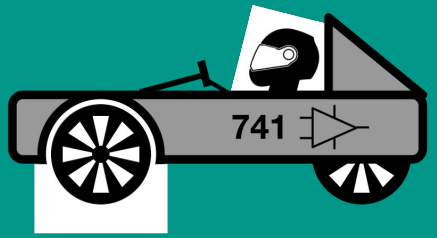


Rebuilt Electric Go-kart

Group 27

Our Team

Abdullah Choudhry
Electrical

Grace Tuomala

Computer Engineering

Julian Yerger

Electrical Engineering

Abdullah Arshad Choudhry

Electrical Engineering

Fouad Braimoh

Computer Engineering

Abdullah Choudhry
Electrical

Motivation and Background: **Electrathon**

- **Electrathon:** competition for electric vehicles to complete as many laps as possible on a **closed-loop track** during a **1-hour** period using at most **1kWh** of energy
- **This project:** an electric go-kart to race in the Tampa Bay Electrathon's **open/lithium-ion class,** designed for performance and efficiency, paired with a **driver assistance app** to display vital information during the race

Abdullah Choudhry
Electrical

Goals and Objectives

	Hardware	Software
Basic	Build custom DC-DC converters to supply power from battery pack to 15V, -15V, 5.5V, and 3.3V rails	In-car Bluetooth display including lap counter, temperature monitor, time left in race, and button to start/stop race, easy to use & visually appealing user interface
Advanced	Motor controller with greater efficiency than typical RC controller, finish at least one Electrathon race	Send race statistics from car to subscribing spectators; measure and display speed, current, and voltage; display compatibility with varying device screen sizes
Stretch	Win a Tampa Bay Electrathon race, Custom 1800W DC fast charger to recharge battery between races	Graphs showing energy budget and/or voltage & current over time, iOS compatibility

Abdullah Choudhry
Electrical

Work Distribution

Julian Yerger (EE)

Abdullah Arshad Choudhry (EE)

Grace Tuomala (CpE)

Fouad Braimoh (CpE)

Electrathon Go-Kart

- Design AC/DC battery charger
- Spot Weld Cells for Battery Pack
- Motor Controller Design
- Power PCB Layout
- Weld Frame
- Sub-converter Design
- Control PCB Design

- Control Board Block Diagram
- Connect Battery Holders
- Logic PCB Layout
- Main Control Board PCB Layout
- Integrate sensors into Main board
- Aid transformer design

