

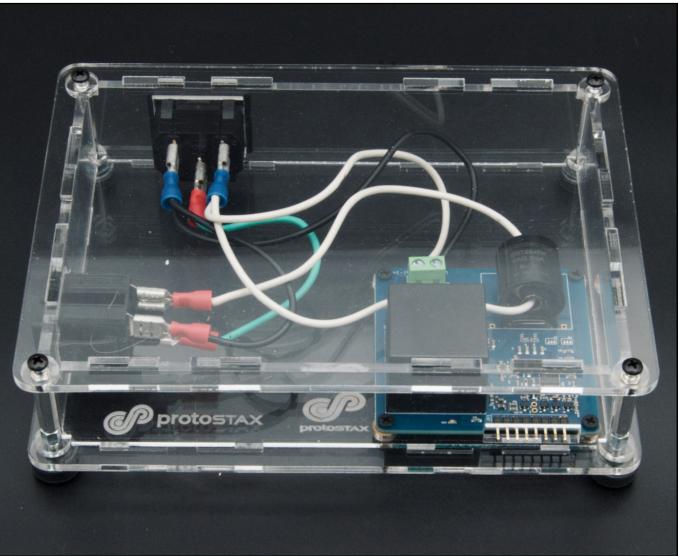
User Manual

Dr. Wattson Energy Monitoring Board V2

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1.

Introduction

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

This manual is to help you get started with the necessary setup. This document will tell you how to wire up your Dr. Wattson. 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 ([ProtoStax Enclosure for Dr. Wattson Energy Monitor](#))

1.1.

Disclaimer



Dr. Wattson is designed to be safe with built-in isolation using current and voltage transformers, and also has an optional 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 knowledgeable and qualified!

Incorrect or improper handling could result in:

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

Upbeat Labs (and Sridhar Rajagopal) cannot be held liable or responsible, and will not accept any type of liability in any event, in case of injury or even death by building and/or using or misusing this information. By accessing, reading, and/or printing the instructions presented here, you agree to be solely responsible as stated in the above disclaimer and exempt Upbeat Labs and/or Sridhar Rajagopal from any criminal and/or liability suit.

Safety is a primary concern with high voltage circuits! Do not attempt unless you know what you are doing and take the necessary precautions!

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 ENIG finish (lead-free) and lead-free solder

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:

DR. WATTSON

Main components to interact with:

- DC Power indicator
- Headers for interfacing with MCU
- Hook up AC connections
- Solder jumpers for configuring I2C addressing if needed
- Replace burden resistors and/or CT and recalibrate to change measurement range - Advanced usage!*

* *Beyond the scope of this document and is 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: [Changing the Measurement Range](#) 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 4 mA to 15 A.

It is possible for you to reconfigure the board to measure a different range - for instance, you can measure from about 1 mA to 4 A ($4A / 4000 = 0.001A$, or 1mA). This enables you to measure really small currents, which is suitable if you want to study, for example, the standby power consumption of your devices. The changes required to the board are discussed in Chapter 10: [Changing the Measurement Range](#).

The terminal connectors on the board are rated for 300v and 12 amps. They are however used to provide voltage measurement to Dr. Wattson and only draw a negligible amount of current (limited via 2 499 kΩ resistors in series) of about 0.12 mA @ 120V.

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.

