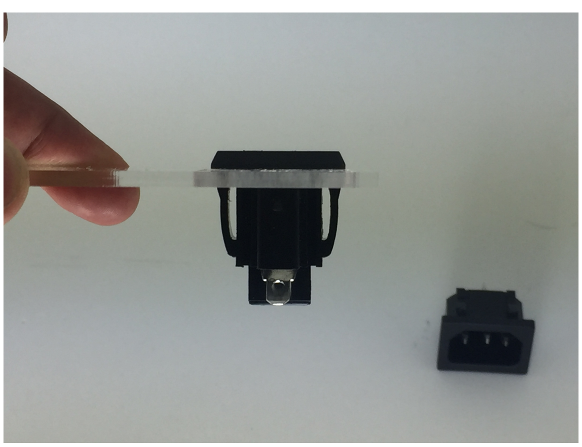



7.2. Step 2 - Install receptacles to cover

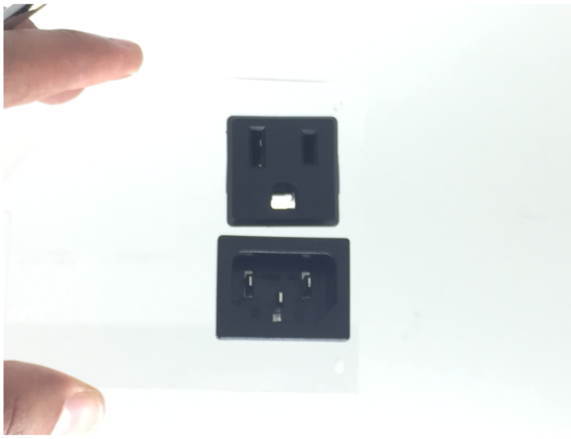
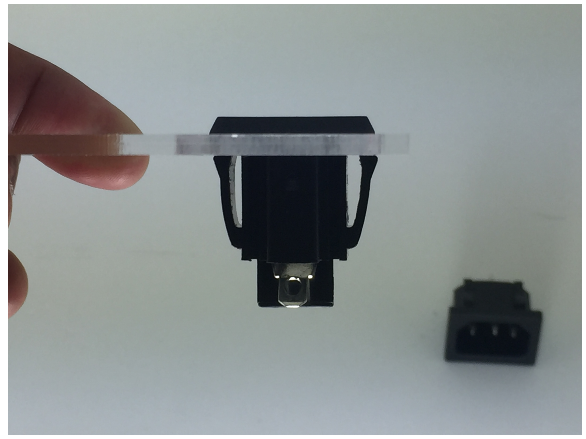
In this step, take care that you don't exert too much pressure on the acrylic cover, as it can snap with excessive force.

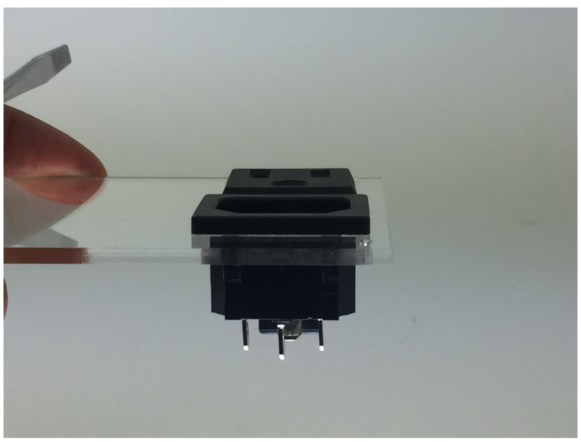



Install the AC receptacle. Use a screw driver to pop out the tabs on the AC receptacle so it won't come loose from the cover. Please be careful not to pop out the tabs too much!



