Smart Energy Monitoring Network

May 1725
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Client: Commercial Product

The Team

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Hardware Designer

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Hardware Designer

Mission statement:

To make a wireless power sensor that can monitor the power usage of different electronic devices and report that power usage back to the user via a user-friendly web application.

Why now?

With the “Smart House” becoming more and more popular, as well as the world becoming more environmentally friendly. Our product satisfies the clientele in these two markets.

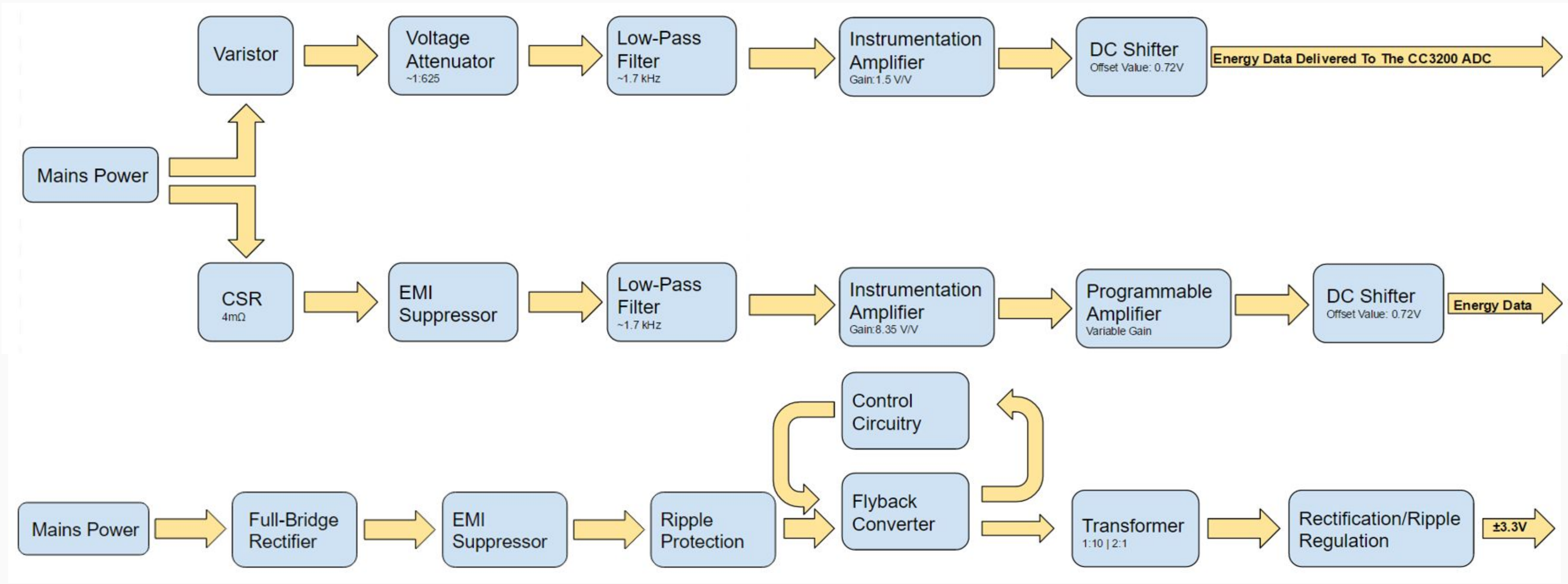
Hardware Requirements

Functional:

- Power Consumption Under 5W
- Operate with current magnitudes ranging from 100mA - 15A RMS
- Provide output with minimal frequency modulation

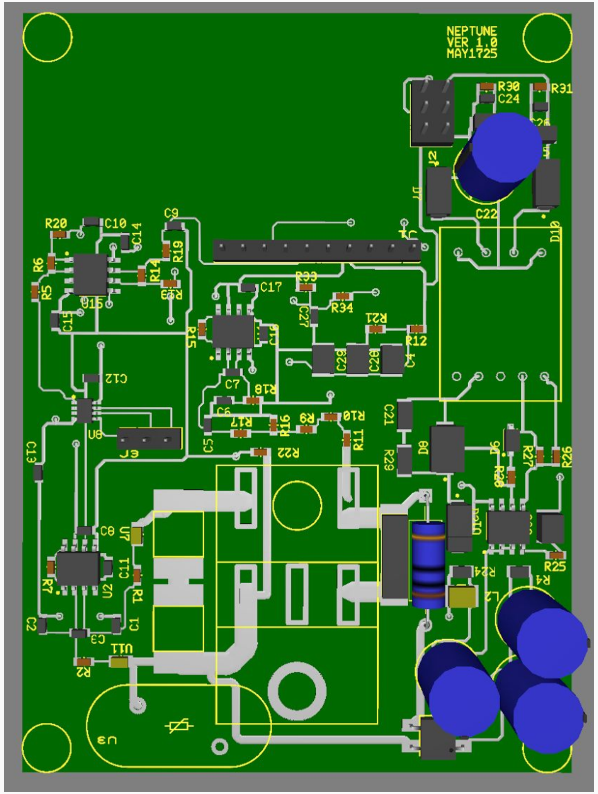
Non-Functional:

- NEMA 5, or equivalent housing
- Non-intrusive to other objects on the outlet
- Negligible Audible Noise

