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Electrical Engineering Capstone Design Project
Power Quality Logger
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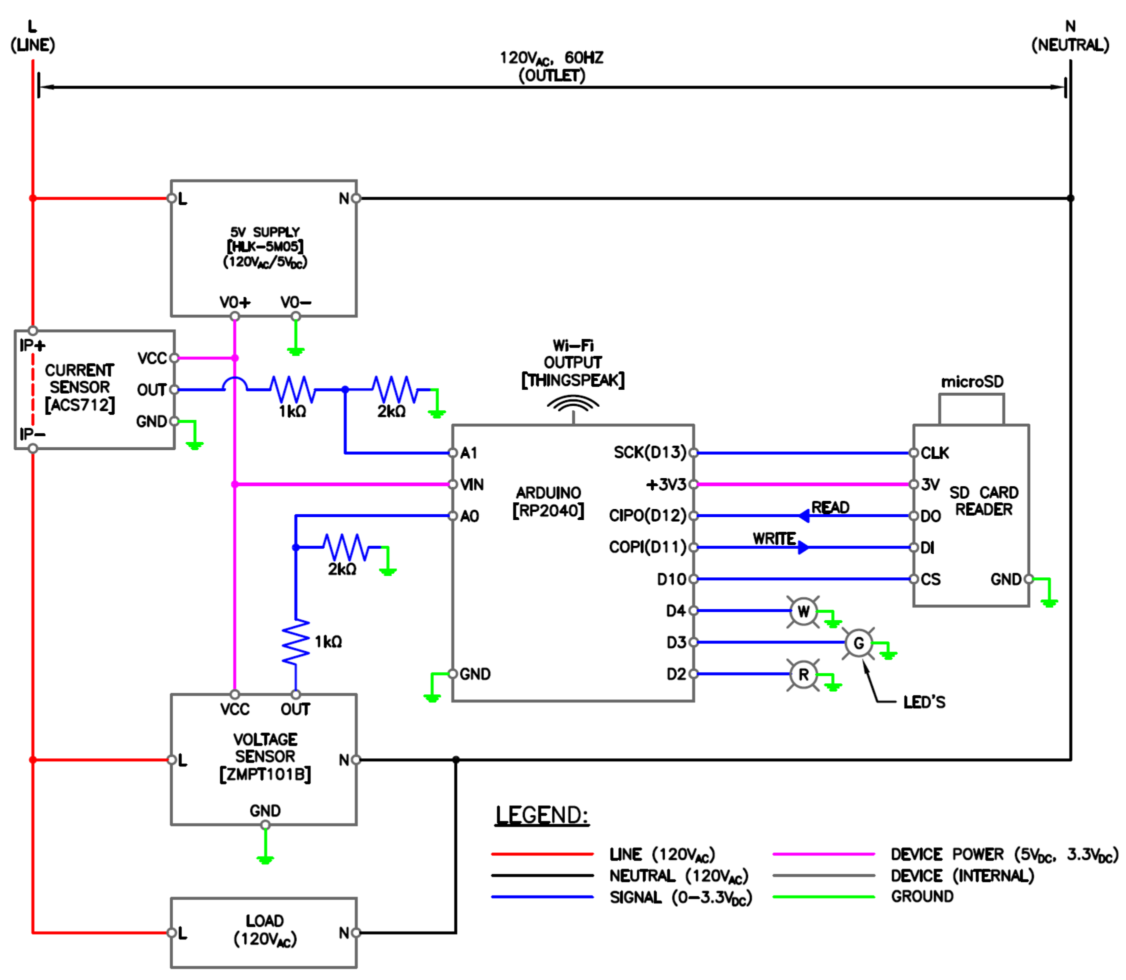
Problem Statement

In times of rising prices, utility expenses continue to reduce the bottom line of homeowners across the country. Additionally, we continue to plug more and more devices into our home's electrical systems, increasing our own power consumption. Team Racer's has developed a power monitoring device for plug-in household items. Our Power Quality Logger will allow any user to identify larger loads throughout the home and devices that are in need of repair or replacement. The device has been designed to upload and store data to the cloud. Data that can be instantly and easily accessed by the intended consumer.