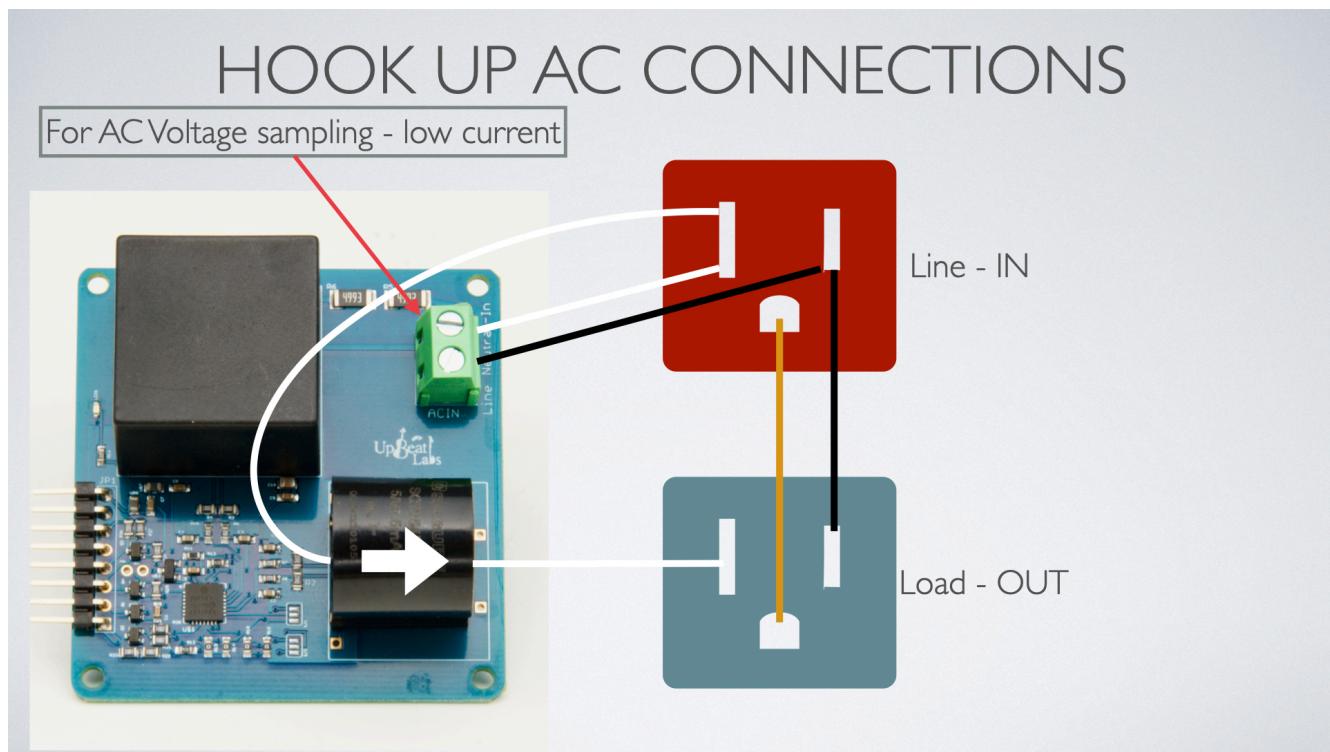
Tools Needed

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

1. #1 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 AWG or better recommended. Please select suitable wiring gauge for your application given the maximum load as per your design
4. Wire cutter/stripper to cut and strip the appropriate gauge wiring (the crimping tool above also has wire strippers)

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.



5.1.

Step 1

Connect wires from Line to Terminal Connector AC IN to neutral and load of your input. This provides connections to the Voltage Transformer and draws a small amount of current for the purpose of AC Voltage sampling (limited via 2 499 kΩ resistors in series = about 0.12 mA @ 120V)

5.2.

Step 2

Thread the Neutral wire from Line through the Current Transformer on Dr. Wattson (note the correct orientation of the wire), and connect to Neutral on your Load side. This enables the AC Current sampling through the Current Transformer. The correct orientation is essential for correct Energy Import/Export calculations (they will be reversed otherwise).

5.3.**Step 3**

Connect “hot” wire (load) from Line to Load.

5.4.**Step 4**

Connect Earth wire from Line to Load as appropriate.

It is possible for you to reconfigure the board to measure a different range - for instance, you can measure from about 1 mA to 4 A ($4A / 4000$ (the dynamic range of MCP39F521) = 0.001A, or 1mA). The changes required to the board are discussed in Chapter 10: [Changing the Measurement Range](#).

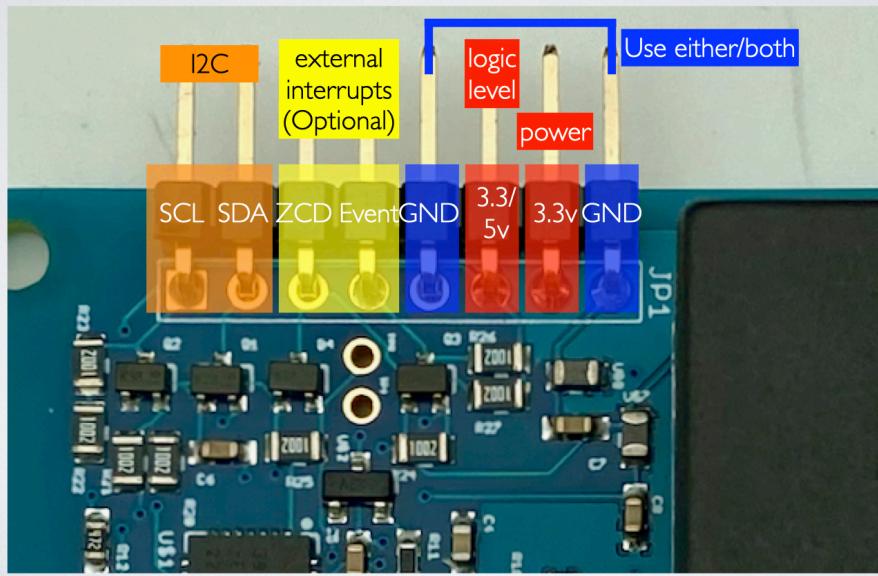
6. Hooking Up Dr. Wattson to your MCU - Low Voltage Wiring