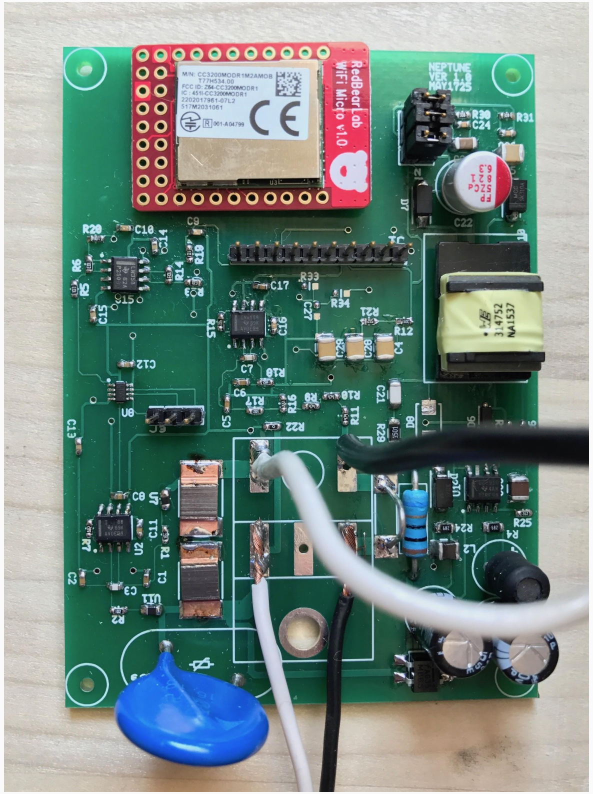


Hardware Block Diagram

PCB layout



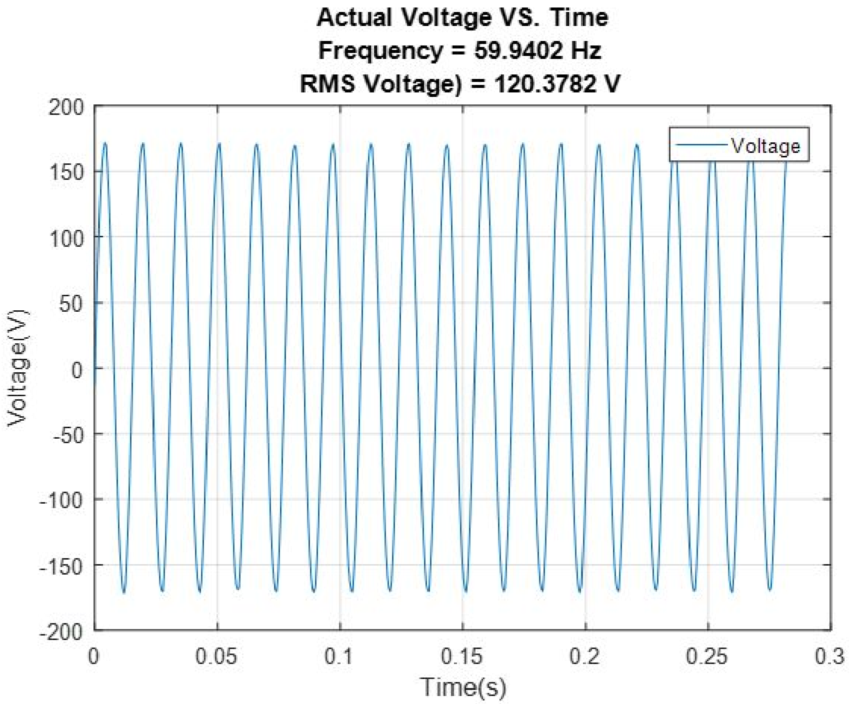
Actual PCB



Implementation

Testing Voltage Sensing

No Load



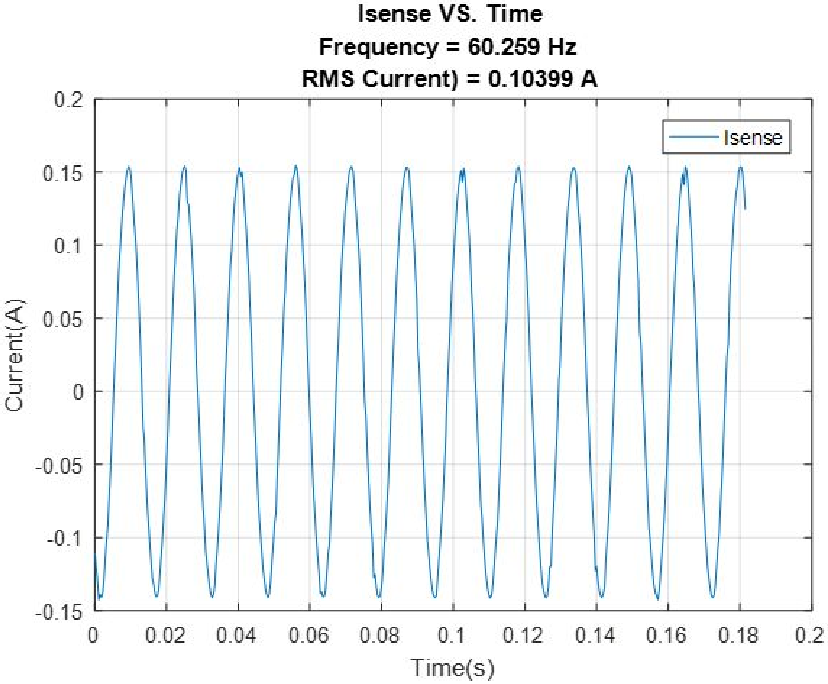
Resistance	**N/A (No Load)**
Power Rating	**N/A (No Load**
Expected Voltage	**120.287 V_{RMS}**

$$Error:$$

$$\frac{120.287 - 120.378}{120.378} * 100 = -1\%$$

Testing Known Load

Analog:
Calibrated Resistive Load



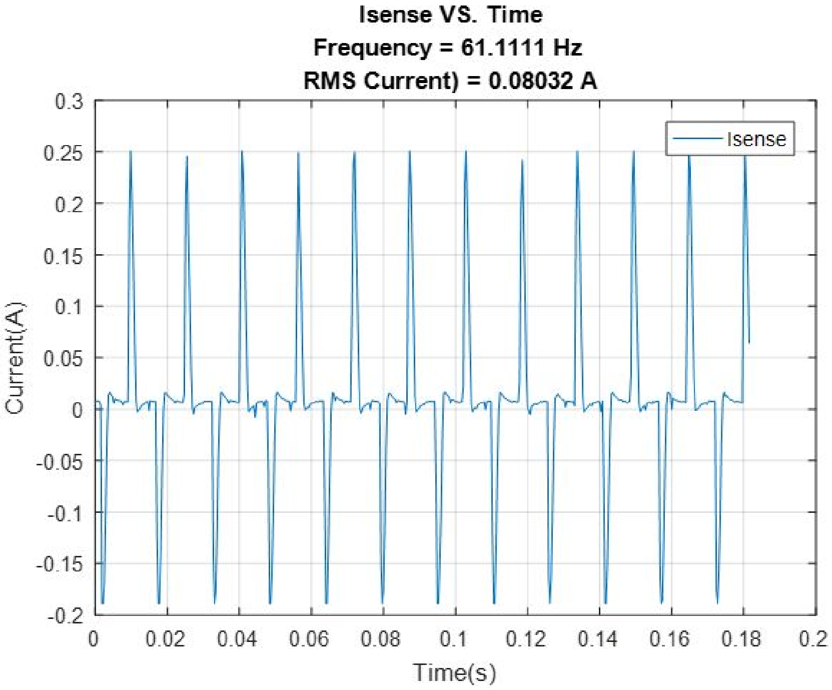
Resistance	**1.192 kΩ**
Power Rating	**10 W**
Expected Current	**101 mA_{RMS}**

