Smart Assessing Breaker for Residential Estates (S.A.B.R.E)

Group 23

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The Problem

- In its current design the conventional breaker lacks:

  - **real time monitoring and data logging**, allowing real, up-to-date analysis of the building's power usage and warnings of energy spikes that could lead to trips in the future.
  - **Remote management** to protect the building from hazards that may occur while away
  - **Limited Diagnostic Capability** and predictive maintenance support monitoring the integrity of the system for possible damage over time.
  - The conventional breaker also has a **failure rate** of roughly **0.83%** as reported in a reliability study by the U.S. Army Corps of Engineer Power Reliability Enhancement Program.

The Solution

Goals

Basic Goals

- Build a Smart Circuit Breaker capable of **protecting against overcurrent, short circuits, conditions** being able to meet standard electrical safety code (NEC/UL/IEEE/NEMA) on a reduced scale.
- Create a **built-in communication system** allowing for remote controlled access via a website to allow for real-time monitoring, remote control operation, and predictive maintenance insights through a user-friendly interface.
- Provide **predictive fault detection** analysis to inform the user of irregularities during power consumption of a house allowing them to respond accordingly if not automatically.
- **Minimize power consumption** of device.

Objectives

Basic Objectives

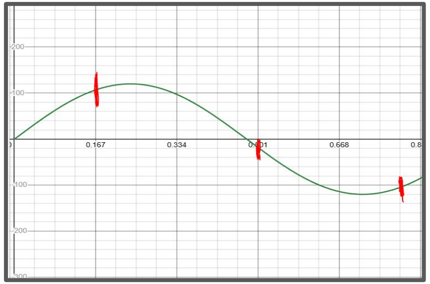
- Integrate Sensors able to send data through to communication systems with minimal error with quick response time to website.
- Incorporate components capable of withstanding surges to prevent replacements and repairs at later times.
- Implement temperature monitoring to warn users of potential heat surges or fires within the system..
- Create an user-friendly, easy to install system where one can easily pick up and place the entire system into their breaker box.

Motivation and Background

- Conventional Circuit breakers used in the United States continue to rely primarily on thermal-magnetic trip mechanisms, a design that has been in widespread use for several decades. Although incremental improvements in materials, safety standards, and protective features have been implemented, these devices still depend on mechanical components that can degrade over time with repeated operation and fault interruptions.

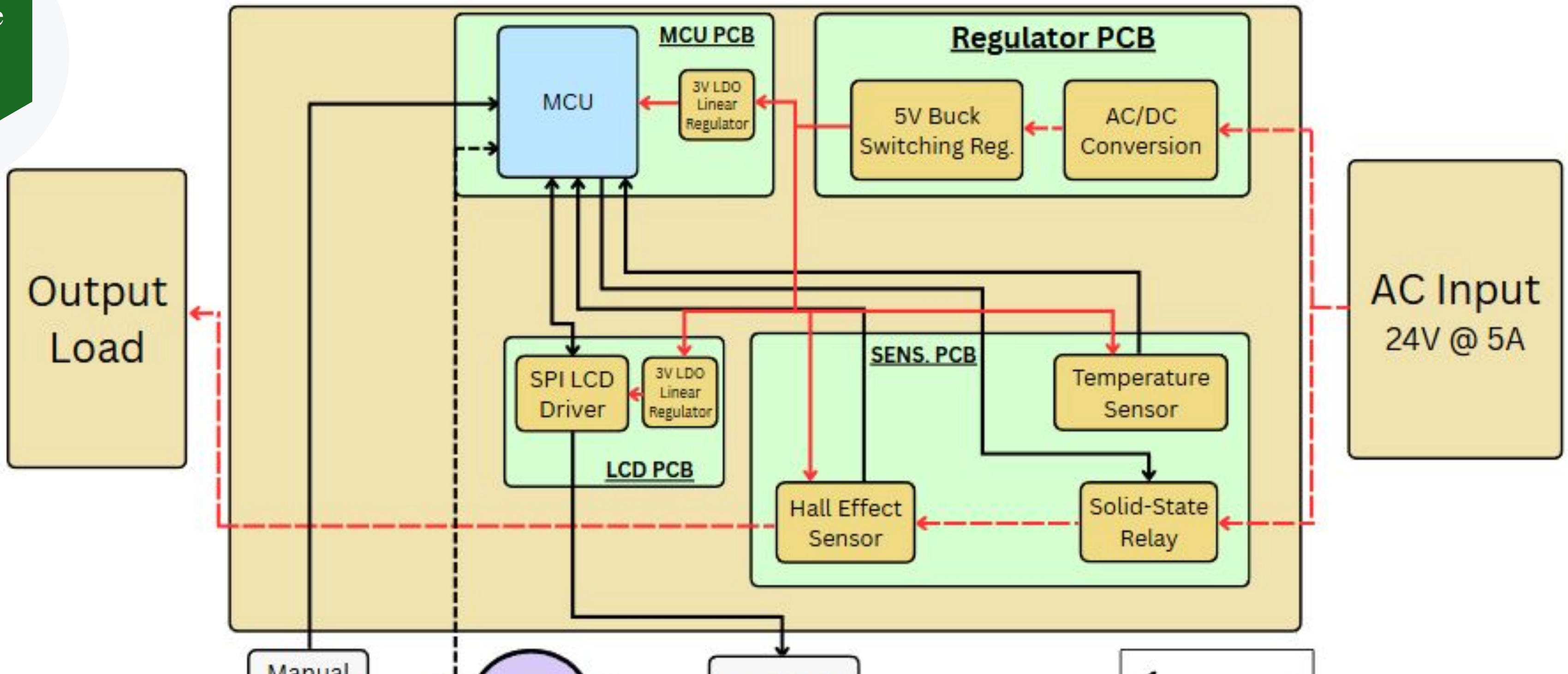
- Our team was tasked by Dr. Qun Zhou Sun from the University of Central Florida and Grid Interactive Things Inc. to innovate the design of the conventional breaker to keep up with modern standards.

Specifications



Overall System Specifications		
Specification	**Target Value**	**Tolerance**
Operating Voltage	25 VAC (single phase)	±10%
Rated Current Capacity	5 A	±5%
Wireless Response Time	< 3 secs	±1%
Interrupt Rating	500 AIC	Scaled Down Proportional to the UL 489 Standard
Continuous Load Rating	95% of rated value	±5%
Comm. Range	≥ 15 m (indoor)	N/A
Operating Temperature Range	-10 °C to 60 °C	IEC 60068 Standard
Power Consumption (electronics)	< 10 W	±10%
Dimensions (HxWxD)	≤ 75 × 40 × 76 mm	Stand. Size - 0 tolerance

Hardware Block Diagram



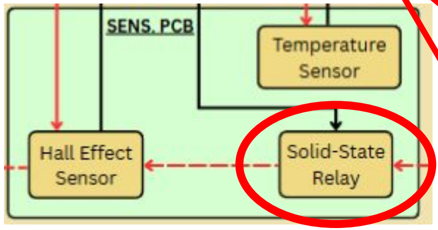
Hardware Selection

Primary Gate Component Selection			
Metrics	Mechanical Relay	Solid-State Relay	MOSFET Configuration
Avg Switching Speed	10ms	1ms	1 µs
Switching Element	Metal Contacts actuated by electromagnetic coil	Triacs, Thyristors, MOSFETS	MOSFET Channel
Isolation	High- Physical gap between coil and contacts	Medium - Optical Isolation	Low - No inherent isolation
Avg. Durability	10^5 operation	10^9+ operations	10^9+ operations
Leakage Current	Extremely low, pA range	Low: µA range	Low: µA range
Form Factor	Bulky: Coil contacts, housing	Very Compact: SMD	Very Compact: SMD
Avg. Cost	$5.00	$25.00	$2.00