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). Pin 6 pulls up 10kΩ resistors to VIN on the MCU side of the level shifters (see [schematic](#)). 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.

HOOK UP ARDUINO/RPI



7.

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:

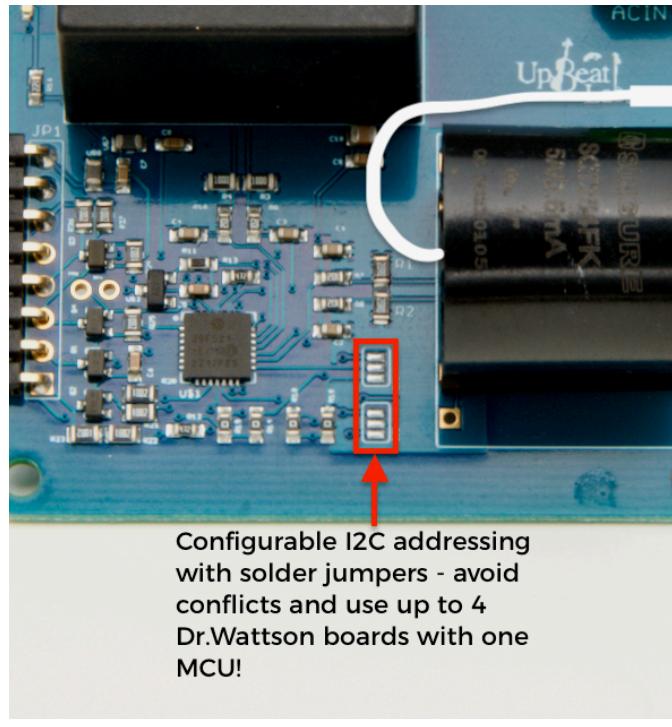
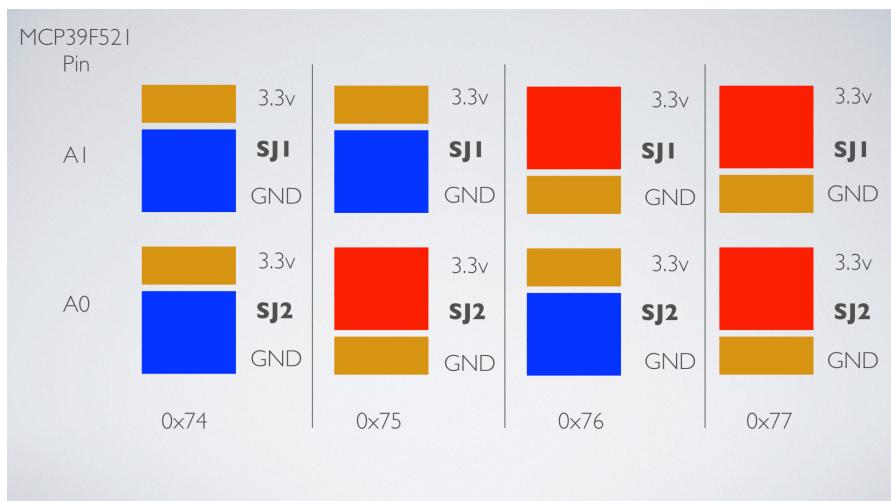
I2C address	SJ1	SJ2
0x74	LOW	LOW
0x75	LOW	HIGH
0x76	HIGH	LOW
0x77	HIGH	HIGH

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. This also enables you to choose an appropriate I2C address to avoid conflicts with other I2C devices your MCU may be connecting to.