$$Error:$$

$$\frac{103.99 - 101}{101} * 100 = 3\%$$

Testing Known Load

Digital:
Cell Phone Charger

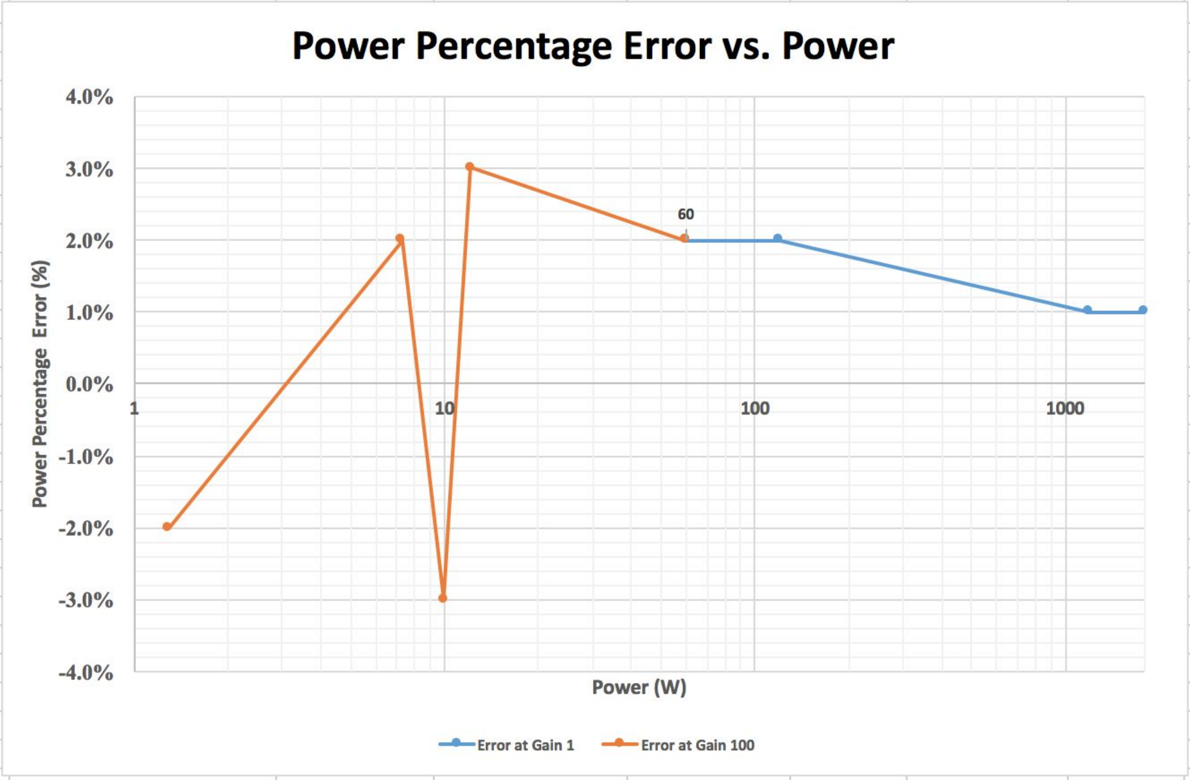


Resistance	N/A (Digital Load)
Power Rating	5 W
Expected Current	83 mA_{RMS}

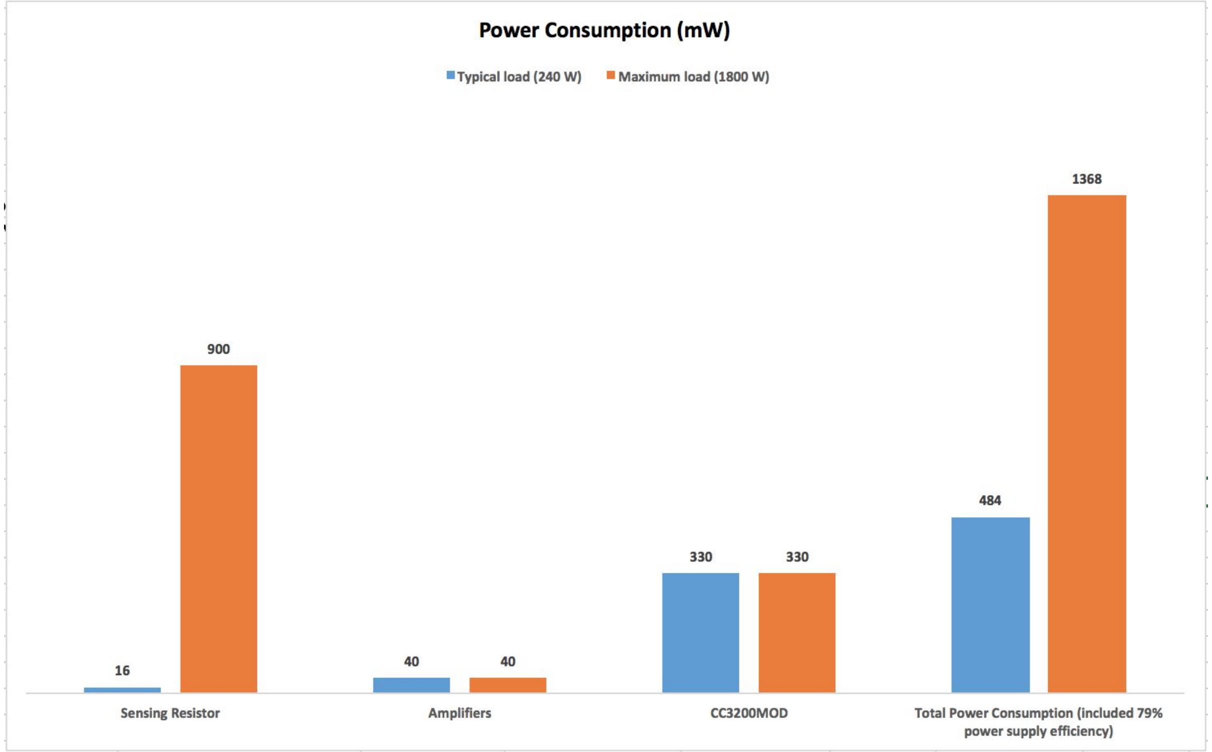
$$Error:$$

$$\frac{80.32 - 83}{83} * 100 = -3\%$$

Power Percentage Error



Device Power Consumption



Software Requirements

Functional:

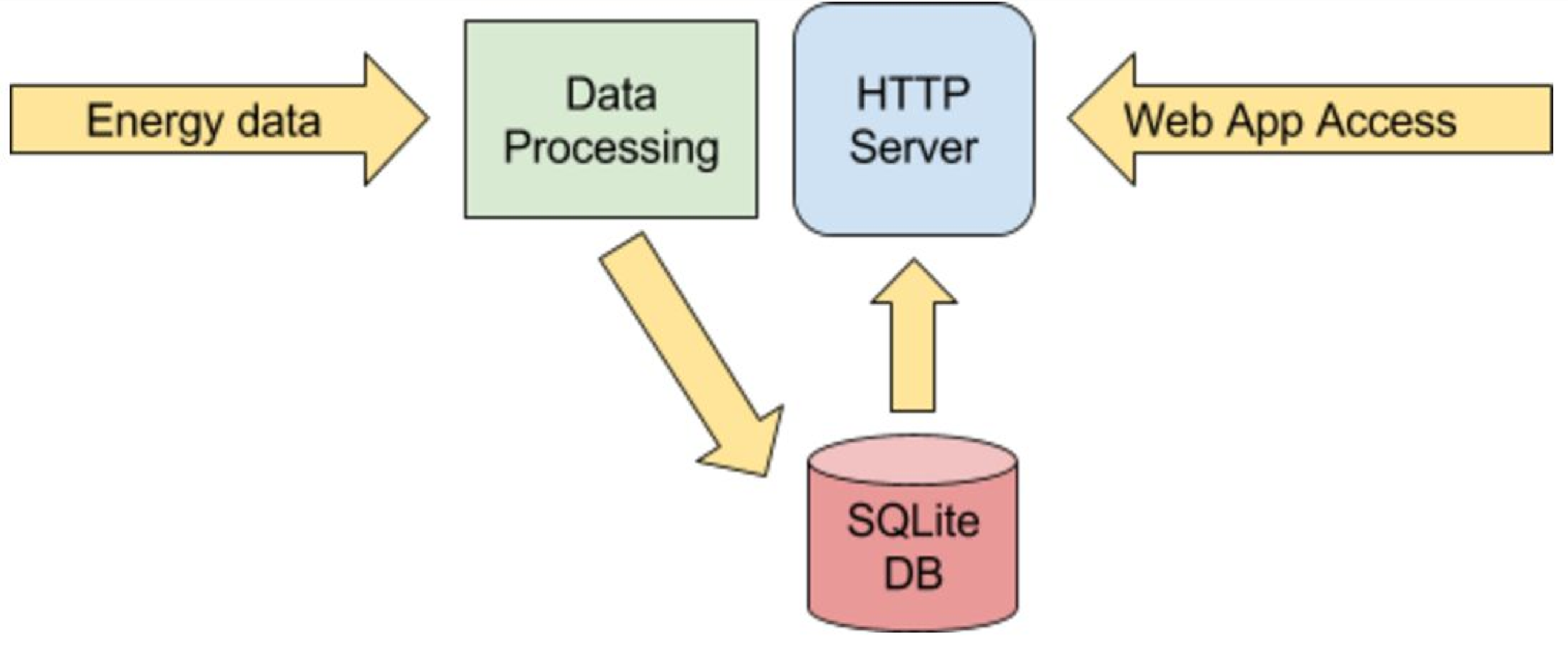
- Web application shall retrieve it’s data from a central database.
- Web application shall allow the user to change the period of energy data collection
- Web application shall show a list of all connected monitoring systems
- Web application shall allow the user to give each station a user-friendly name

Non-Functional:

- Web app should be modern and well-designed, with a sensible UI.
- Web app should have easy to use buttons and controls for the UI.
- Web app should have easy access to different monitoring stations.