Determines lifespan of breaker due to degradation

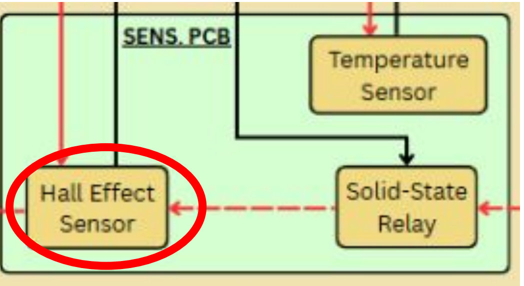
Improves accuracy of measurements

Needs to be small to fit on PCB



Hardware Selection

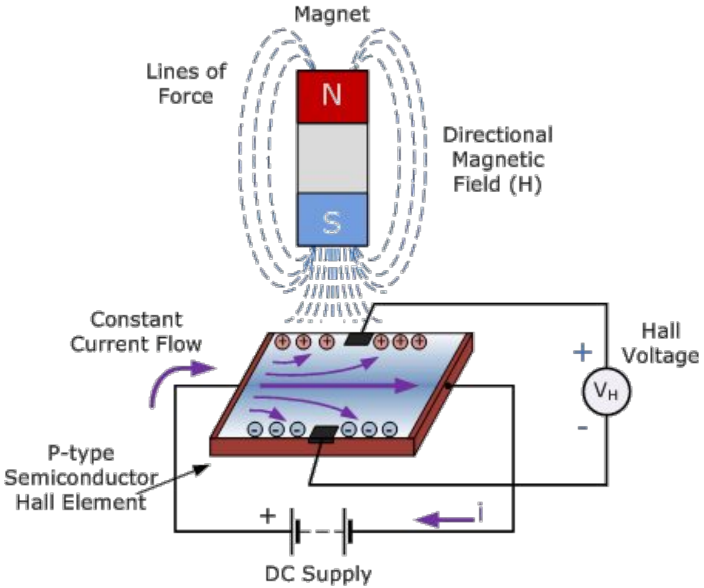
We selected the Hall-Effect Sensor for current measurement because it provides essential galvanic isolation between the high-power circuit and the MCU



Current Measuring Methodologies		
Metrics	**Current Transformer with Shunt Resistor**	**Hall-Effect Sensor**
Accuracy	High	Good
Detection Method	KCL	Magnetic FIeld Detection
Form Factor	Relatively Large for our desired PCB size	Very Compact: SMD
Power Loss?	Minimal	Minimal
Cost	≈ $20.00	≈ $12.00

Hardware Selection

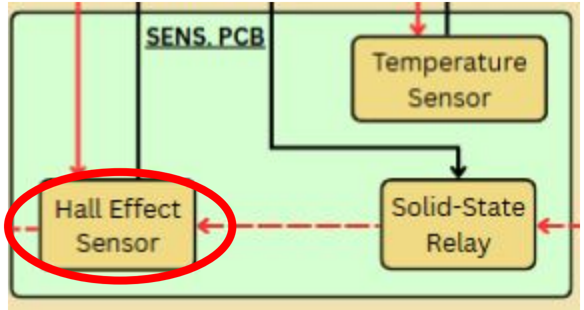
Hall Effect Sensor (ACS712-30A)



$$V_H = \frac{BI}{qnt}$$

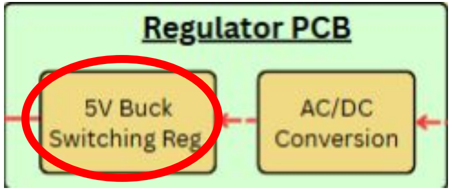
- Electric Current produces magnetic field causing hall voltage to be applied
- Standalone component

Current Range	30 A
Input Supply Voltage	5 V DC
Form Factor	Integrated Circuit
Mounting Method	SMD
Output Resolution	66 mV/A
Cost	$12.00



Hardware Selection

We selected a **Buck Regulator** for the system's voltage step-down because it offers superior efficiency and thermal management compared to linear regulators.

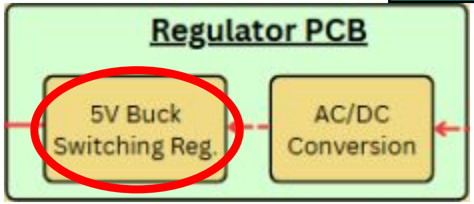


Voltage Step-Down Methodologies			
Metrics	**AC Transformer**	**Linear Regulator**	**Buck Regulator**
Efficiency	Best	Poor	Good
Heat Dissipation	Best	Poor	Best
Isolation	Best	Poor	Good
Avg. Size	Poor	Best	Good
Avg. Cost	Good	Good	Good

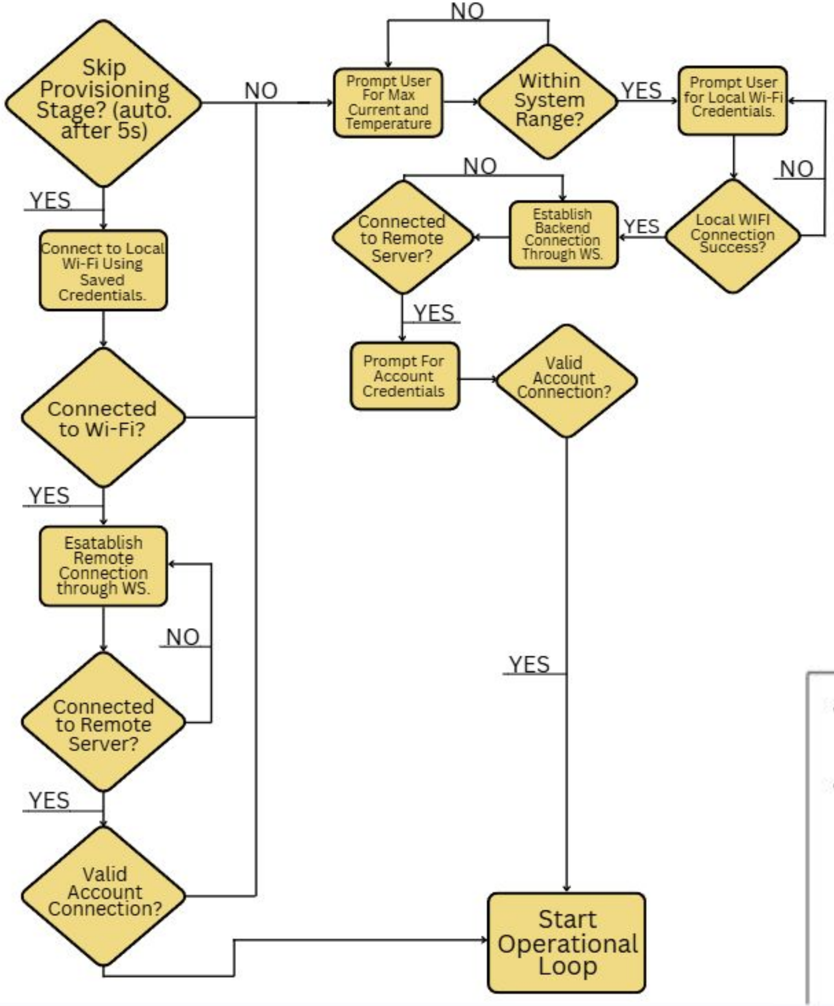
Hardware Selection

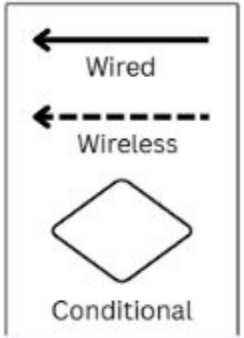
Buck Regulator Selection				
Metrics	LM5180	LM2576HV	LM5160DNT	LMR71915F-DDA
Avg. Cost	$4.50	$3.50	$5.00	$2.82
Efficiency	88%	88%	85%	90%
Size	4mm x 4mm	10.2 mm x 15.2 mm	4mm x 4mm	SMD only
Max Power Capability	7 W	45 W	130 W	172.5 W
Max Input Voltage	65 V	60 V	65 V	115 V
Max Supply Current	1.5 A	3 A	2 A	1.5 A

The **LM2576HV** was chosen for its high-voltage capability and reliability in industrial-grade applications. It provides a robust, easy-to-implement solution with excellent thermal performance