Circuit Schematic Concept



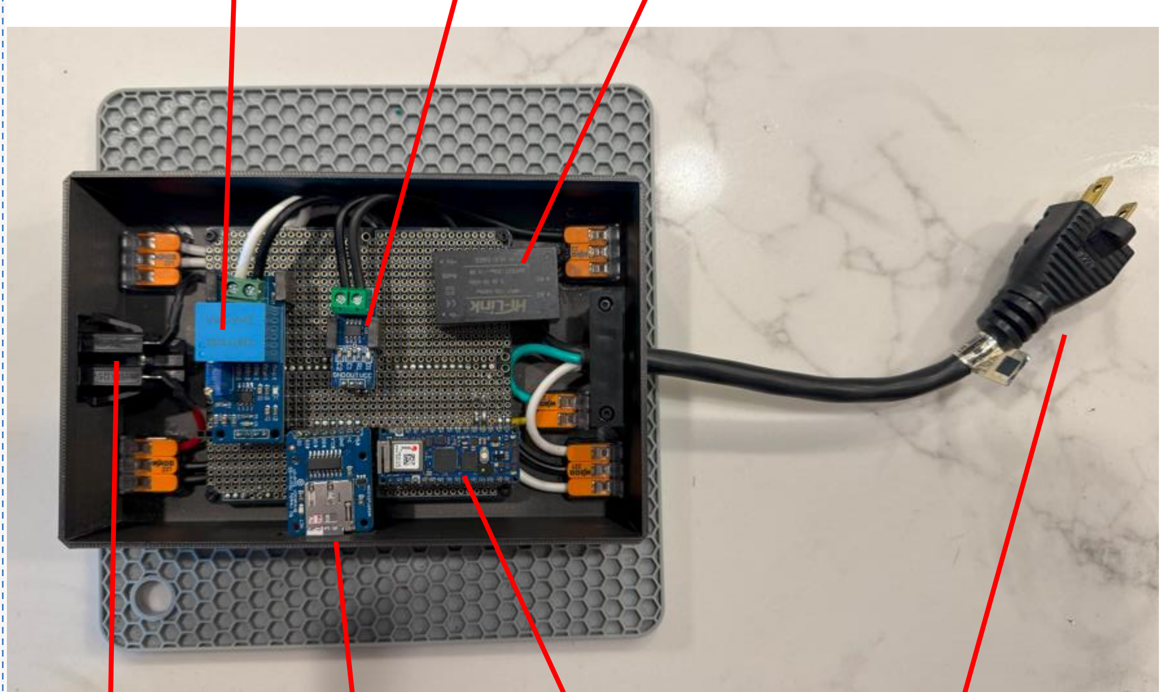
The circuit schematic shown above contains the overall design of the device. This shows how all the sensors are connected to the Arduino RP2040, along with the power and ground system. This diagram was referenced when building the final product.