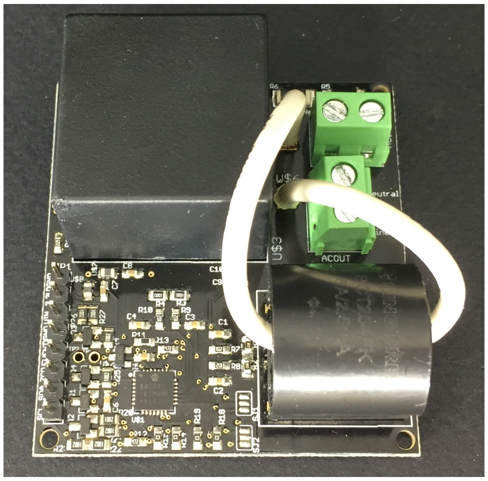

Push in the IEC receptacle. Note the correct orientation. Ensure that it is a snug fit and does not come loose from the acrylic cover when you try to push it out. This will mean that its plastic tabs have locked into place.




7.3. Step 3 - High Voltage Wiring

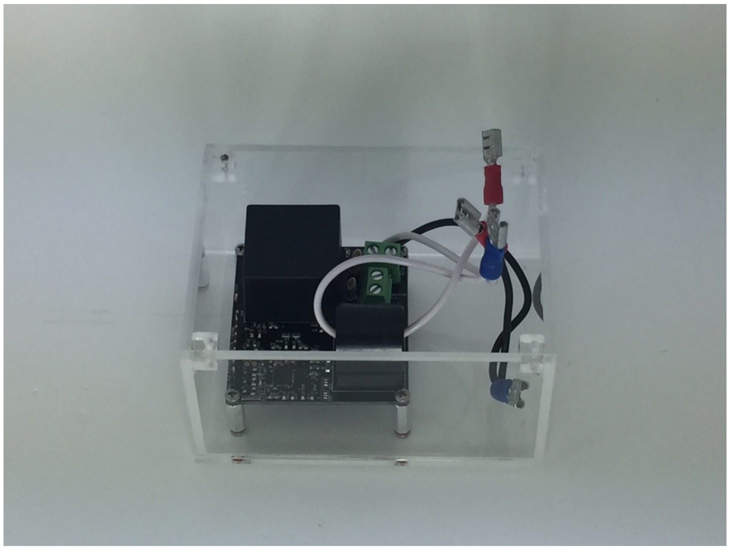
Determine if you are going to do “regular” wiring or “alternate” wiring. If you are doing “alternate” wiring, you will first need to thread a suitable gauge wire through the Current Transformer core, and solder it into the corresponding pads on the PCB. Please note the correct orientation.

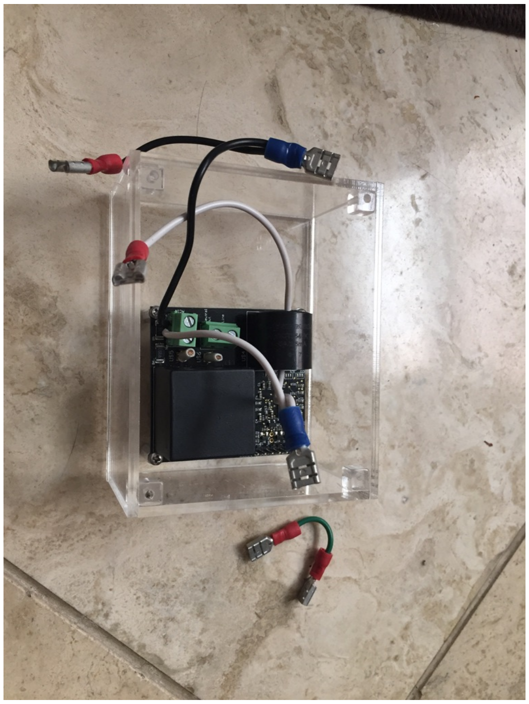


If you are doing “regular” wiring, thread a suitable gauge Neutral wire through the Current Transformer’s core (note the correct orientation).