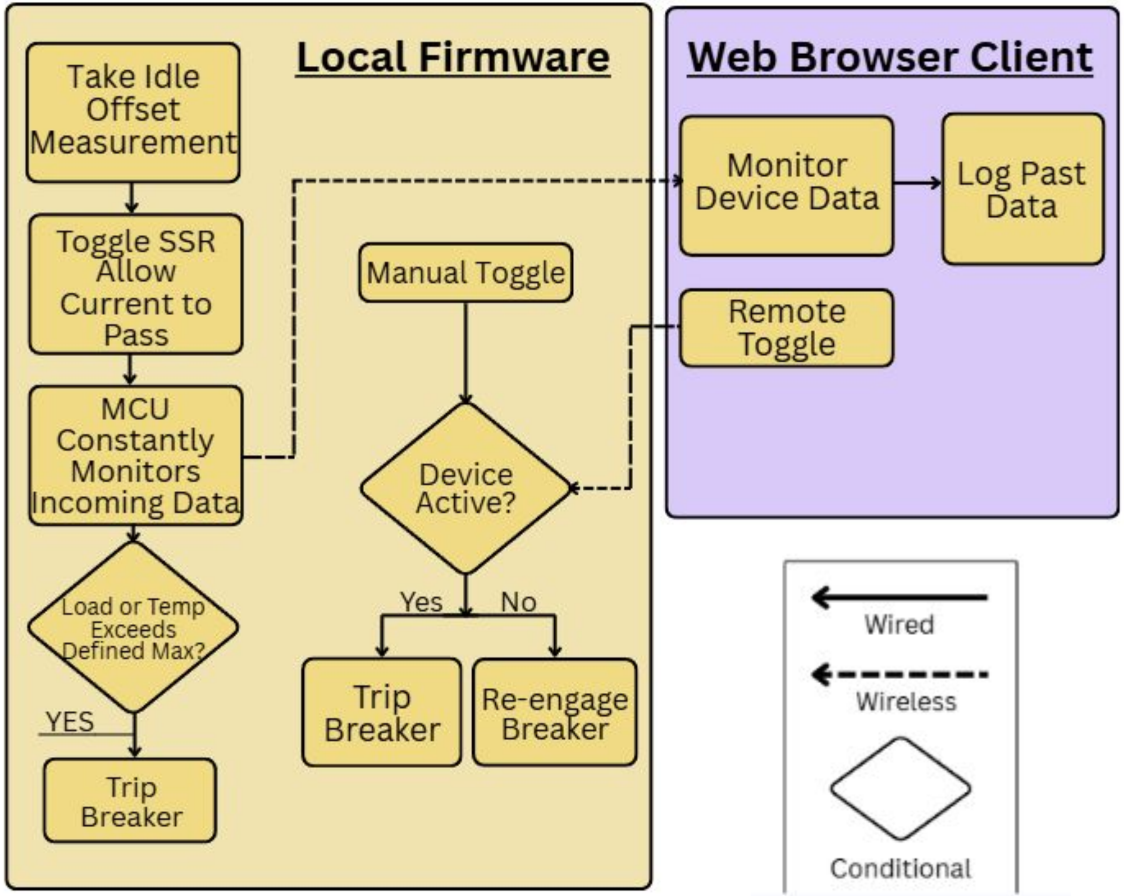


Software Block Diagram





Software Block Diagram



Measuring Alternating Current

Measuring DC signal with HE sensor is trivial. With an AC signal however, there are some things to take into account.

The change in the AC signal will affect the proportional analog voltage signal depending on where the measurement takes place in the sin wave.

To account for this, samples are taken along a given window that corresponds to a number of full cycles.

According to the Nyquist rule, sampling must be at least twice that of the incoming signal to capture meaningful data. For a 60Hz signal, would need at least 120 Hz. $f_s > 2 \cdot f_{signal}$

Take N number of samples over a single cycle. Square each individual value and sum them together. Square root the mean of these samples to produce RMS voltage. $\sqrt{\frac{1}{N} \cdot \sum_{n=1}^{N} V_N^2}$

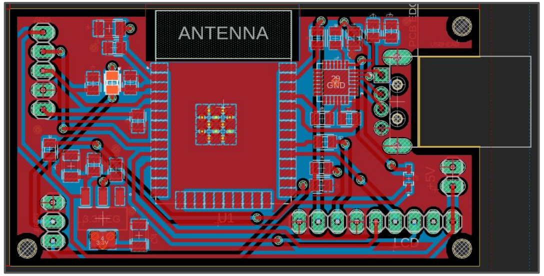
Calculate RMS current by using the conversion specified by the sensor in the datasheet.

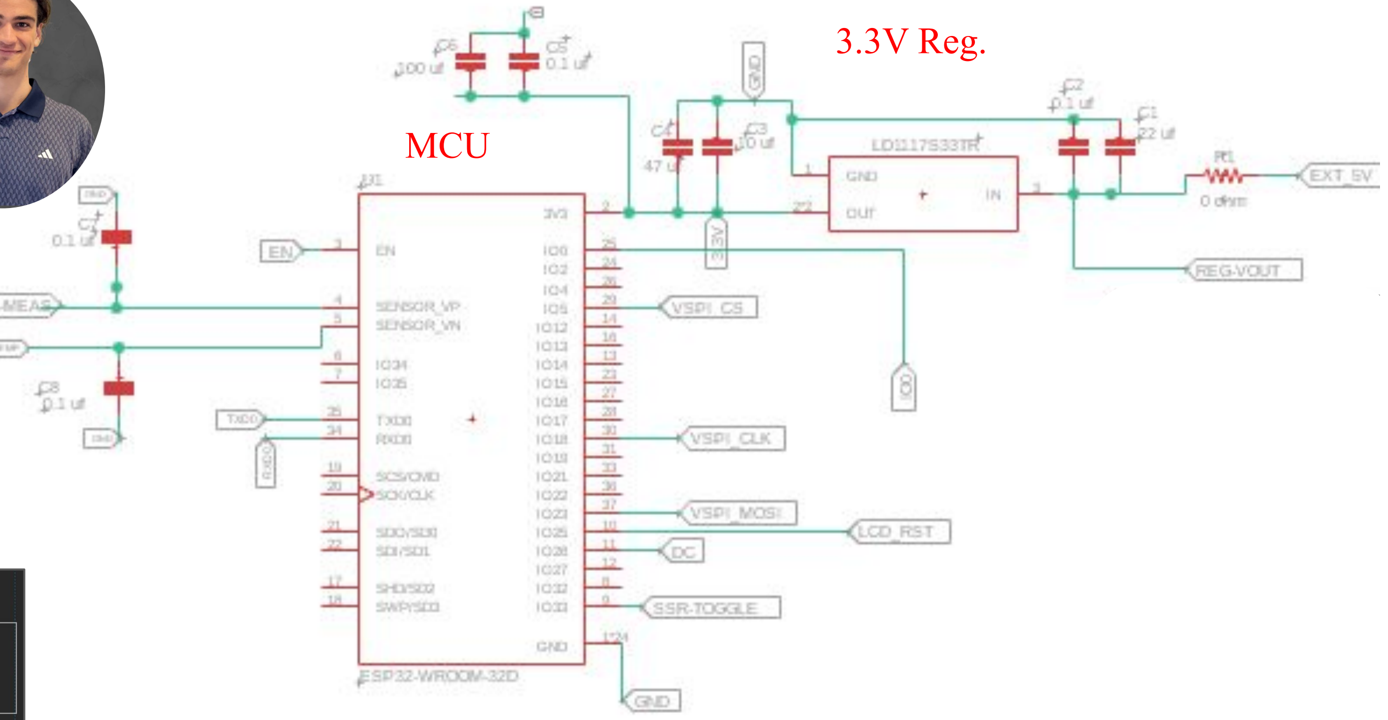
MCU Selection

ESP32's Wifi capabilities and price justified its selection

MCU Selection					
Metrics	**ESP32**	**CC3235 MODx**	**Pico 2W**	**nRF52840x**	**STM32WB55**
Processor	Dual Core 240 MHz	Single Core 80 MHz	Dual Core 133 MHz	Single Core 64 MHz	Dual Core 64 MHz + 32 MHz
UART	Yes				
RAM	520 KB SRAM	256 KB SRAM	520 KB SRAM	256 KB DRAM	256 KB SRAM
ADC	Yes - 12 bit				
Operating Voltage	3.3 V	3.3 V	5 V	5 V	1.6 V - 3.6 V
Power Consumption	0.528 Wh	0.736 Wh	0.297 Wh	0.0158 Wh	0.029 Wh
Cost Dev. Board	$8.00	$71.00	$7.00	$49.00	$45.00
Cost Individual Module	$7.00	$26.00	$7.00	$49.00	$45.00