Software Design

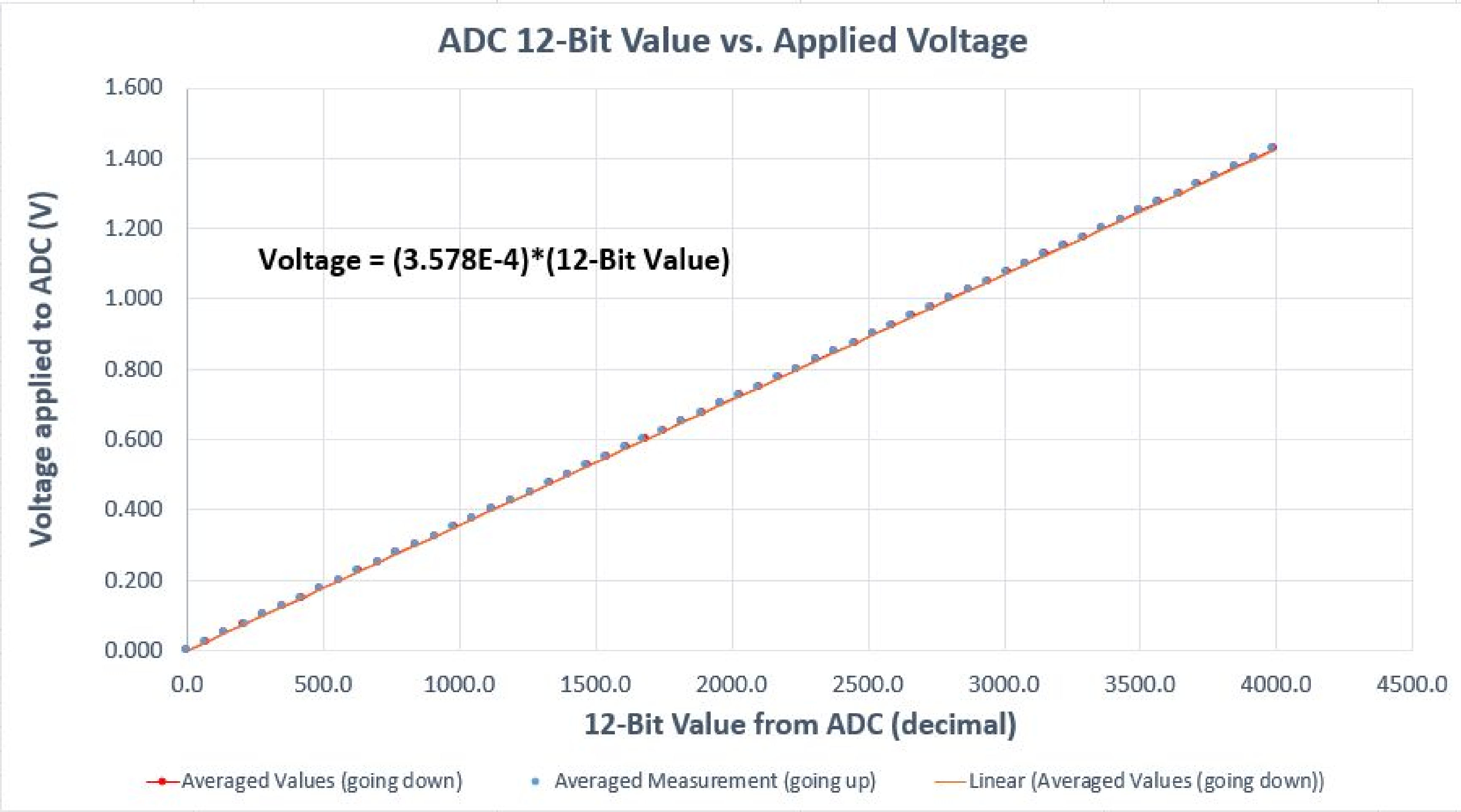
- Each sensor has a WiFi enabled microcontroller
  - Texas Instruments CC3200
  - 32-bit ARM core
- Data is sent from each sensor to a central hub
  - Connection is UDP-based
  - Sensor samples are stored in a central database
- Central hub hosts a web server accessible from any device
  - Web application is mobile-friendly
  - User has the option to create graphs



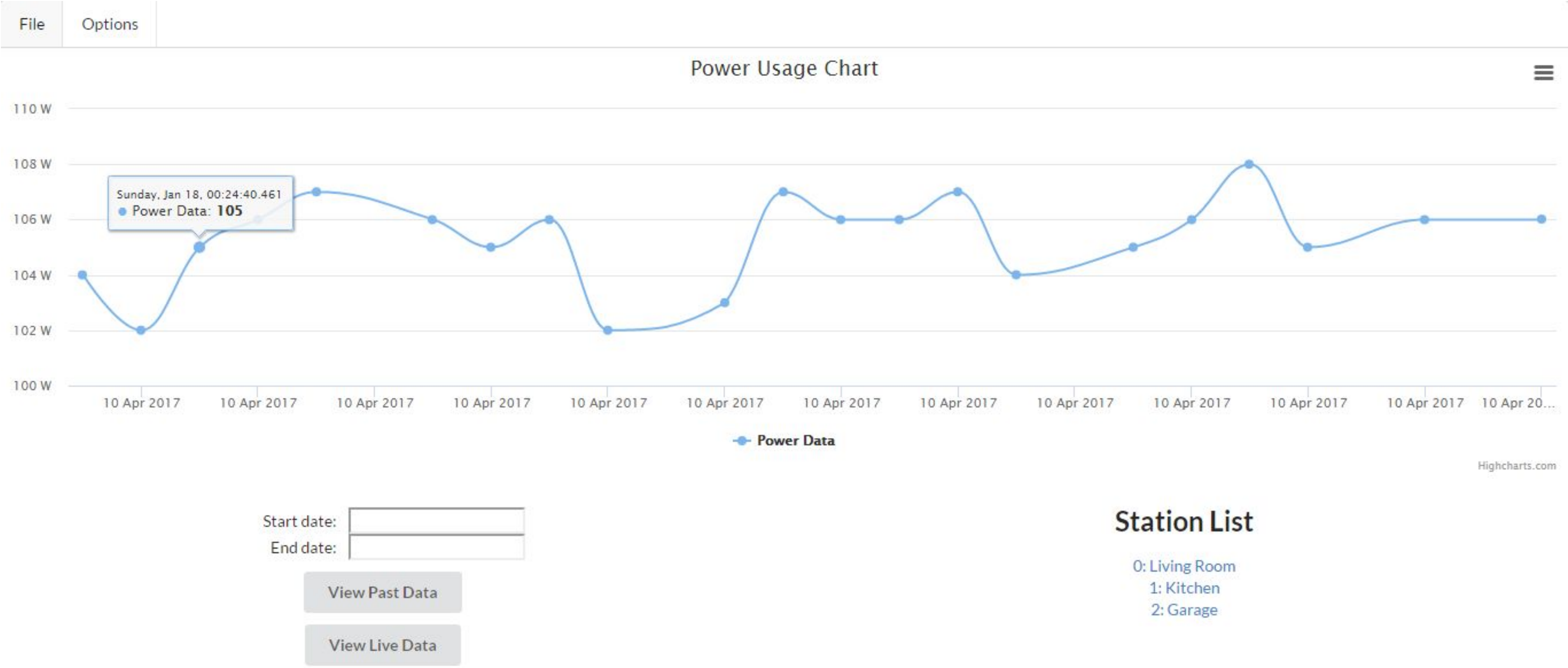
Network Block Diagram

Software Technology Platforms

- Code Composer Studio
  - Free version of IDE from Texas Instruments
- SQLite
  - Connectionless database fits our lightweight model
  - Stores all past sensor measurements
- Python
  - Runs on central hub to provide sensor connection and web application