Preliminary System Design

ZMPT101B Voltage Sensor

5v DC Step Down Power Supply

ACS712 Current Sensor

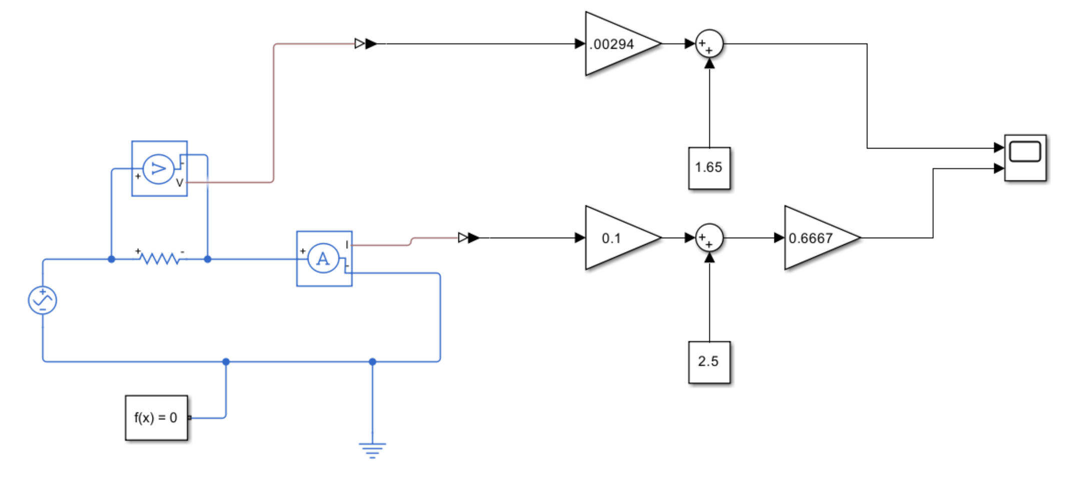


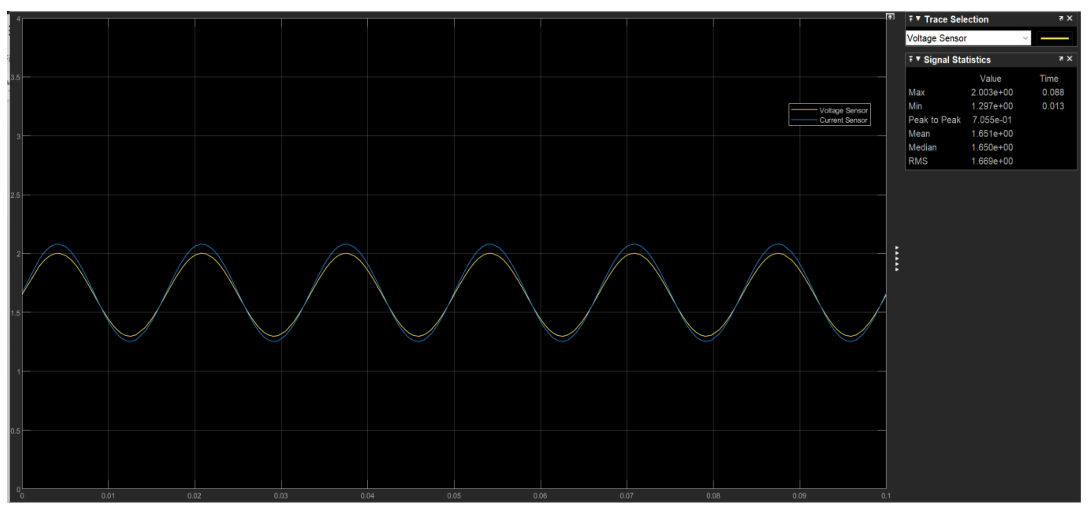
Micro USB Breakout Board

AC Power Source

120v Load Receptacle

Arduino Nano RP2040





The Simulink/Simscape schematic and plot output above shows how the device theoretically operates. A current and voltage sensor is implemented in the circuit of an AC power supply and load. The plot shown is with a 120V supply and 5.7A load.

System Components

ACS712 Current Sensor	Hall Sensor device that take incoming current and outputs 0-3.3V
ZMPT101B Voltage Sensor	Voltage sensor that takes incoming voltage and outputs 0-3.3V
5v DC Step Down Power Supply	Takes incoming 120VAC and converts it to a consistent and stable 5VDC supply
AC Power Source	Incoming 120VAC Male receptacle
Arduino Nano RP2040	Microcontroller that processes all incoming signals, reports to cloud service, and writes to SD card
Micro SD Breakout Board	External SD card module that connects to Arduino
120VAC Load receptacle	Connection point for load. Uses a standard 120VAC US female receptacle

Concept and Theory

Voltage and current sensors within the PQL allow the device to safely monitor residential electrical loads. After converting the signals into low-voltage analog signals, and using the Arduino's ADC and processing power, the device can compute important power quality parameters.