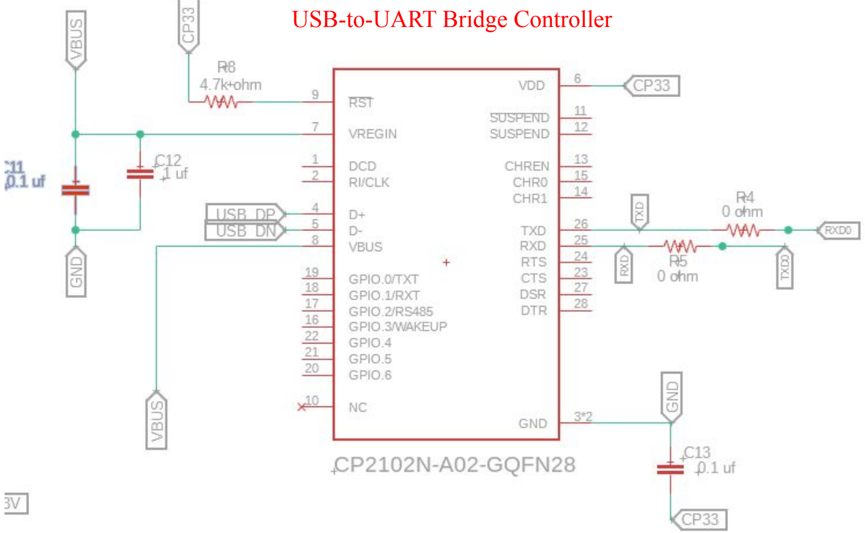
1st PCB Board

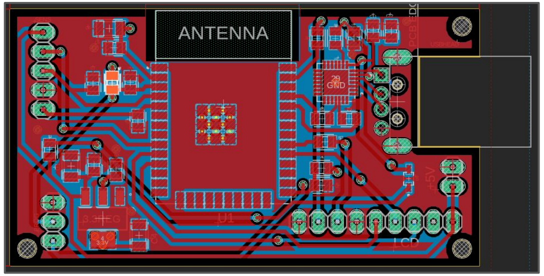




1st PCB Board pt.2

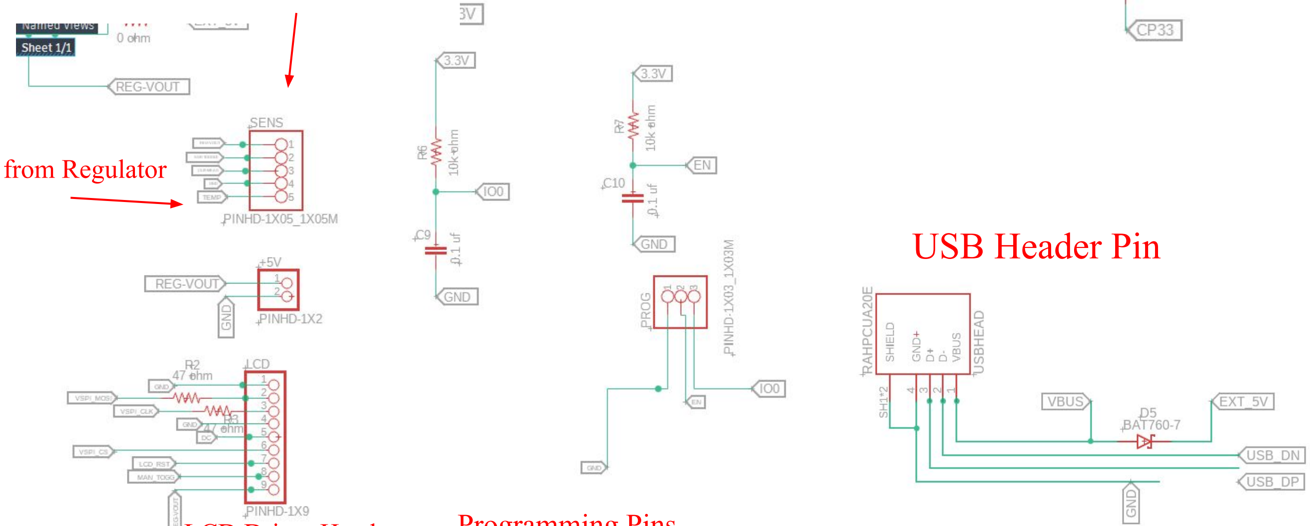
USB-to-UART Bridge Controller





SSR Board Output

Output from Regulator

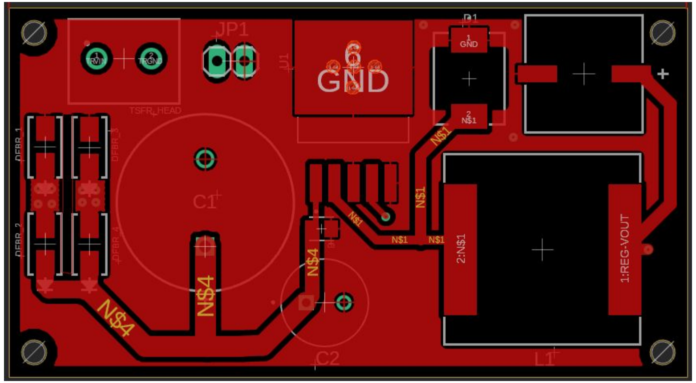


USB Header Pin

LCD Driver Header

Programming Pins

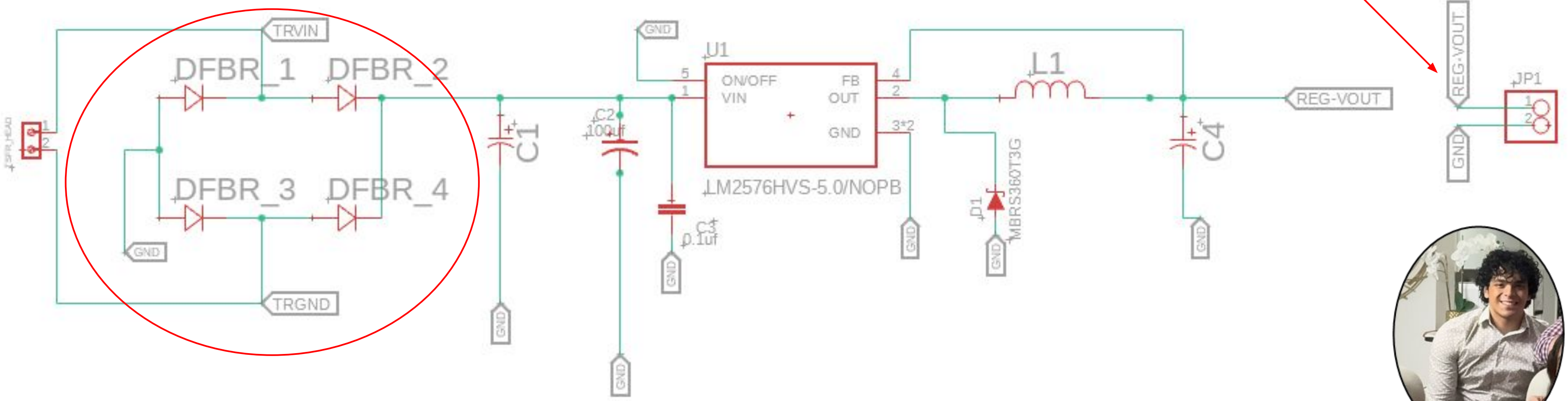
2nd PCB Board



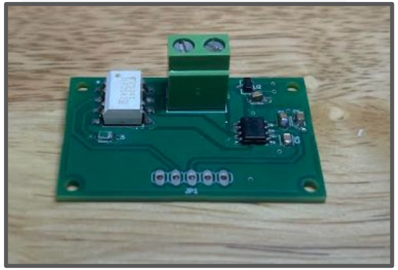
Full-Wave Rectifier

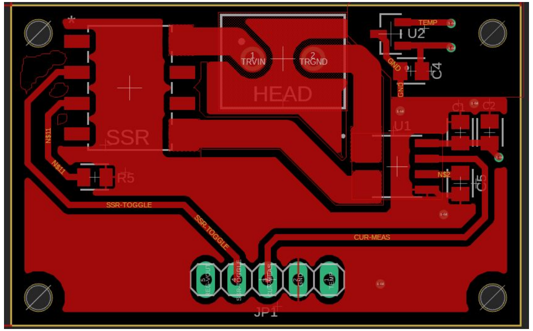
Step-Down Regulator

Output

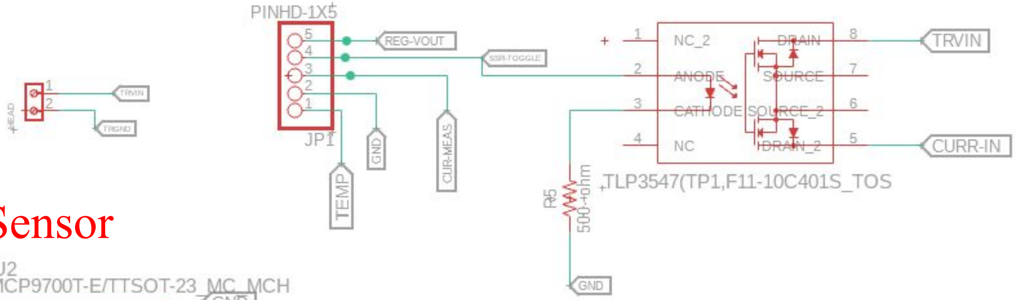


3rd PCB Board

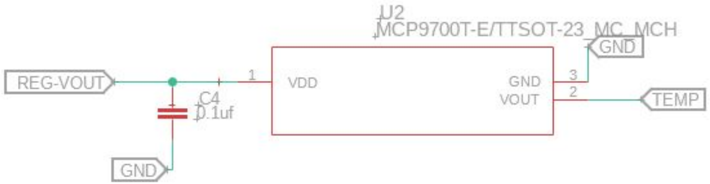




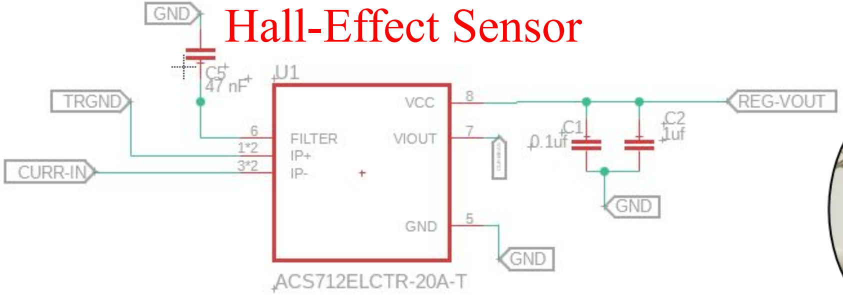
Solid-State Relay



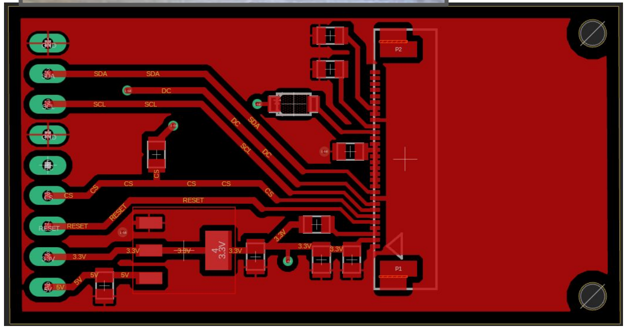
Temperature Sensor

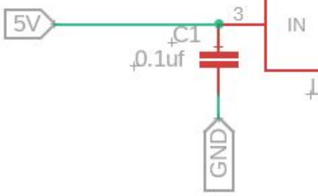


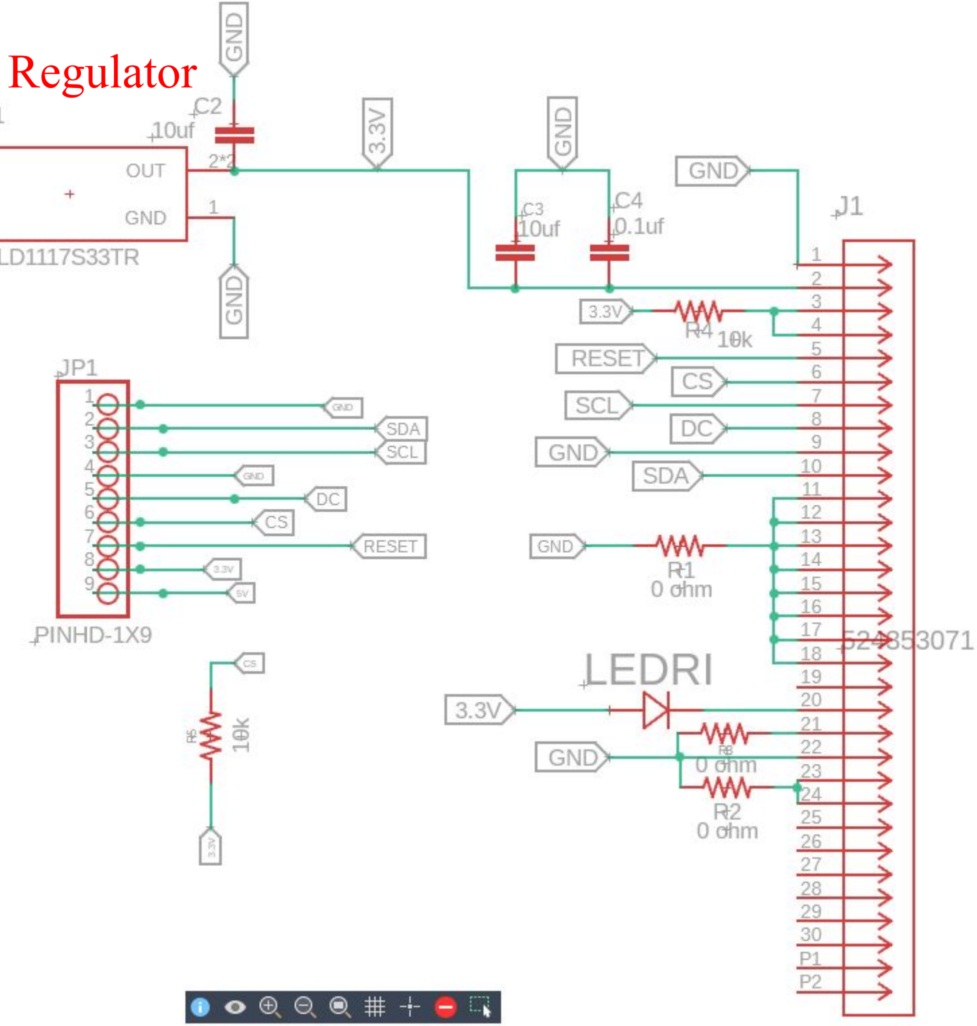
Hall-Effect Sensor



4th PCB Board

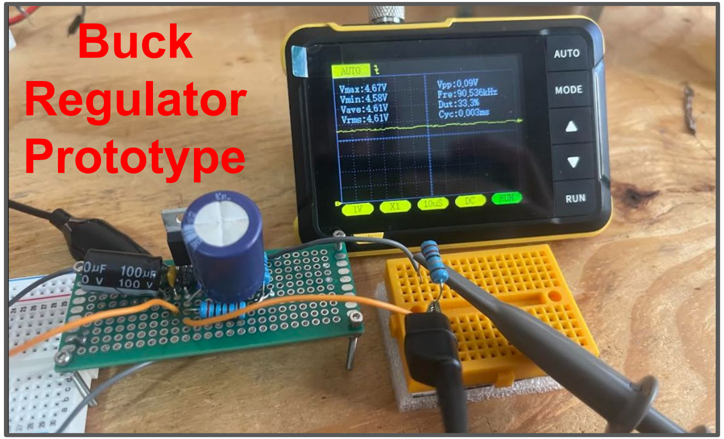




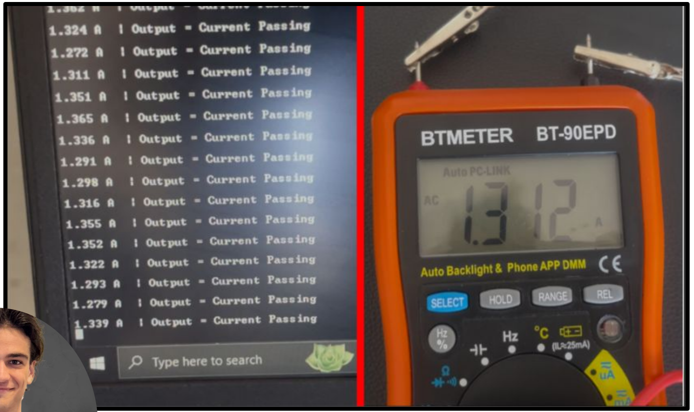


Prototyping

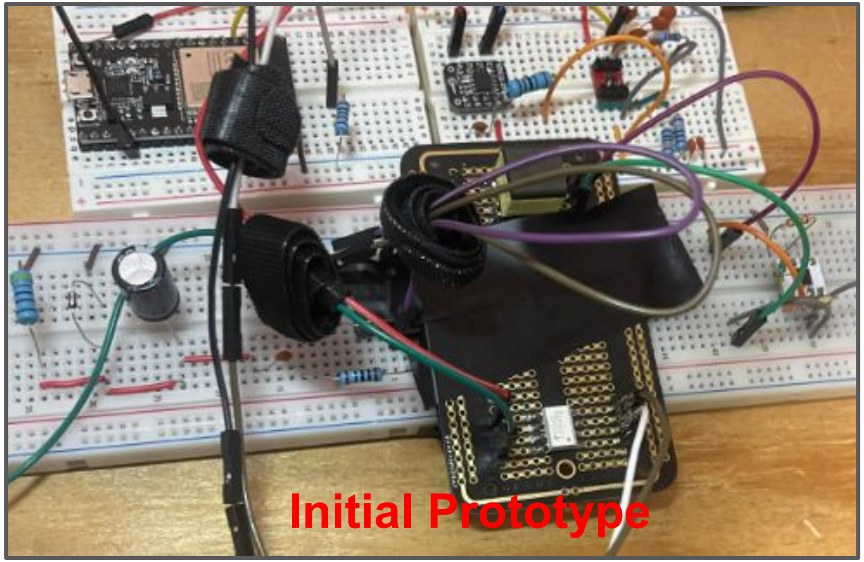
Transformer for test conditions



Buck Regulator Prototype



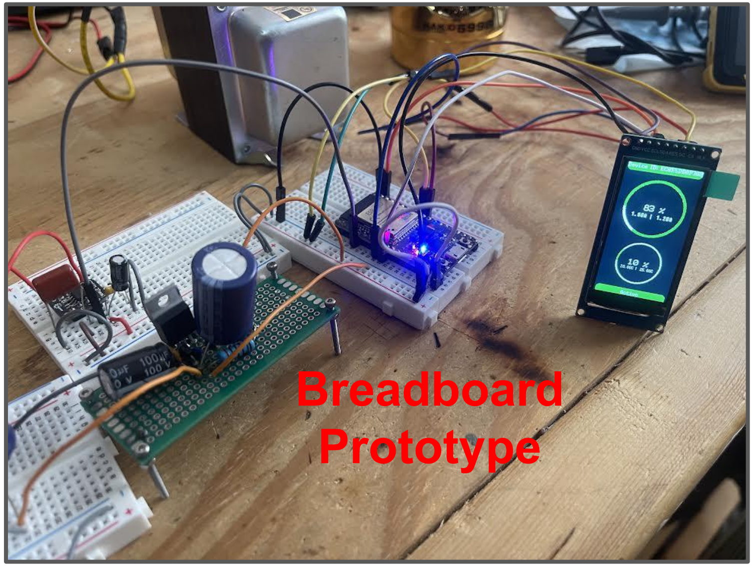
Load Measurements

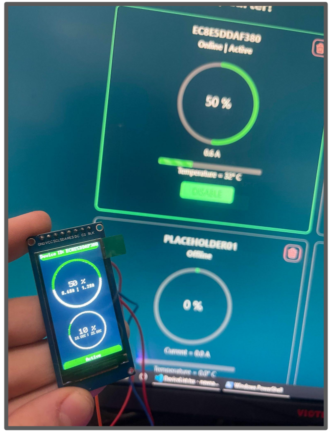


Initial Prototype

Prototyping Testing

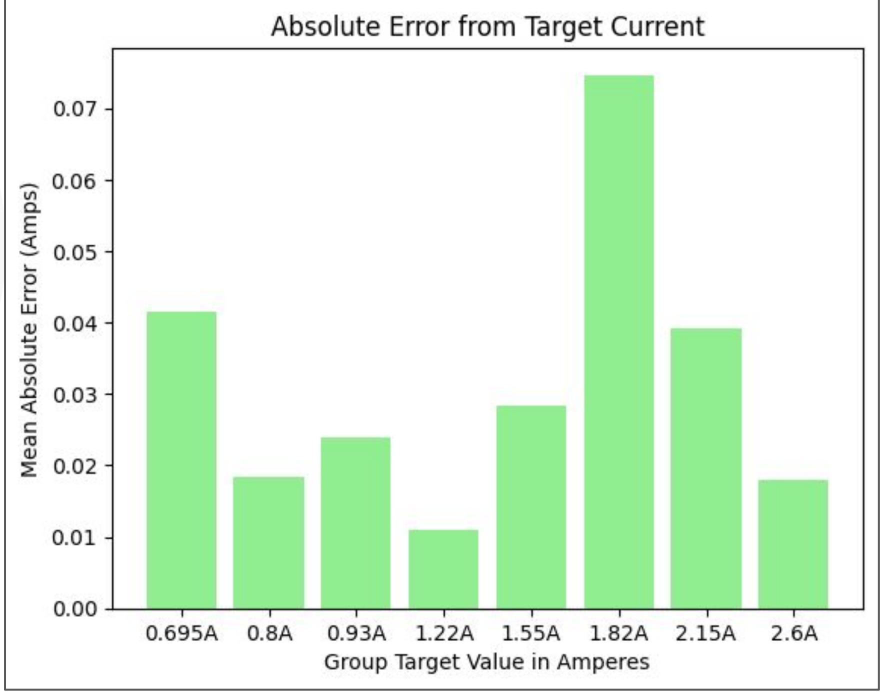
Terminal Startup Sequence





Synced up Display with Website

Testing