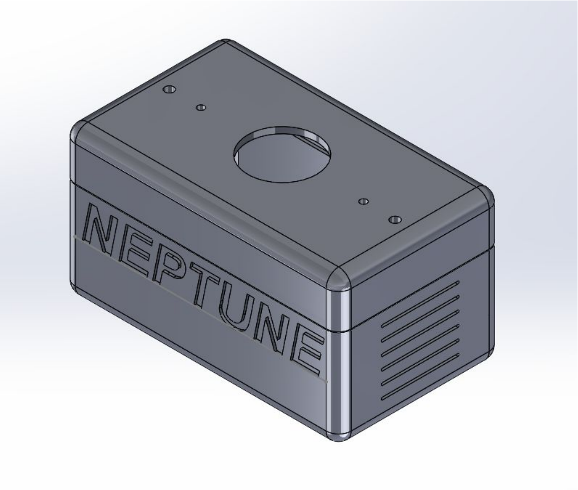

ADC 12-Bit Value vs. Applied Voltage
Voltage = (3.578E-4)*(12-Bit Value)
Voltage applied to ADC (V)
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0.0
500.0
1000.0
1500.0
2000.0
2500.0
3000.0
3500.0
4000.0
4500.0
12-Bit Value from ADC (decimal)
Averaged Values (going down)
Averaged Measurement (going up)
Linear (Averaged Values (going down))

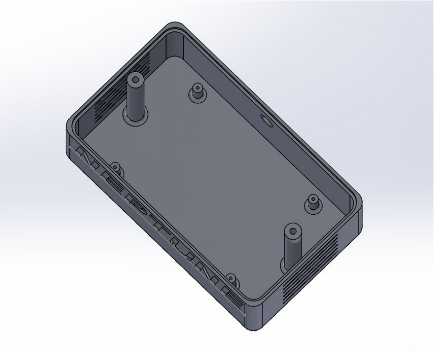
Website Screenshot

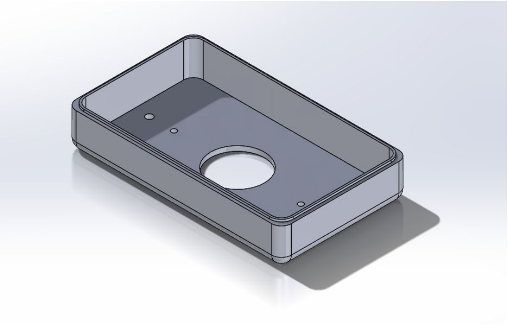


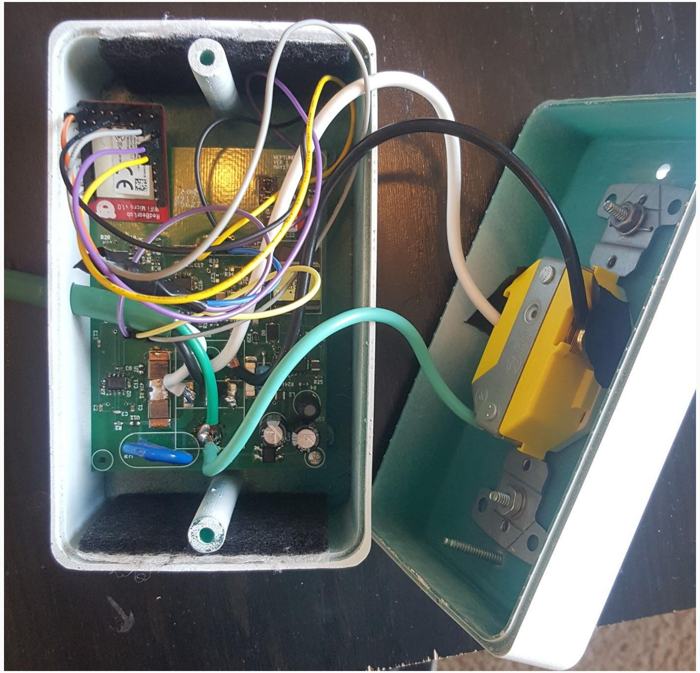
Case

- Designed using SolidWorks 2016
- Fabricated using the Form 2 SLA 3D Printer
- Uses "tough" 3D printing material
- Houses an outlet for power connection, the PCB, and the CC3200 microcontroller
- Provides safety for the user from wires and contacts on the PCB
- Ventilation designed for dissipating any heat





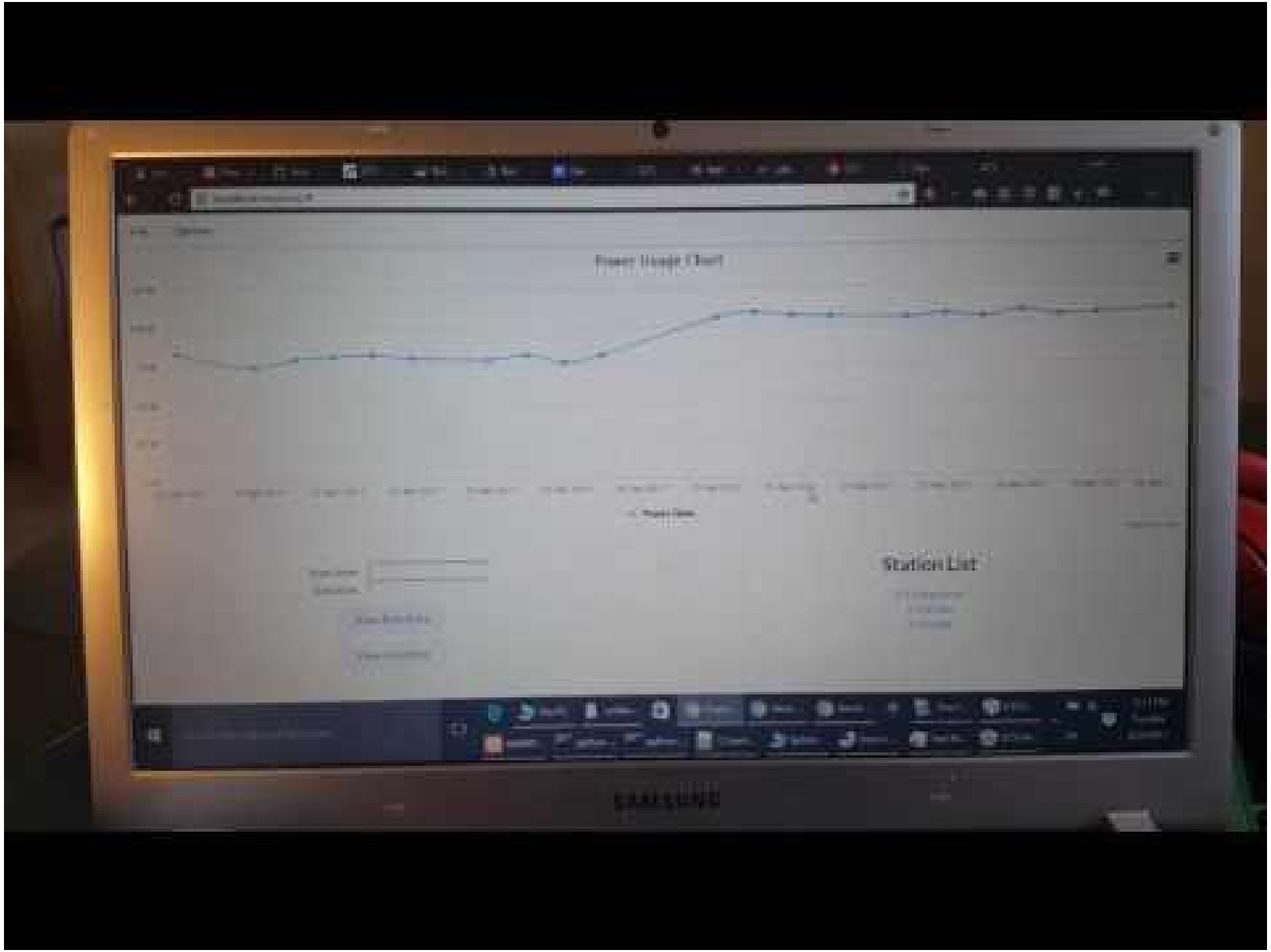




Final Fixture

Device Cost Summary

PCB	$12
CC3200MOD	$11
Passive Components	$24
Active Components	$9
Case and Miscs	$50
Total	**$106**


Station List

Questions?