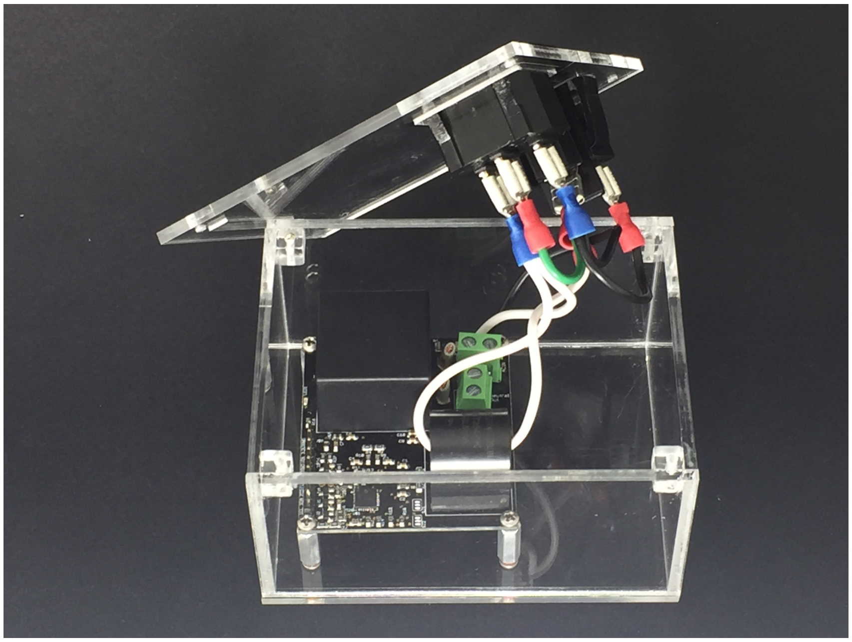
Crimp suitable gauge wires to the spade connectors. If you are doing “regular” wiring, there will be 2 wires coming from the spade connectors connecting to the Neutral and Hot from the Line (IEC receptacle) - use the blue spade connectors, which are big enough to accommodate two wires.

The other end of the Neutral and Hot wires that connect to the AC receptacle will be crimped to two red spade connectors. The result will look something like this:



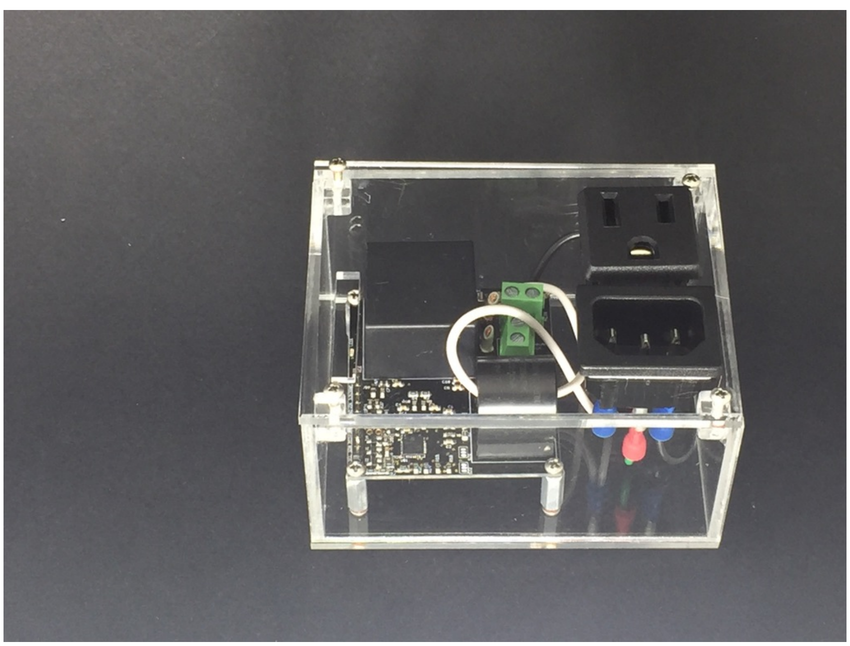


Additionally, you will also crimp two red spade connectors to an Earth wire that you will connect between the Earth connectors of the AC receptacle and the IEC receptacle. Screw the ends of the extra wires from the IEC receptacle into the AC IN terminal connectors on Dr .Wattson. The result will look like this (with Dr. Wattson mounted on the standoffs with the 2-56 screws):



7.4. Step 4 - Close the Enclosure

Use the provided 2-56 (or 4-40) screws to screw the Enclosure Cover into the Enclosure. Your completed Dr. Wattson will look like this!