8. Changing the Measurement Range

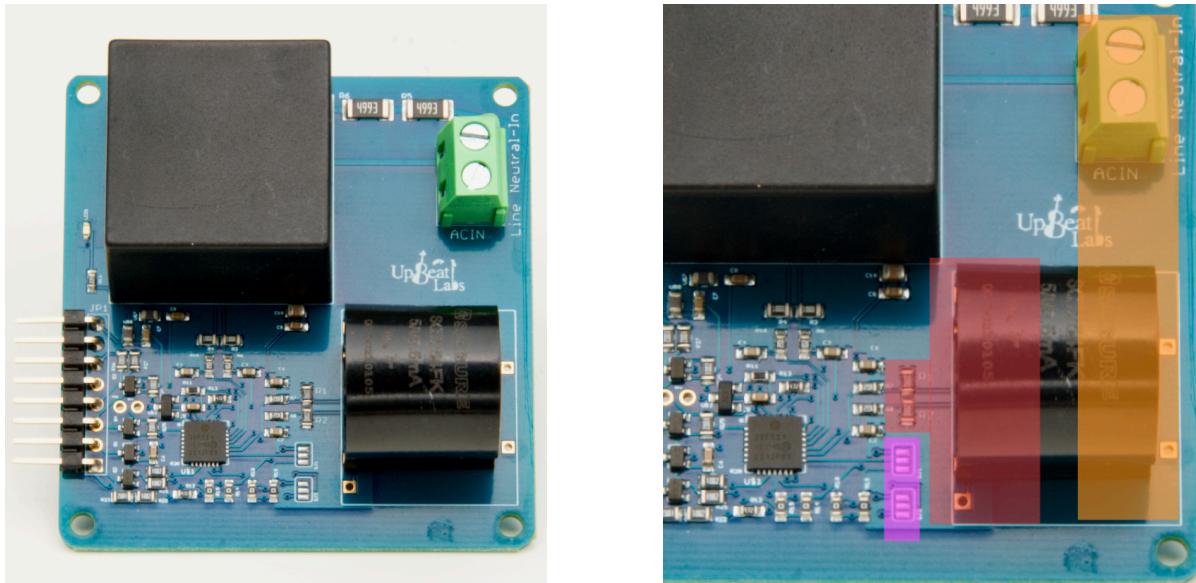
Dr. Wattson is based on MCP39F521, an energy monitoring chip from Microchip. MCP39F521 is a single-phase energy monitoring chip capable of 0.1 % accuracy over a 4000:1 Dynamic range.

Dr. Wattson is itself designed to measure currents from about 4 mA to 15 A.

It is possible for you to reconfigure the board to measure a different range - the MCP39F521 energy monitoring chip has a 4000:1 Dynamic Ratio - so you can, for instance, measure from about 1 mA to 4 A ($4A / 4000 = 0.001A$, or 1mA). 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.

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. Please refer to the [Schematic](#).



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.

Our V1 Board was first released with a measurement range of 1mA-4A. In July 2019, we released a mod for the board that supported measurements up to 15A. We did the hard work of the calibration and burden resistor calculation. You simply had to 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 step applied the appropriate calibration constants (we had done the hard work for you) to change the measurement range (in combination with the burden resistor replacement) to 15A. The current V2 board already comes configured and calibrated to measure up to 15A (using the default argument of `CALIBRATION_CONFIG_15A_V2`).

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.

9. 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.