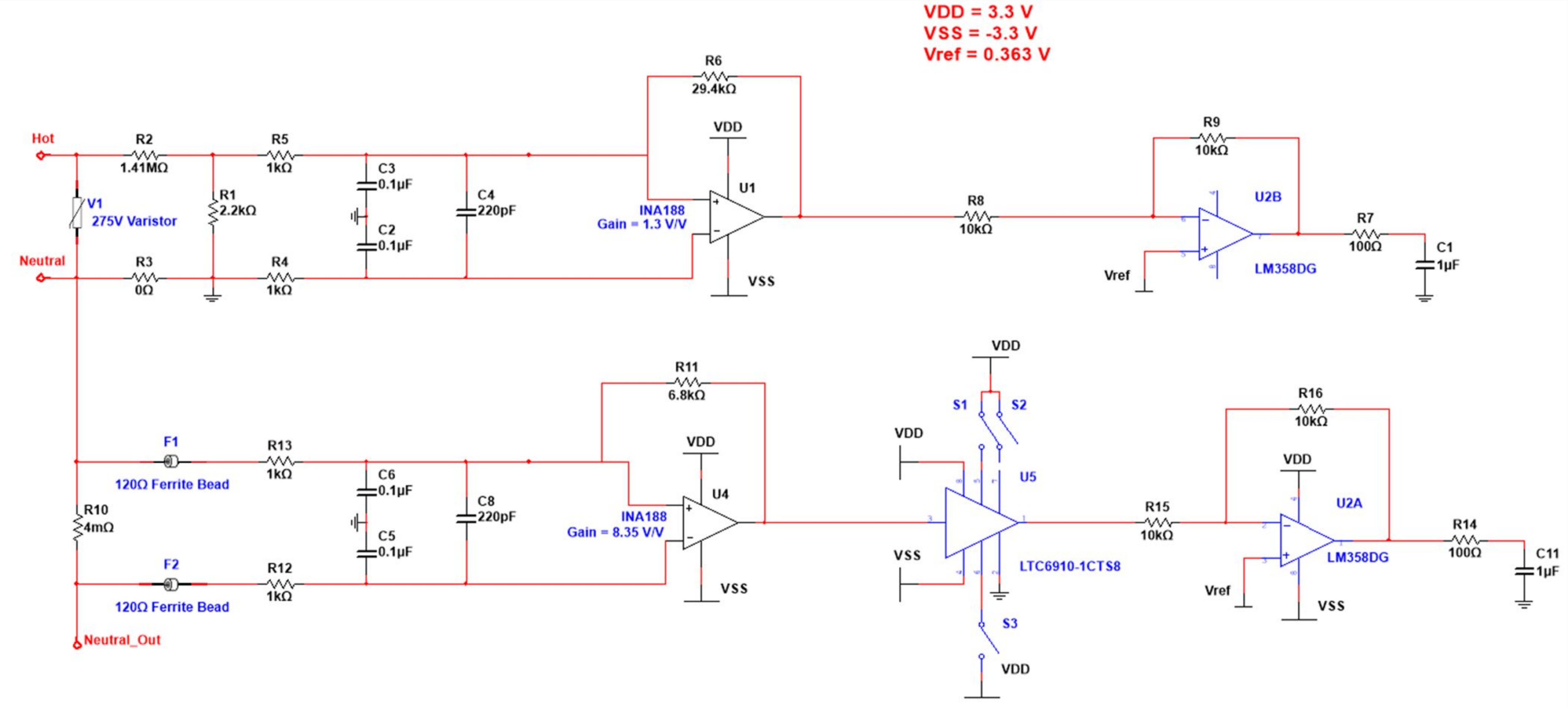
Appendix

REST API (Database Server)


```
[
  - {
        power: 3.600853497959622,
        station_id: "1",
        timestamp: 0
    },
  - {
        power: 9.868210043072839,
        station_id: "1",
        timestamp: 1
    },
  - {
        power: 9.078286273047317,
        station_id: "1",
        timestamp: 2
    },
  - {
        power: 6.427535907109449,
        station_id: "1",
        timestamp: 3
    },
```



```
[
  - {
        id: 1,
        name: "Living Room"
    },
  - {
        id: 2,
        name: "Kitchen"
    },
  - {
        id: 3,
        name: "Garage"
    }
]
```



Hardware Schematic

Quantity	Description	RefDes	Package	Price	Total Cost
1	RESISTOR, 2.2kΩ	R16	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	RESISTOR, 29.4kΩ	R15	IPC-7351\Chip-R0603	$ 0.12	$ 0.12
1	RESISTOR, 6.8kΩ	R7	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	RESISTOR, 41.2kΩ	R12	IPC-7351\Chip-R0603	$ 0.12	$ 0.12
1	RESISTOR, 5.1kΩ	R21	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	Varistor, S20K275	U3	Ultiboard\VAR_S20K230	$ 0.95	$ 0.95
1	RESISTOR, 0Ω	R22	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	OPAMP, LTC6910-1CTS8	U8	IPC-7351\TSOT23-8	$ 2.79	$ 2.79
1	OPAMP, LM358DG	U15	ON Semiconductor\SOIC-8-8(CASE 751-07AJ)	$ 0.47	$ 0.47
1	CAPACITOR, 0.22µF	C27	IPC-7351\Chip-C0603	$ 0.10	$ 0.10
1	RESISTOR, 200kΩ	R33	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	RESISTOR, 1kΩ	R34	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	INDUCTOR, 10mH	L1	IPC-2221A/2222\CAPPR350-800X1150	$ 0.29	$ 0.29
1	INDUCTOR, 10µH	L2	IPC-7351\Chip-L1210	$ 0.26	$ 0.26
1	MOSFET_DRIVER, UCC27325_SO8	U1	IPC-7351\SOIC-D-8	$ 1.59	$ 1.59
1	RESISTOR, 2.7kΩ	R25	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	CAPACITOR, 10µF	C20	IPC-7351\Chip-C1210	$ 0.86	$ 0.86
1	RESISTOR, 30kΩ	R26	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	RESISTOR, 100kΩ	R27	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	RESISTOR, 120Ω	R28	IPC-7351\Chip-R0603	$ 0.10	$ 0.10
1	SWITCHING_DIODE, BAS21H	D6	NXP Semiconductors\SOD-123-2(SOD123F)	$ 0.19	$ 0.19
1	DIODE, 1N4004G	D2	ON Semiconductor\SMA-2(CASE 403D-02F)	$ 0.47	$ 0.47
1	RESISTOR, 1.5kΩ	R29	IPC-7351\Chip-R1206	$ 0.10	$ 0.10
1	CAPACITOR, 100pF	C21	IPC-7351\Chip-C1206	$ 0.31	$ 0.31
1	PROTECTION_DIODE, 1SMB170AT3(	D8	ON Semiconductor\SMB-2(CASE 403A-03G)	$ 0.46	$ 0.46
1	SCHOTTKY_DIODE, 1N5822G	D7	ON Semiconductor\SMA-2(CASE 403D-02F)	$ 0.68	$ 0.68
1	CAP_ELECTROLIT, 820µF	C22	IPC-2221A/2222\CAPPR350-800X1150	$ 0.67	$ 0.67
1	CAPACITOR, 10µF	C23	IPC-7351\Chip-C1206	$ 0.25	$ 0.25
1	CAPACITOR, 100µF	C25	IPC-7351\Chip-C1206	$ 0.74	$ 0.74
1	SCHOTTKY_DIODE, MBR3100RLG	D10	ON Semiconductor\SMA-2(CASE 403D-02F)	$ 0.60	$ 0.60
1	RESISTOR, 10Ω	R32	IPC-2221A/2222\RES1600-1000X400	$ 0.72	$ 0.72
1	Transformer, XMFR314752	U13	Ultiboard\XMFR314752	$ 7.63	$ 7.63
1	GENERIC, HDR2X3	J2	Generic\HDR2X3	$ 0.25	$ 0.25
1	MB6S	U14	Ultiboard\MB6S	$ 0.38	$ 0.38
1	GENERIC, HDR1X3	J3	Generic\HDR1X3	$ 0.25	$ 0.25
1	GENERIC, HDR1X10	J1	Generic\HDR1X10	$ 0.50	$ 0.50
1	CC3200MOD	U11	MCU	$ 10.63	$ 10.63
2	CAPACITOR, 220pF	C3, C7	IPC-7351\Chip-C0603	$ 0.11	$ 0.22
2	Instrumentation, INA188	U2, U4	IPC-7351\SOIC-8	$ 2.08	$ 4.16
2	RESISTOR, 2mΩ	R3, R8	Ultiboard\RES3921	$ 2.21	$ 4.42
2	RESISTOR, 100Ω	R19, R20	IPC-7351\Chip-R0603	$ 0.10	$ 0.20
2	CAPACITOR, 1µF	C9, C10	IPC-7351\Chip-C0603	$ 0.19	$ 0.38
2	BLM21BD121SN1, BLM21BD121SN1	D7, U11	IPC-7351\Chip-L0805	$ 0.15	$ 0.30
2	CAP_ELECTROLIT, 4.7µF	C18, C19	IPC-2221A/2222\CAPPR350-800X1150	$ 0.48	$ 0.96
2	RESISTOR, 6.8kΩ	R4, R24	IPC-7351\Chip-R0805	$ 0.10	$ 0.20
2	CAPACITOR, 0.1µF	C24, C26	IPC-7351\Chip-C0603	$ 0.10	$ 0.20
2	RESISTOR, 2kΩ	R30, R31	IPC-7351\Chip-R0603	$ 0.10	$ 0.20
3	RESISTOR, 470kΩ	R9, R10, R11	IPC-7351\Chip-R0603	$ 0.10	$ 0.30
3	CAPACITOR, 100µF	C4, C28, C29	IPC-7351\Chip-C1210	$ 0.74	$ 2.22
4	CAPACITOR, 0.1µF	C1, C2, C5, C6	IPC-7351\Chip-C0603	$ 0.10	$ 0.40
4	RESISTOR, 1kΩ	R1, R2, R17, R18	IPC-7351\Chip-R0603	$ 0.10	$ 0.40
4	RESISTOR, 10kΩ	R5, R6, R13, R14	IPC-7351\Chip-R0603	$ 0.10	$ 0.40
8	CAPACITOR, 0.1µF	C8, C11, C12, C13, C14, C15, C16, C17	IPC-7351\Chip-C0603	$ 0.10	$ 0.80