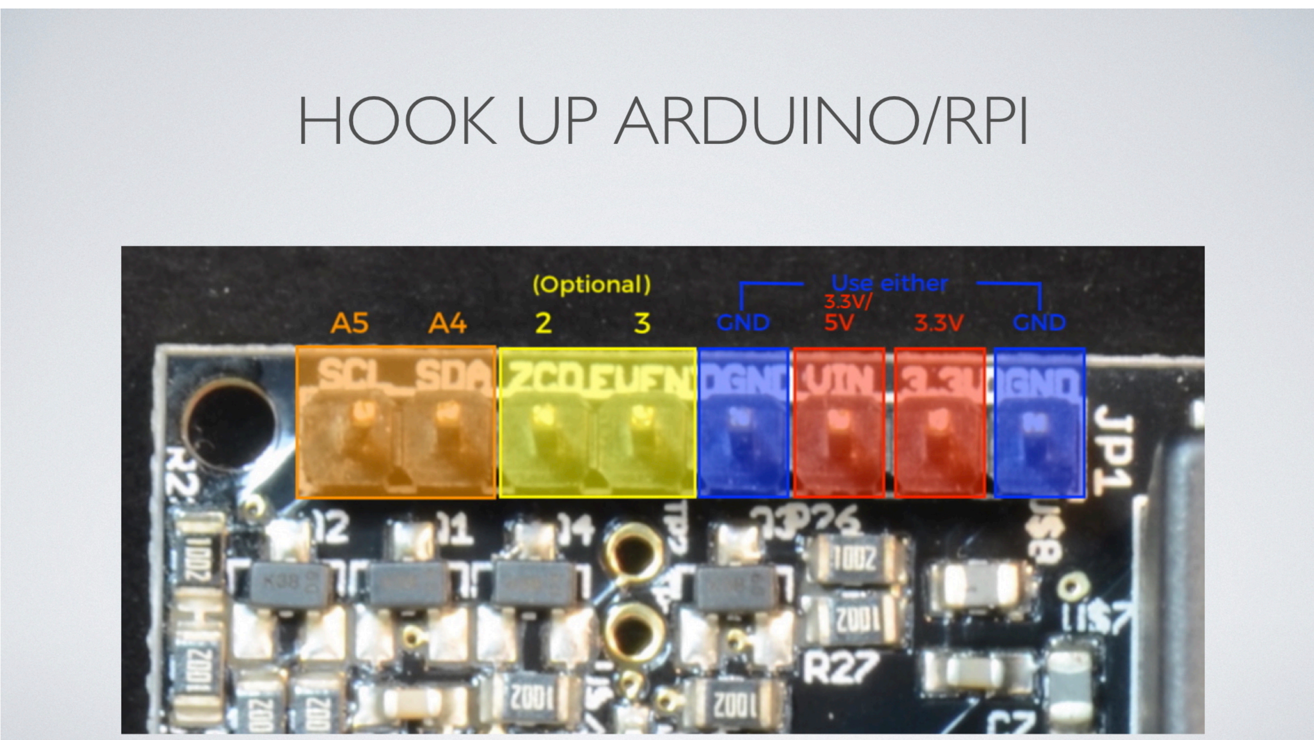
You are now ready to hook it up to your micro-controller!!

8. Hooking Up Dr. Wattson to your MCU - Low Voltage Wiring

Communication with Dr. Wattson happens over I2C. Connect the first two pins to SCL and SDA pins on your Arduino or Raspberry Pi (refer to instructions of your micro-controller for the right pins to connect to)