Average Absolute Error for a sample selection w/ known Amperage.

Based on these preliminary assessments, we found the average deviation from the known target current to be about ~50mA.

Estimated Turn-Off time from the moment a sampling window begins to the SSR actually flipping off is at worst case roughly 17.7ms. Average roughly 8.2ms.

Based on current configuration of taking 100 samples along a single cycle at 6 KHz + worst case SSR turn off time of 1.0ms.

Embedding Programing Comparison

we selected **C/C++** utilizing the **Arduino Core** framework because it offers the optimal balance between high-level abstraction for rapid development and the "Good" to "Fast" performance speeds essential for real-time circuit protection.

Programming Language Comparison			
Metrics	**C/C++**	**MicroPython**	**Rust**
Library Ecosystem	Large: Many existing libraries covering needs	Large: Many existing libraries covering needs. Not as large as C/C++	Moderate: Library support is growing, but not as vast compared to other options.
Speed	Fast: Compiled Language	Slow: Interpreted Language	Fast: Compiled Language
Ease-of-Use	Easy: Standard Development Process	Very Easy: Fast Development Process	Hard: Steep Learning Curve

Software Development Framework		
Metrics	**Arduino Core**	**ESP-IDF**
Ease-of-Use	Very Easy	Moderate
Performance	Good	Maximum
Abstraction	Primarily higher level abstraction	Full access to low level hardware
Library Support	Massive library ecosystem	Large, but pales in comparison to Arduino Core

Full Stack Comparison

We selected this stack to optimize the system for high-frequency dashboard updates and scalable, low-latency communication with the MCU.

Category	Our choice	Alternative	Reason
Frontend	React	Angular/Vue	React’s massive ecosystem and virtual DOM are more efficient for high-frequency dashboard updates.
Backend	Node.js	Python	Node’s non-blocking event loop is better at handling thousand of concurrent IoT socket connections. In addition Node offers extensive library support and packet management.
Database	MongoDB	PostgreSQL	NoSQL is more flexible for varying sensor data and is better for high volume logging.
Comm. Protocol w/ MCU	WebSockets	HTTP Polling	WebSockets reduce overhead by keeping one connection open, whereas HTTP a new handshake for every sensor update

Programming Language

Frontend: React with TypeScript — provides type safety, component reusability, and a responsive UI for the dashboard, settings, and authentication pages

Backend/Firmware: C/C++ via Arduino framework on the ESP32 MCU — handles real-time sensor polling, fault detection logic, SSR control, and Wi-Fi communication.