Bill of Materials

Actual Current	Error at G1	Error at G10	Error at G100
10.8 mA_{RMS}	354%		-2%
60.6 mA_{RMS}	42%	7%	2%
83 mA_{RMS}	12%	-4%	-3%
101 mA_{RMS}	10%	5%	3%
0.5 mA_{RMS}	8%	3%	
1 A_{RMS}	5%		
10 A_{RMS}	-4%		
Actual Voltage	**Error**		
120.287 V_{RMS}	1%		

Error Summary

Current Software Status

- CC3200 SDK working and example code running
  - Connected to WiFi network and pinged external website
  - ADC is running
- UDP Transmission of sensor data
  - CC3200 sends a UDP packet over the WiFi to the central hub
  - Packet is received by Python UDP server and inserted into the database

Provides a Degree of Protection Against the Following Conditions	Type of Enclosure									
	1 *	2 *	4	4X	5	6	6P	12	12K	13
Access to hazardous parts	X	X	X	X	X	X	X	X	X	X
Ingress of solid foreign objects (falling dirt)	X	X	X	X	X	X	X	X	X	X
Ingress of water (Dripping and light splashing)	...	X	X	X	X	X	X	X	X	X
Ingress of solid foreign objects (Circulating dust, lint, fibers, and flyings **)	...	...	X	X	...	X	X	X	X	X
Ingress of solid foreign objects (Settling airborne dust, lint, fibers, and flyings **)	...	...	X	X	X	X	X	X	X	X
Ingress of water (Hosedown and splashing water)	...	...	X	X	...	X	X	...	...	...
Oil and coolant seepage	...	...	...	..	...	...	...	X	X	X
Oil or coolant spraying and splashing	...	...	...	...	...	...	...	...	...	X
Corrosive agents	...	...	...	X	...	...	X	...	...	...
Ingress of water (Occasional temporary submersion)	...	...	...	...	...	X	X	...	...	...
Ingress of water (Occasional prolonged submersion)	...	...	...	...	...	...	X	...	...	...

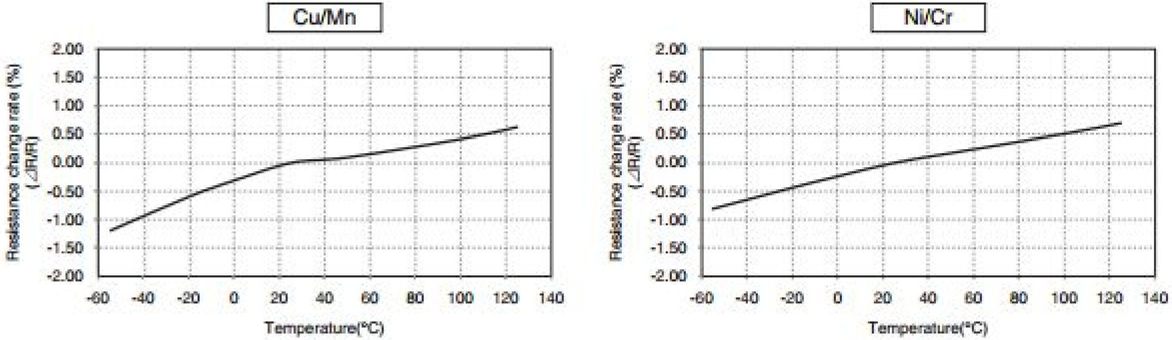
NEMA Rating Requirements

General	
Dimensions	5 x 3 x 3.5 inches
Plug options	US, 15 Amp
Color	White
Enclosure	NEMA 5 Rating
Operating Temprature (°C)	-20 < T < 85
Storage Temprature (°C)	-40 < T <125
Radio	
-Sensitivity	-74 dBm minimum
-Output Power	14.5 dBm minimum
Power Supply	120 V(RMS)
Power Consumption (Typ.)	1 W

Functions	
Power Meter	
-Voltage Range	120 V(RMS)
-Current Range	100 mA - 15A(RMS)
-Accuracy	Typ +/- 5.0%
-Voltage Sensitivity (Typ.)	133mA/V
-Resolution	0.342mV/bit
-Auto-Ranging Threshold	1.2 V