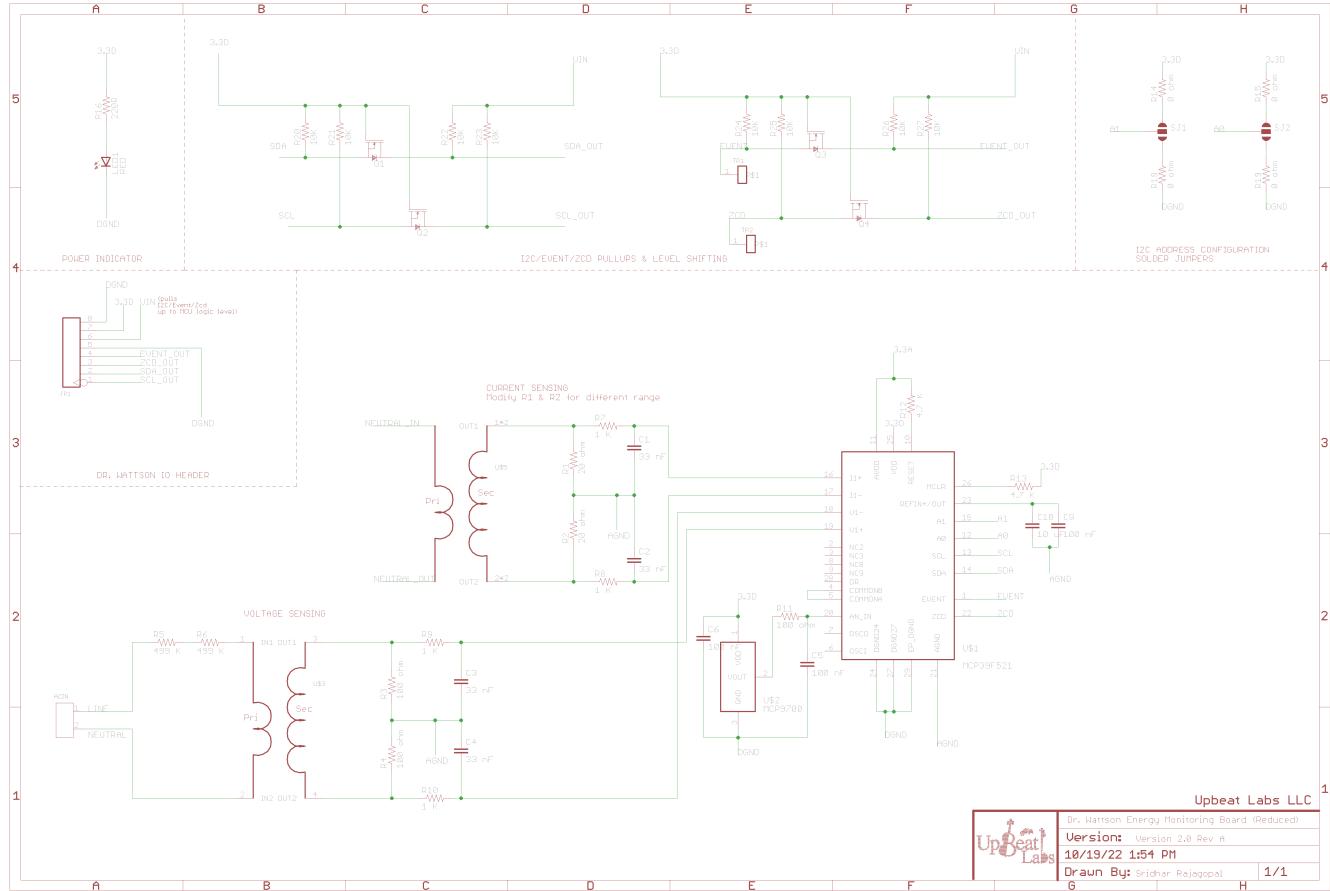
There is currently an Arduino library and a Python library that can be run on a Raspberry Pi or a BeagleBone Black or any other linux board. The GitHub link will be the up-to-date repository for the library and information, including this document. Any updated versions of this document will be present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

10.

Schematic



Upbeat Labs LLC	
Dr. Wattson Energy Monitoring Board (Reduced)	
Version:	Version 2.0 Rev A
Date:	10/19/22 1:54 PM
Drawn By:	Sridhar Rajagopal
1/1	

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

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, the enclosure or the guides / user manuals, please let us know!

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TikTok - [@protostax](#)

Email - support@upbeatlabs.com, support@protostax.com

Please use the following hashtags to tag posts - #drwattson #protostax

Get the libraries and code samples:

Dr. Wattson - <https://github.com/upbeatlabs>

ProtoStax - <https://github.com/protostax>

Get Dr. Wattson!

<https://www.protostax.com/products/dr-wattson-energy-monitoring-board-v2>

Get ProtoStax Enclosure for Dr. Wattson Energy Monitor!

<https://www.protostax.com/products/protostax-enclosure-for-dr-wattson-energy-monitor>

12.

Appendix: References

12.1.

Datasheets

[MCP39F521 Datasheet](#)

12.2.

Documents

Instruction Manual for ProtoStax Enclosure for Dr. Wattson Energy Monitoring Board V2 -
<https://github.com/upbeatlabs/drwattson/blob/master/DrWattsonProtoStaxEnclosure.pdf>