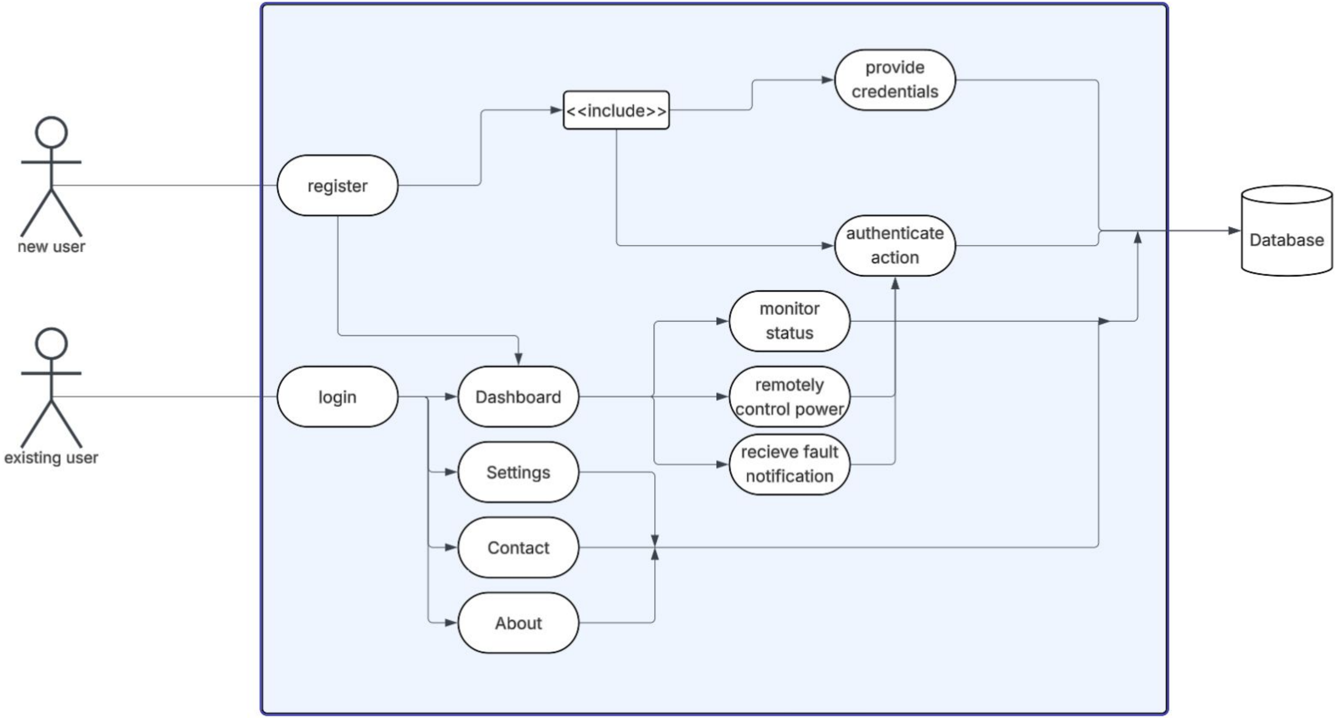
Backend Server: Node.js & Express — A high-performance middleware layer that exposes RESTful endpoints for the ESP32 to post sensor data and provides a WebSocket server for pushing real-time updates to the React dashboard.

Database: MongoDB — NoSQL document database used by the Node.js backend to store persistent sensor logs, device configurations, and user profiles.

Communication Protocol(s): REST API — Used for standard CRUD operations and interaction with the database. (Login, Authentication, etc.)

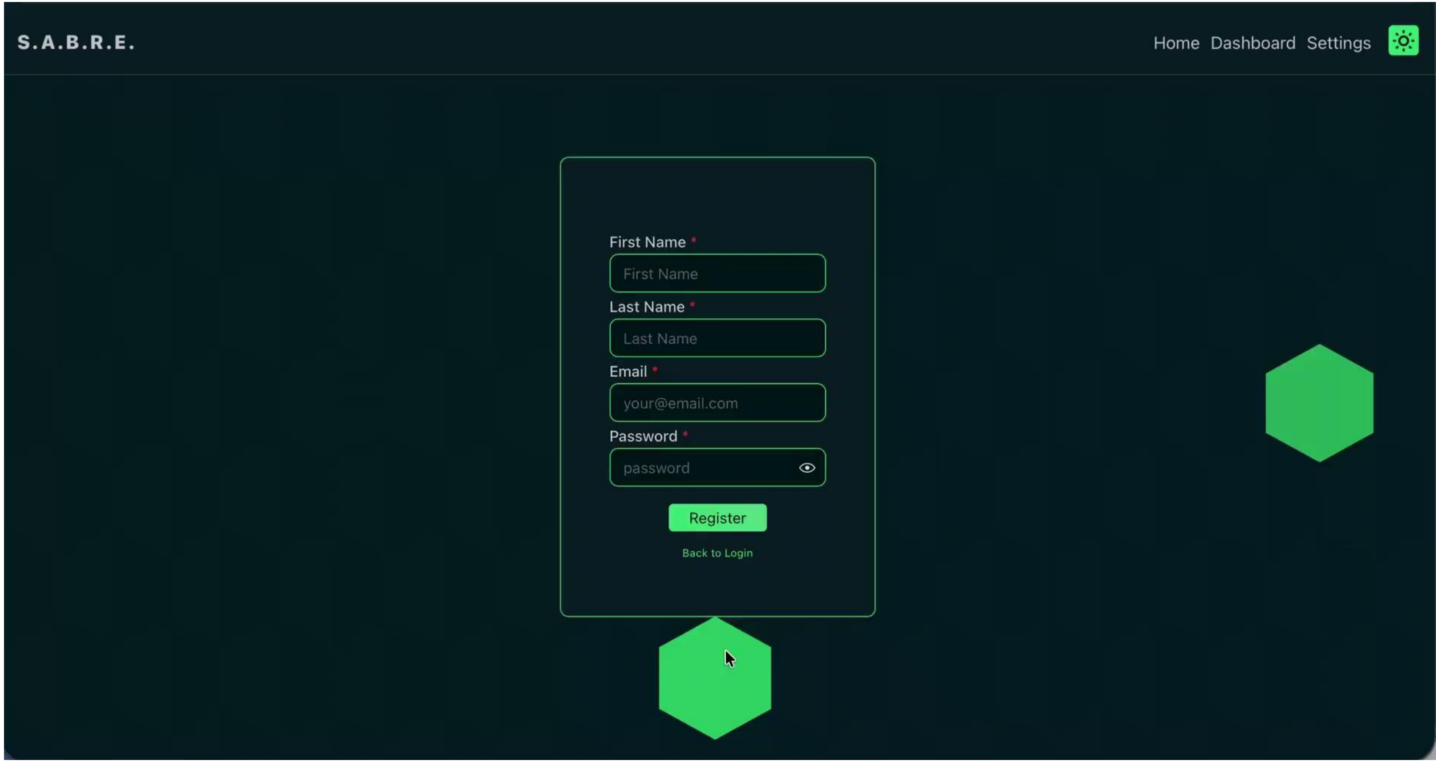
Websockets — the MCU posts sensor data (current, temperature) to individual websocket connections based on matching deviceID and userID. Allows for full-duplex communication w/ minimal overhead relative to standard REST API.