Hardware

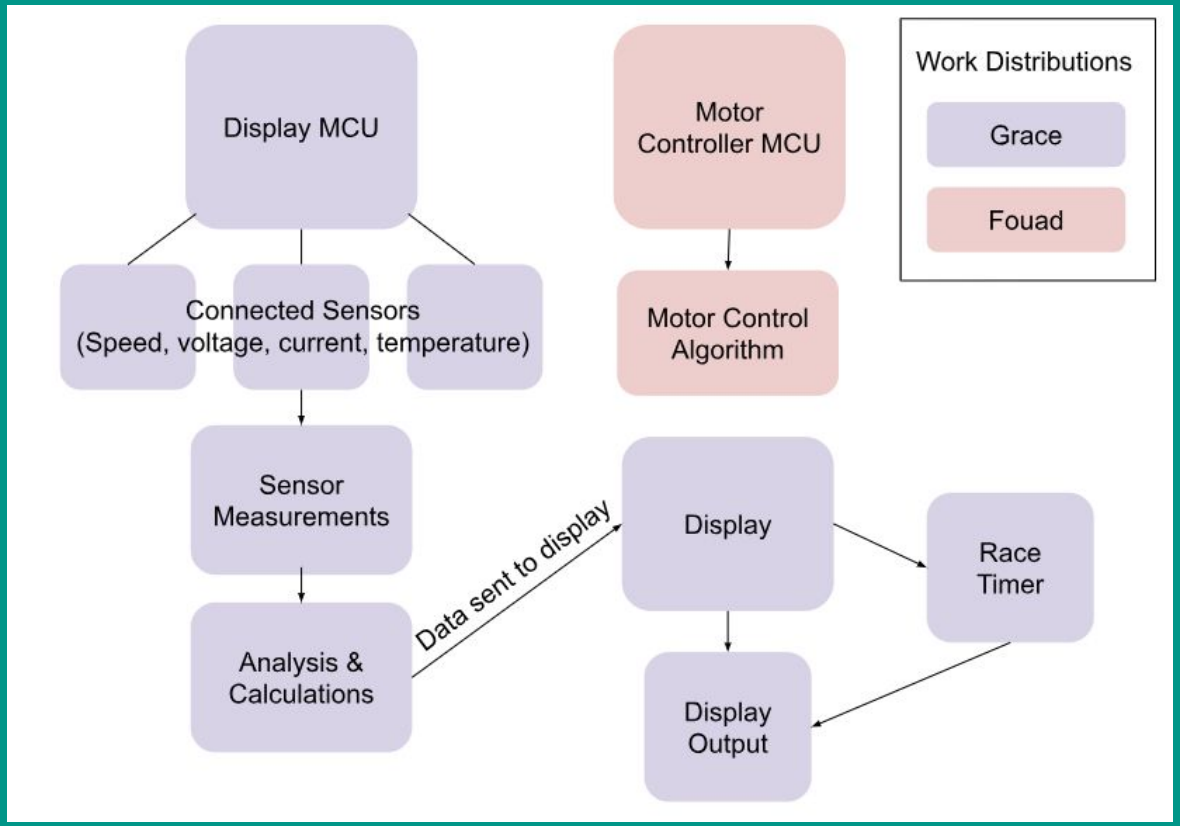
Software

Display MCU
- Read measurements from sensors
1. Voltage Divider for battery pack voltage
2. Current
3. Speed (magnet on wheel)
- Analysis and Calculations to be sent to display output

Motor Controller MCU
- Writing up the algorithm

Grace Tuomala
Computer

Software Design: Work Distribution



Abdullah Choudhry
Electrical

Engineering Specifications

Powertrain	**Battery Capacity (0.1C)**	1000Wh, +/- 5%
	Battery Weight (cells)	< 15lbs
	Motor Controller Peak Efficiency	> 90%
User Interface	**Voltage Measurement Accuracy**	+/- 5%
	Lap Counter Accuracy	+/- 10%
	Display Response Time	3 seconds
Battery Charger	**Maximum Voltage**	63V +/- 5%
	Maximum Current	36A +/- 5%

Abdullah Choudhry
Electrical

Hardware Technology Comparison: Motor

	Brushed DC Motor	Brushless DC Motor
Cost	Lower initial, higher maintenance	Pricier, low maintenance
Efficiency	Low	High
Lifespan	Low	High

Most Electrathon teams use a brushed motor, which is notably simpler to design and implement, but less efficient

Abdullah Choudhry
Electrical

Hardware Technology Comparison: Battery

Types of Battery Packs	Description
Alkaline	Cheaper option which is decent for every application but are not rechargeable
Nickel Metal Hydride (NIMH)	Reusable and more environmentally friendly but they are heavy and have a low nominal voltage
Lithium Ion	High cost and sub-optimal performance at extreme temperatures but offer higher voltage and are lighter

Abdullah Choudhry
Electrical

Hardware Technology Comparison: Semiconductor Material

	Si	SiC	GaN
Band Gap (eV)	**1.1**	**3.2**	**3.4**
Critical Field (10^6 V/cm)	**0.3**	**3**	**3.5**
Electron Mobility	**1450**	**900**	**2000**
Electron Saturation Velocity (10^6 cm/sec)	**10**	**22**	**25**
Thermal Conductivity (Watts/cm^2 K)	**1.5**	**5**	**1.3**

Abdullah Choudhry
Electrical

Hardware Comparison

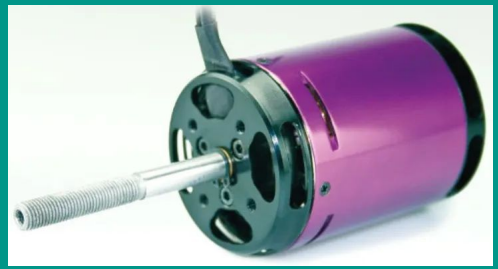
	Relative Permittivity	Dielectric Str. (V/μm)	Typical Value (μF)	Dissipation Factor x10^-4
Ceramic Class 1	12 to 90	< 100	10^-6 to 1	10 at 1-MHz
Ceramic Class 2	200 to 14,000	< 35	10^-6 to 1	251 at 1-MHz
Electrolytic	9.6	710	1 to 47,000	100 at 120-Hz
Tantalum	26	625	1 to 100	600 at 120-Hz
Mica	5 to 8	118	10^-6 to 3*10^-3	4 at 1-MHz
Polyester Film	3.3	470/220	10^-4 to 10	170 to 300 at 100-kHz
Polypropylene Film	2.2	650/450	10^-4 to 102	2 to 25 at 1-MHz