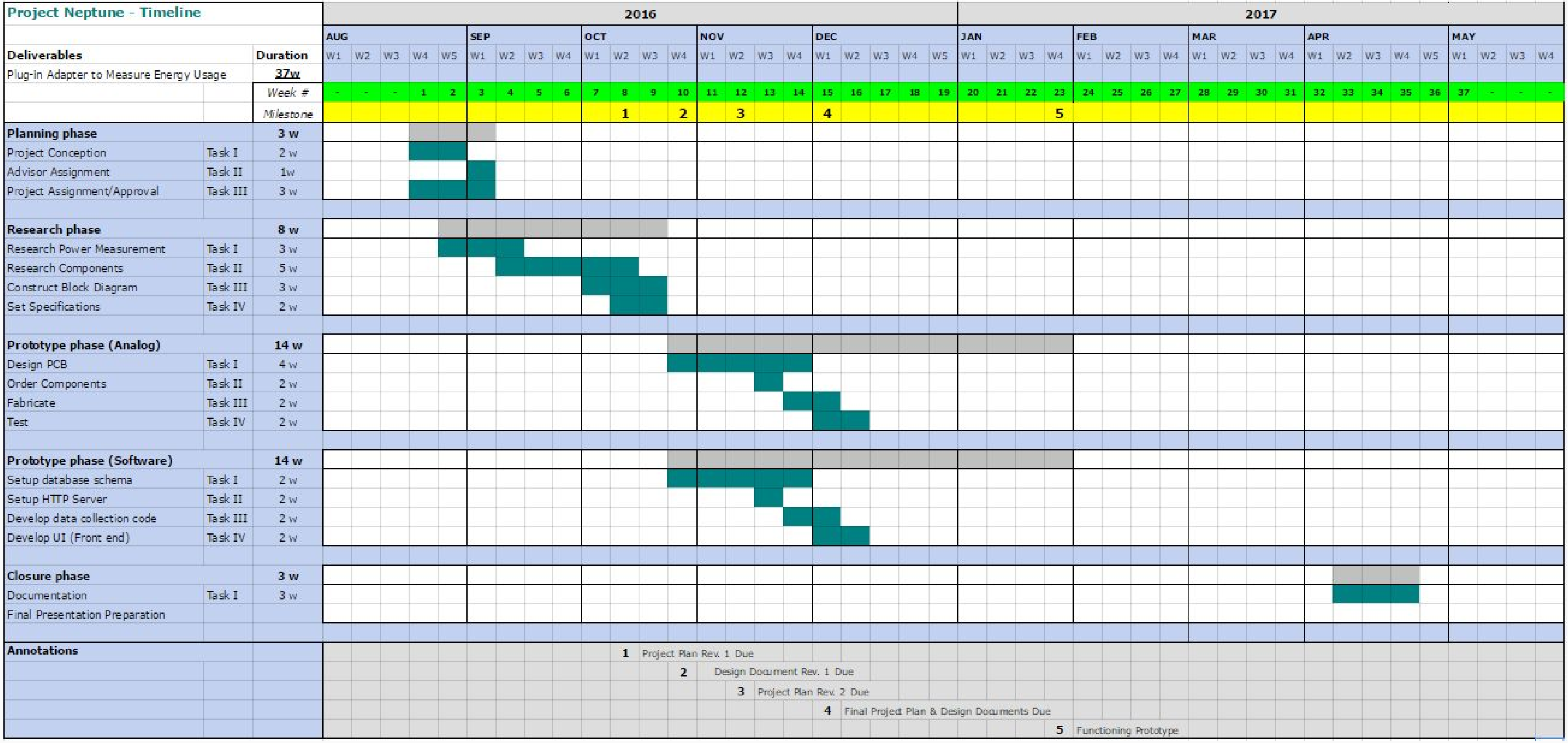
Technical Specifications

●**Variation of resistance with temperature** (Reference temperature is 20°C)



Part No.	L	W	H	b	Resistance	t	Material
PSR400	10±0.3	5.2±0.3	0.5±0.1	2.0±0.6	0.3mΩ	1.85±0.15	Cu / Mn
					0.5mΩ	1.30±0.15	
					1.0mΩ	0.90±0.15	
					2.0mΩ	1.15±0.15	Ni / Cr
					3.0mΩ	0.90±0.15	

Vin (V)	V_resistor (V)	I_resistor (A)	R(Ω)	
0.001	0.000127	0.03	0.004233333	
0.01	0.000601	0.147	0.004088435	
0.02	0.00118	0.275	0.004290909	
0.03	0.001649	0.406	0.004061576	
0.04	0.00217	0.534	0.00406367	
0.05	0.002704	0.666	0.00406006	
			0.004132997	Average Resistance



Project Timeline

Risks

1. Electric Shock/Surges
2. Damaging Excessive Steady Current
3. Accuracy
4. Multi-Device Communication

Mitigations

1. Capacitive & Diode Protection Circuitry
2. Time Delayed 15A Fuses
3. Auto-Ranging Gain
4. UDP

Milestones

Dec | Jan | Feb | Mar | Apr | May

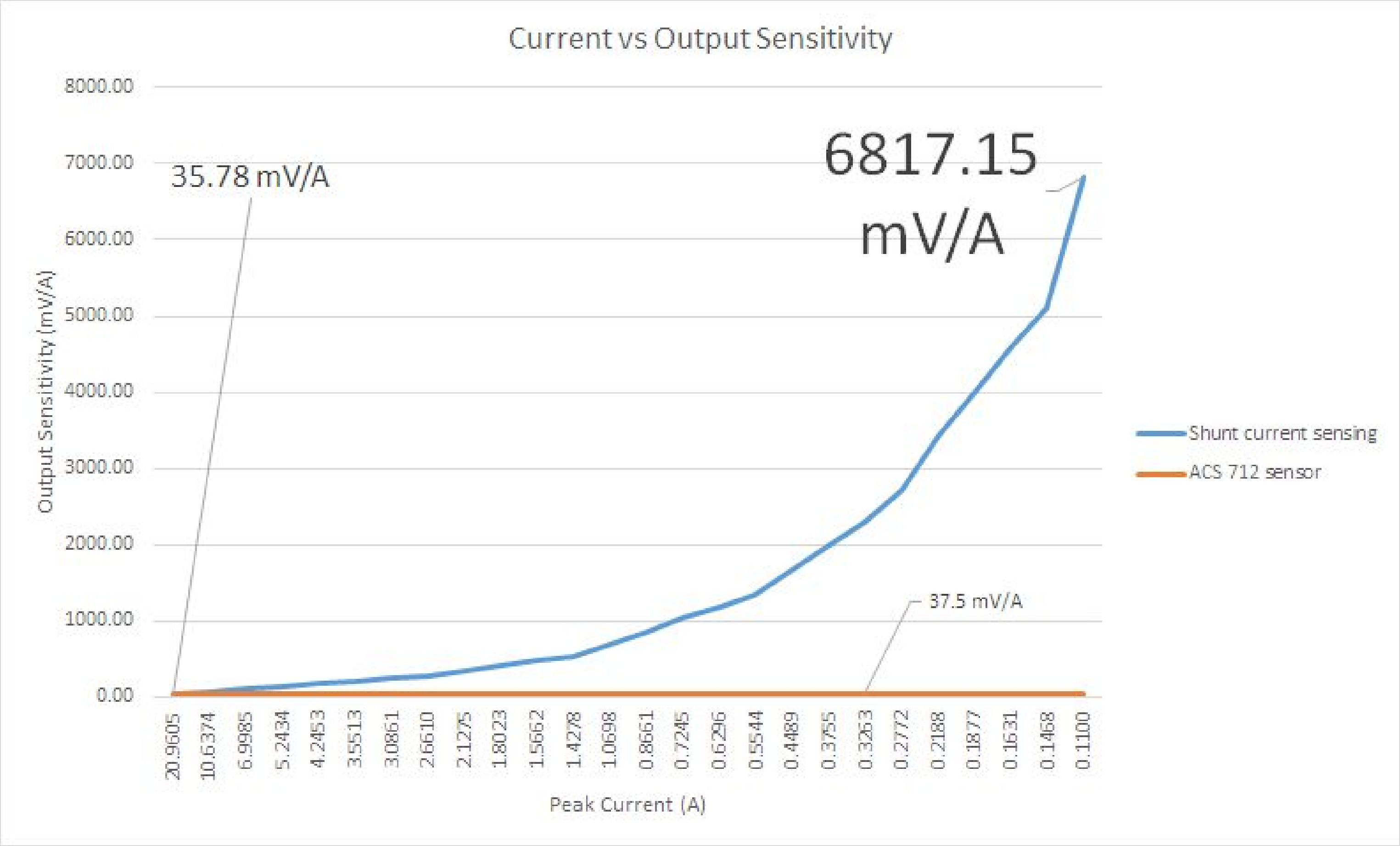
Current Status
Nearly Functional Separate Prototypes

Jan 2016
Functioning Separate Prototypes

Feb 2016
Functioning Prototype Device

Apr 2016
Refinement/Debugging Complete

May 2016
Final Submission



Measured Sensitivity Function