Website Use Case Diagram

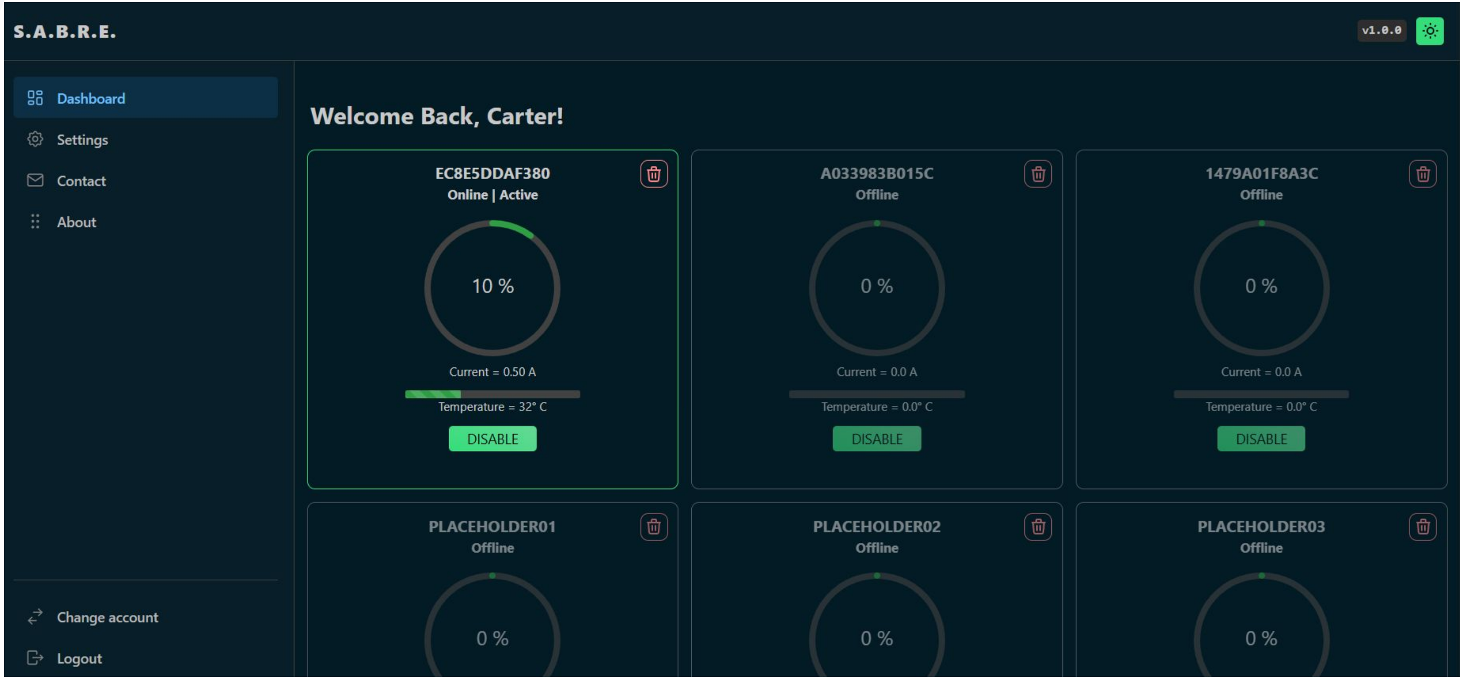


Website Interface

Login Attempts

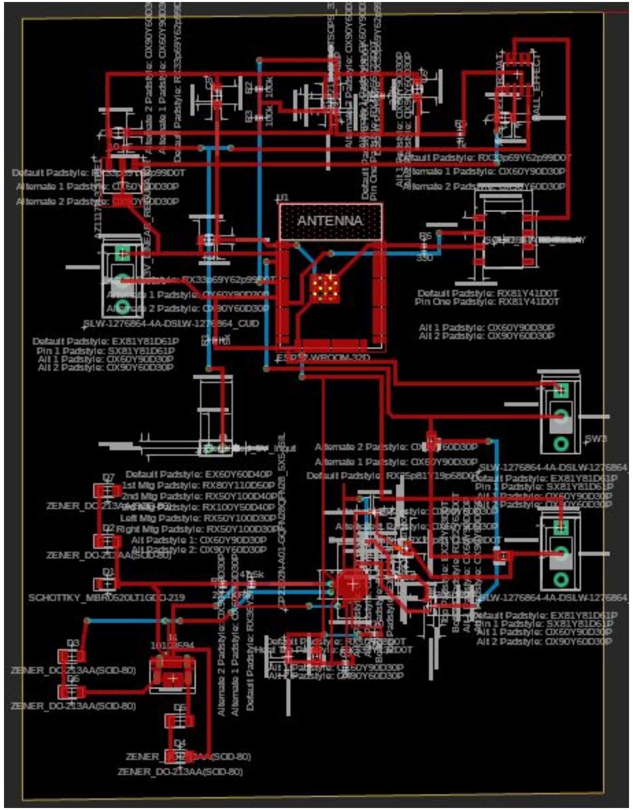


Website Interface



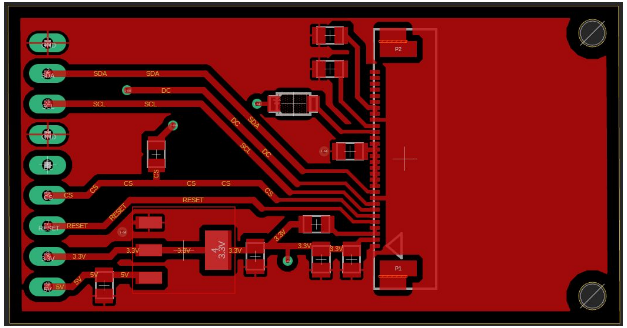
Challenges Faced

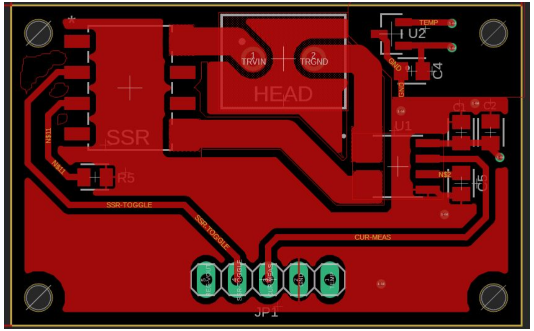
Chasis required specific dimensions



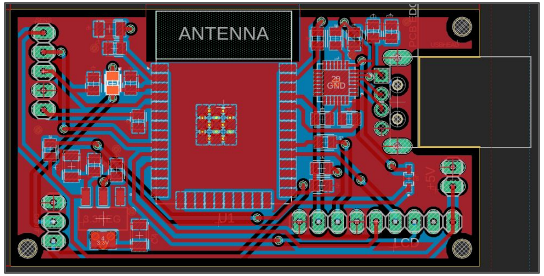
Wires became too intertwined

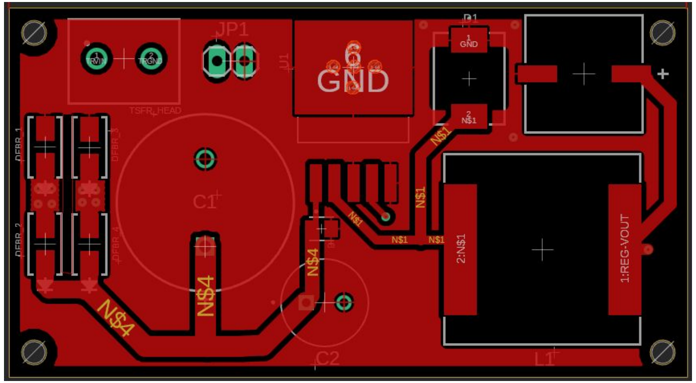
How We Solved the Challenges





- Multiple iterations of chassis were made
- PCB split into 4 separate PCBs





Work distribution

Work Distribuition	
Name	**Responsibilities**
Emmanuel Lopez	Adminisitrative Content
	PCB Design
	Schematics Design
	PCB Soldering
Carter Harman	PCB Design
	Embedded Design
	Website backend
	PCB Soldering
David Durosinimi	Website Frontend
	Embedded Design
	PCB Soldering
	Website Communication
Eliezer Urdaneta	Project Lead
	Design Documentation
	Research Documentation
	PCB Manufacturing

Budget

Bill of Materials for PCB			
Component	**Name**	**Qty**	**Cost**
Flyback Regulator	LM5180NGUR	5	$22.65
Replacement Buck Reg.	LM2576HV	3	$26.40
30-Pin LCD Connector	WM7976CT-ND	2	$5.42
60 mA LED DRV	AL5809-60P1-7	2	$1.44
3.3 Linear Reg.	LD1117S33TR	5	$1.70
30V Schottky Diode	BAT760-7	3	$1.41
ESP32	ESP32-WROOM	2	$9.68
UART Bridge	CP2102N	3	$12.96
Hall Sensor 1	ACS71230A	2	$5.84
Hall Sensor 2	ACS71220A	2	$5.84
Screw Terminal	691137710002	5	$1.80
Temperature Sensor	MCP9700T-E/TT	5	$2.00
60V Schottky Diode	MBRS360T3G	4	$1.28
FT LCD Display	ER-TFT019-1	2	$12.78
Solid State Relay	TLP3547	3	$22.98
SOT23 TO DIP ADAPTE	1568-00717-ND	2	$2.50
LCD Breakout Boards	SPI TFT LCD Display Module	2	$15.99
USBA Female Header	MEETOOT	10	$6.99
Wirewound Potentiomete	Electronics-Salon 200W 500 OHM	1	$35.00
100VA Transformer	TR100VA001	1	$54.99
Micro Current Transform	DL-CT08CL5	2	$7.99
Generic Perfboard Kit		32	$8.50
Misc.	Resistors, Capacitors, Inductors		$82.44
PCB Boards		5	$41.61
PCB Shipping		5	$84.01
Total			$474.20

Citations

[1] Espressif Systems, "ESP32-WROOM-32E & ESP32-WROOM-32UE Datasheet," Espressif Systems, Shanghai, China, pp. 1–50, 2023.

[2] Toshiba Electronic Devices & Storage Corp., "TLP3547 photorelay (MOSFET output) datasheet," Toshiba Semiconductor, pp. 1–20, Mar. 2020.

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