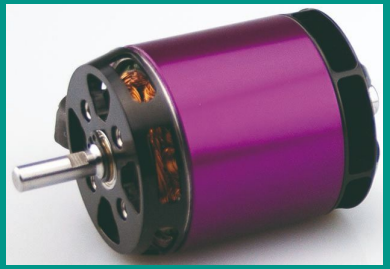
Julian Yerger
Electrical

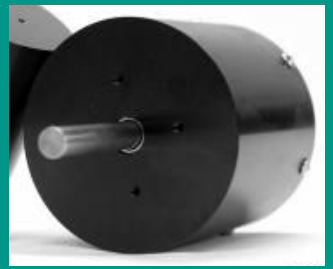
Hardware Part Selection: Motor

Table 3.5 - Motor Performance Parameters

	Rotomax 150cc	Astro 3220	KDE7 215XF	CA120	Hacker A50-16L	Hacker Q100	Hacker A60-18L
kV (RPM/V)	150	137	135	150	265	110	149
R_M (ohms)	0.011	0.05	0.057	0.005	0.031	0.0106	0.02
I_0 (amps)	5.2 at 51.8V	1 at 50V	0.5 at 10V	13 at 20V	0.95 at 8.4V	1.86 at 8.4V	1.6 at 8.4V
Loss (W/RPM)	0.035	.0073	0.0037	0.087	0.0036	0.0169	0.0107
Weight (kg)	2.53	1.8	0.56	2.73	0.45	1.83	0.91
Peak Efficiency	93.1	94.8	95.7	90.8	94.3	96.1	94.9







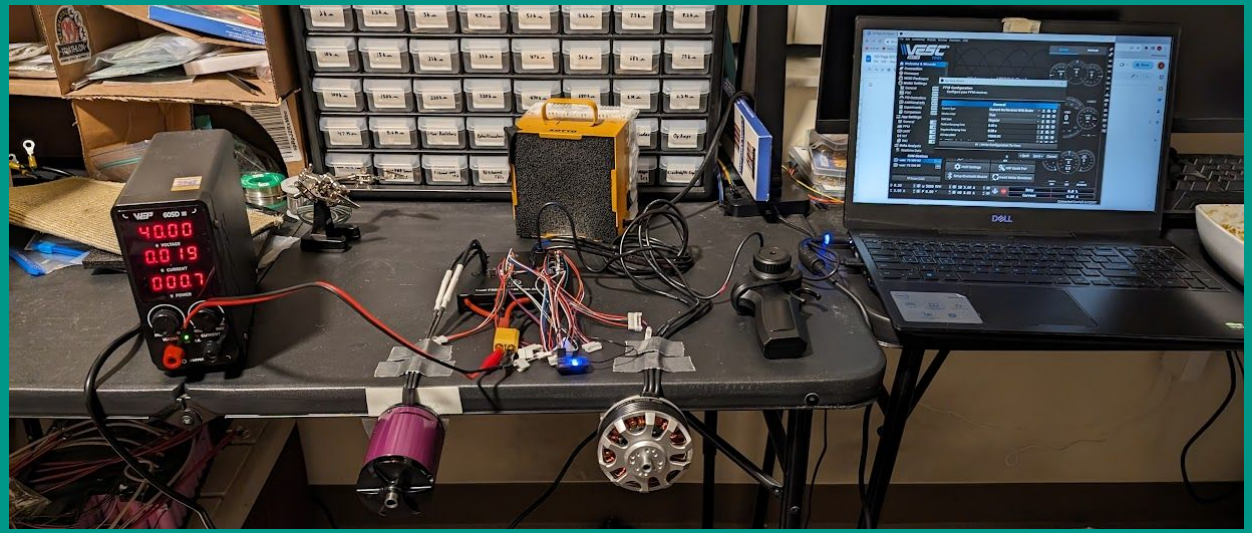
Julian Yerger
Electrical

Hardware Part Selection: Motor

Table 3.6 - Motor Efficiency Curves							
	Rotomax 150cc	Astro 3220	KDE7 215XF	CA120	Hacker A50-16L	Hacker Q100	Hacker A60-18L
η at 500W	84.1	91.3	94.5	78.9	92.8	92.1	91.5
η at 1000W	87.4	93.1	95.4	83.2	94.2	93.7	93
η at 1500W	89	94	95.7	85.3	94.2	94.5	93.9
η at 2000W	90	94.5	95.4	86.7	–	95	94.4
η at 2500W	90.7	94.8	94.9	87.6	–	95.4	94.8
η at 3000W	91.2	94.8	94.4	88.4	–	95.7	–
η at 4000W	92	94.5	93.1	89.4	–	96.1	–
η at 5000W	92.6	94	–	90.2	–	–	–
η at 6000W	93.1	93.3	–	90.8	–	–	–