Sensing

Voltage Sensing: The voltage sensing device consists of a step-down transformer that reduces the 120Vac to a low voltage. The signal is biased so the Arduino can interpret the signal it without damaging its inputs, which are limited to 3.3Vdc. This gives a waveform representing the AC voltage.

Current Sensing: A hall effect sensor detects the magnetic field created by current flow. It outputs a voltage centered around 2.5V that shifts up or down based on the current, allowing the Arduino to track AC current.

Processing

Sampling: The Arduino reads voltage and current waveforms thousands of times per second.

RMS and Frequency Calculation: It computes the root-mean-square to get effective voltage and current values and frequency of the wave.

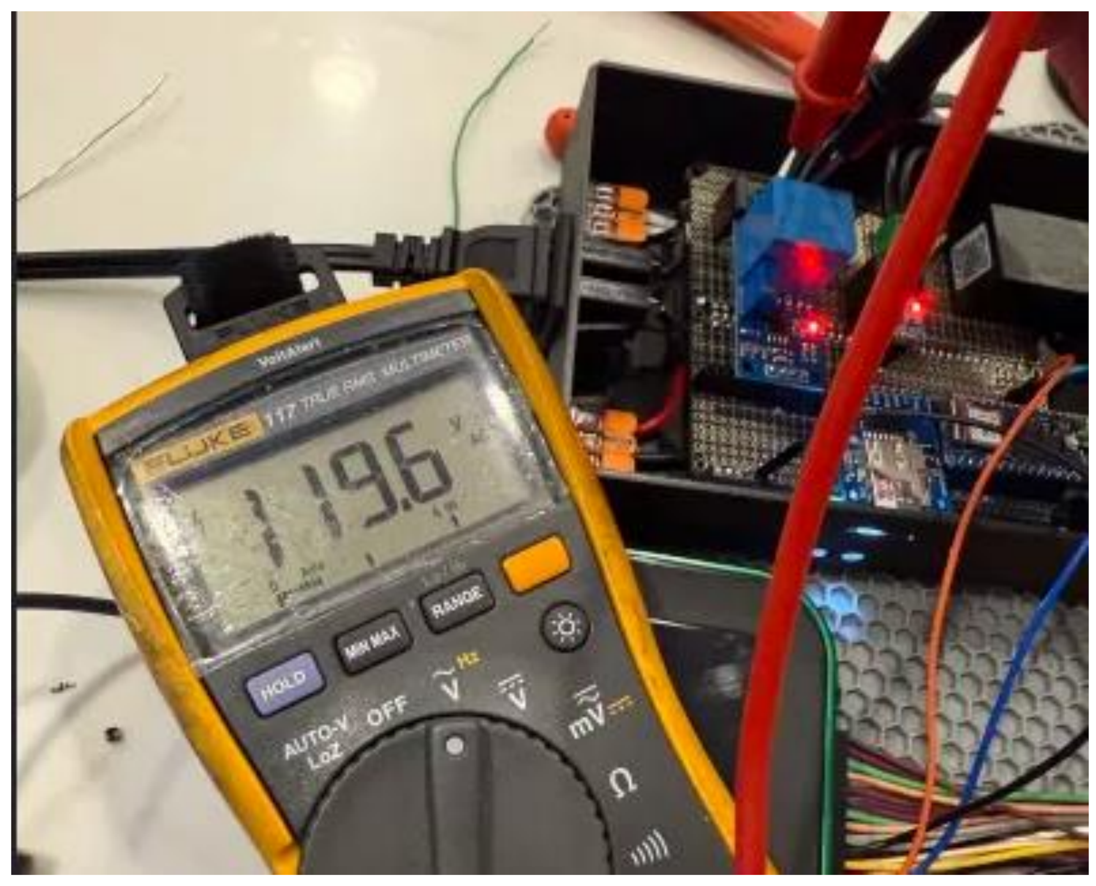
Power Calculations:

- Real Power = Voltage × Current × cos(θ)
- Apparent Power = $V_{RMS} \times I_{RMS}$
- Power Factor = Real Power ÷ Apparent Power

Fast Fourier Transform (FFT): Converts the waveform into frequency components to measure total harmonic distortion (THD).

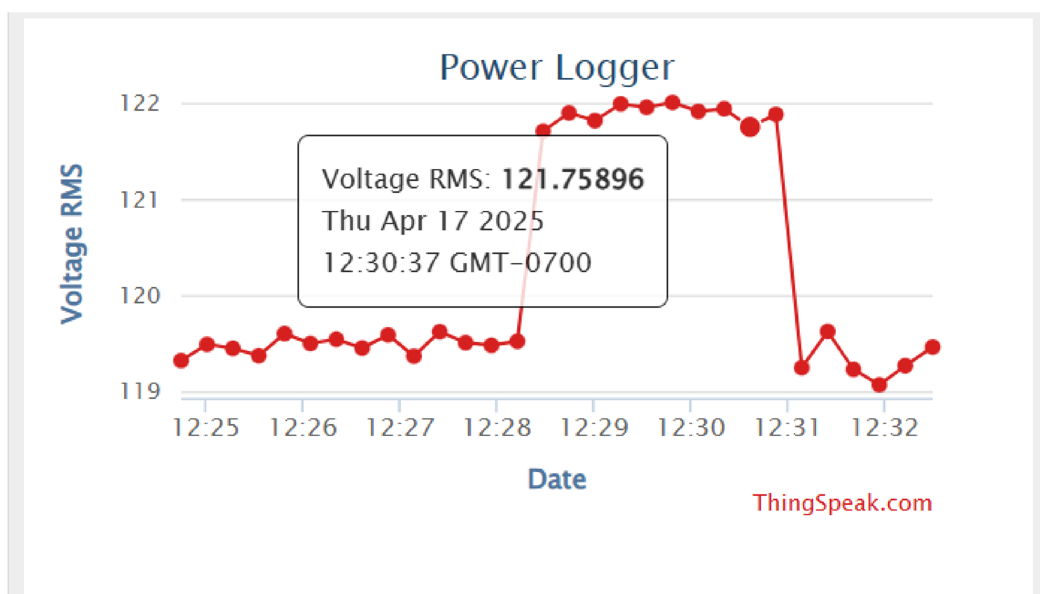
Testing and Results

To test the logger after assembly, a dummy load was applied with a Fluke™ 177 true RMS multimeter and a Fluke™ 323 true RMS clamp meter connected to verify accuracy.



Accuracy results:
Frequency was measured at 60 Hz and found to have **+/- 0.03%** accuracy.
Voltage AC RMS was measured at 120V and found to have **+/- 1.8%** accuracy.
Amperage AC RMS was measured at 5.7A and found to have **+/- .40%** accuracy.

Once the logger was shown to be accurate the results were verified to be shown on the cloud service ThingSpeak™ to complete testing:



Results: all testing was successful! Device measures and logs Voltage, Current, Frequency, THD, Power Factor, Volt-Amps and Watts in the project scope and displays them on the cloud correctly. Device also alarms on low / high voltage and frequency as expected.

Conclusion

- The prototype PQL functioned correctly, measuring, capturing, and uploading sampled/calculated data to the cloud. All accuracy specifications were met and exceeded expectations!
- The prototype enclosure functioned correctly as well, housing all components securely and providing protection for end users.
- The team demonstrated collaboration and teamwork skills in design, assembly, and testing to produce a working prototype.