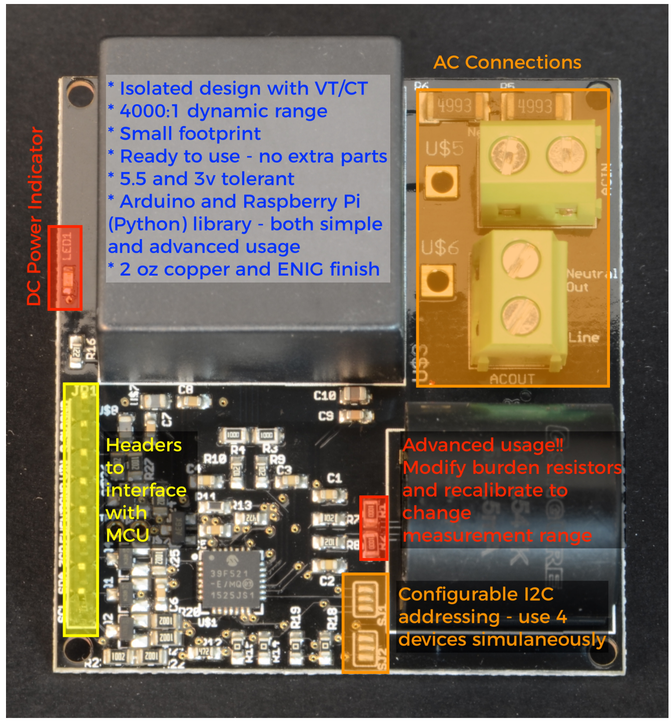
The next two pins are GPIO outputs to indicate ZCD (Zero-Cross Detection) and when EVENTs of interest (such as Voltage Sag, Voltage Surge, Over-Current and Over-Power) occur. These two pins would typically be connected to any externally interruptible pin on your micro-controller, such as pins 2&3 on your Arduino Uno, and allow it to receive notifications via Interrupt Service Routines. If you don't plan on using EVENT or ZCD notifications, you can leave these unconnected.

The next 4 pins pertain to the DC power supply for the functioning of Dr. Wattson. Pins 5 and 8 are ground pins (only one needs to be connected). Pin 7 is connected to 3.3v supply voltage (Dr. Wattson runs on 3.3v). Pin 6 (VIN) is for the Reference voltage of the logic pins of the micro-controller (connected to 5v on the Arduino Uno or 3.3v on the Raspberry Pi or Arduino Pro Mini 3.3v). This enables the appropriate bi-directional level shifting, allowing Dr. Wattson to be used with a multitude of micro-controllers without worrying about voltage levels or level shifting.



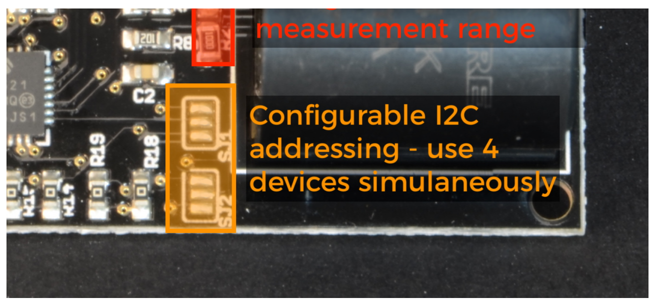
9. Configuring I2C address

MCP39F521 supports configurable I2C addressing through two pins A0 and A1. These pins can either be driven high or low, based on which there are 4 possible combinations, resulting in 4 possible I2C addresses.



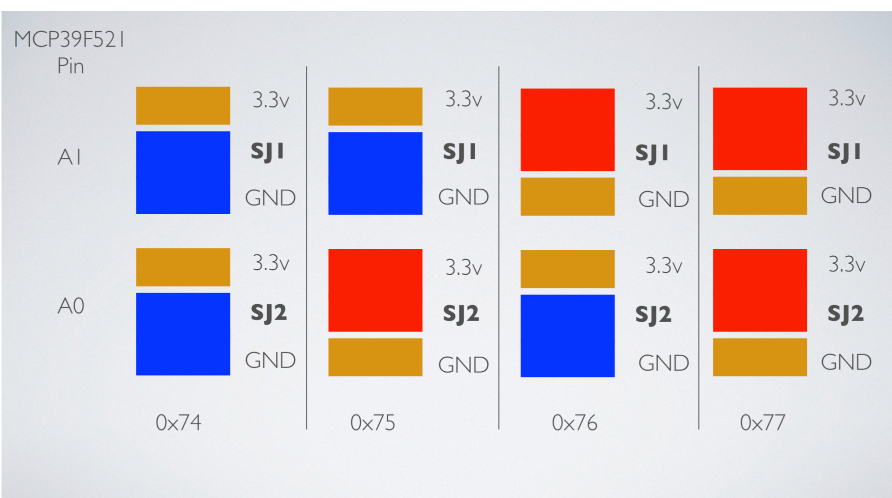
Dr. Wattson exposes these pins and the ability to drive them high or low via the use of solder jumpers SJ2 and SJ1 on the board. Based on whether they are pulled high or low, the corresponding I2C address is as follows:

I2C address	SJ1	SJ2
0x74	LOW	LOW
0x75	LOW	HIGH
0x76	HIGH	LOW
0x77	HIGH	HIGH



By choosing 4 different addresses, it is possible for you to control 4 different Dr. Wattson boards connected to 4 different loads, all from a single micro-controller by connecting to the same I2C bus.

Choose your solder jumper configuration for the address of your choice, as shown below.



The boards come with the solder jumpers not configured, so you will have to choose one of the configuration choices to set the addressing appropriately.

10. Changing the Measurement Range

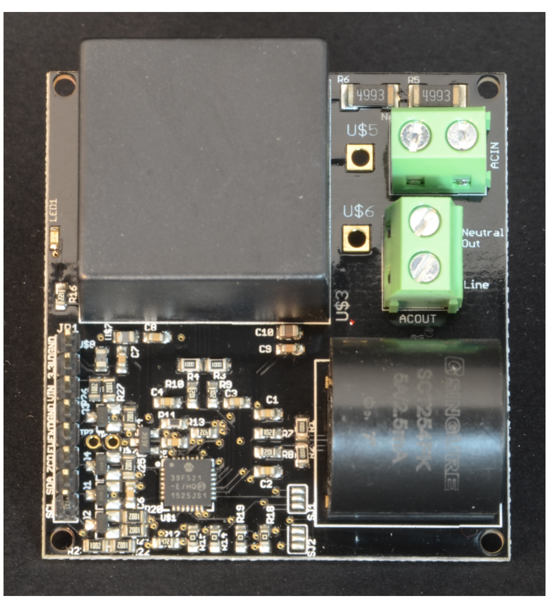
Dr. Wattson is based on MCP39F521, an energy monitoring chip from Microchip. MCP39F521 is a single-phase energy monitoring chip capable of 0.1 % accuracy over a 4000:1 Dynamic range.

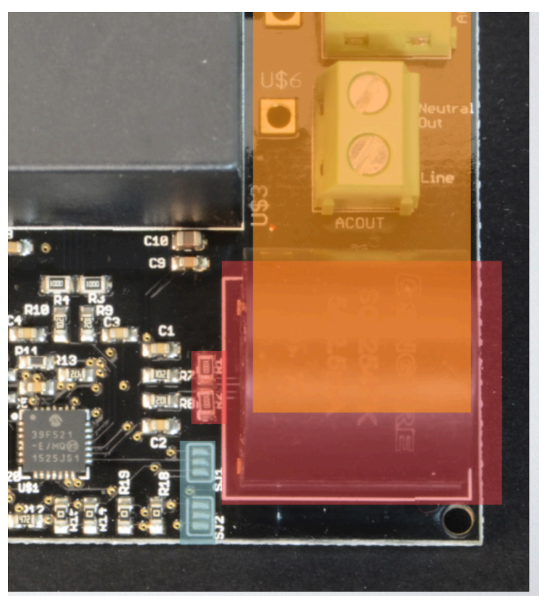
Dr. Wattson is itself designed to measure currents from about 1 mA to 4 A. This thus enables you to measure really small currents, which is suitable if you want to study, for example, the standby power consumption of your devices.

It is possible for you to reconfigure the board to measure a different range - the MCP39F521 energy monitoring chip has a 4000:1 Dyanamic Ratio - so you can, for instance, measure from about 4 mA to 15 A (15A / 4000 = 0.00375A, or 3.75mA).

The exact details are advanced usage and are beyond the scope of this document and not supported. But this product is for the Maker/Hacker, so it would be remiss to not point this out.

In order to do this, you will need to replace the burden resistors (R1 & R2 near the CT) on Dr. Wattson to the appropriate values for your range of measurement, and potentially change the CT as well to support your current range, and also recalibrate the board*. The CT combined with the burden resistors provides the differential current input channels for the Delta Sigma ADC Current Channel Input Pins I+ and I- of the MCP39F521, whose differential voltage range is ±600 mVPEAK/GAIN with VREF = 1.2V. The Gain values can be seen and set with the System Config Registers. The burden resistors are to be chosen for the CT in question to ensure that the I+ and I- voltage values are within this range.





The physical board changes coupled with the MCP39F521 calibration and configuration routines that are supported by the Arduino and Python libraries means you can modify it to suit your needs. Recalibration of the board will require you to get familiar with the MCP39F521 and its calibration methodology, as well as utilize stable reference voltage and current loads for the calibration. You can refer to the MCP39F521 Datasheet for more information.

As of July 1st, 2019, we have released a mod for the board that will support measurements up to 15A. We have done the hard work of the calibration and burden resistor calculation. Simply replace the burden resistors to 20 ohms each (as shown above), and call the resetCalibration routine with CALIBRATION_CONFIG_15A as the argument.

```
UpbeatLabs_MCP39F521 wattson = UpbeatLabs_MCP39F521();
wattson.resetCalibration(CALIBRATION_CONFIG_15A);
```

This will apply the appropriate calibration constants (we have done the hard work for you) to change the measurement range (in combination with the burden resistor replacement) to 15A.

Periodically, we may release other calibration constants, burden resistor values and or CT information for other ranges, which would enable you to easily reconfigure Dr. Wattson for other ranges by replacing the burden resistor to the appropriate values as well as resetting the calibration constants on the boards to the supplied values (by means of calibration routines in the Dr. Wattson library). We may also release other versions of the Dr. Wattson board that supports these ranges so you can easily use those without much further ado. There is no estimate on when these may occur however. Please subscribe to our newsletter or follow us on social media to stay abreast of developments.

11. Programming Your Arduino, Raspberry Pi or other Maker-friendly MCU

Please refer to the GitHub repository https://github.com/upbeatlabs/drwattson for access to the Dr. Wattson libraries, as well as instructions for setting up and example code to explore various features to get started with using the library to access data from your Dr. Wattson board.

There is currently an Arduino library and a Python library that can be run on a Raspberry Pi or a BeagleBone Black or any other linux board. The GitHub link will be the up-to-date repository for the library and information, including this document. Any updated versions of this document will be present in the GitHub link.

The Samples presented in the GitHub link explore different features and areas of functionality of Dr. Wattson, as well as suggested integrations with other hardware and software services.

- Getting basic energy data (V_{RMS}, I_{RMS}, Active/Reactive/Apparent Power, Power Factor, Line Frequency)
- Turning on/off energy accumulation and getting energy accumulation data (Active Energy Import, Active Energy Export, Reactive Energy Import, Reactive Energy Export)
- Setting Event Thresholds and turning on Event notifications
- Zero-Cross Detection notifications
- Reading and writing data from/to EEPROM
- Advanced applications like writing energy data to SD card in CSV format for later analysis/plotting; using AWS IoT to publish data to the cloud and to client devices;

MakerFaire example that collected and analyzed energy consumption by time of day incorporating an RTC; and so on.

12. Final Thoughts

Dr. Wattson - your energy monitoring building block for Arduino, Raspberry Pi and other Maker-friendly MCUs!

We would love to hear about how you are using Dr. Wattson, as well as stories and links to your own projects! If you have any questions, comments or suggestions, please get in touch with us! If there is anything we can do to improve Dr. Wattson, its libraries, or this guide, please let us know!

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Get the libraries and code samples:

https://github.com/upbeatlabs/drwattson

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