Julian Yerger
Electrical

Hardware Part Selection: Motor



- At 40V, I_0 was 1.7A for the A60 and 1.73A for the KDE
- Datasheet not necessarily wrong, just measured at a lower voltage
- Winding resistance was 33.6 for A60 vs 76.8 mohms for KDE
- Used a 4-wire Kelvin method, but still has resistance in connectors

Julian Yerger
Electrical

Hardware Part Selection: Battery

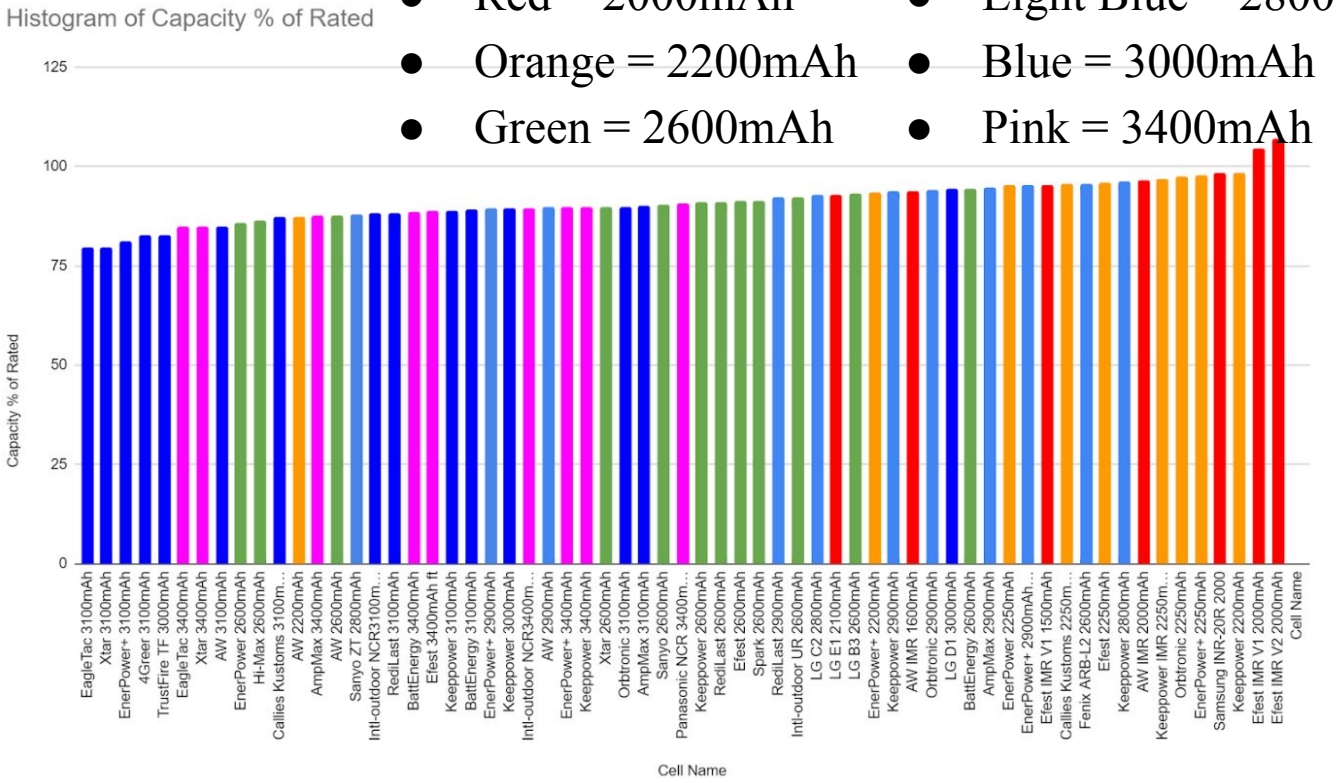
18650 case size

5A discharge

Smaller cells have lower resistance and higher percent of rated capacity

Will use 2Ah cells in 15S x 9P config.

- Red = 2000mAh
- Orange = 2200mAh
- Green = 2600mAh
- Light Blue = 2800
- Blue = 3000mAh
- Pink = 3400mAh



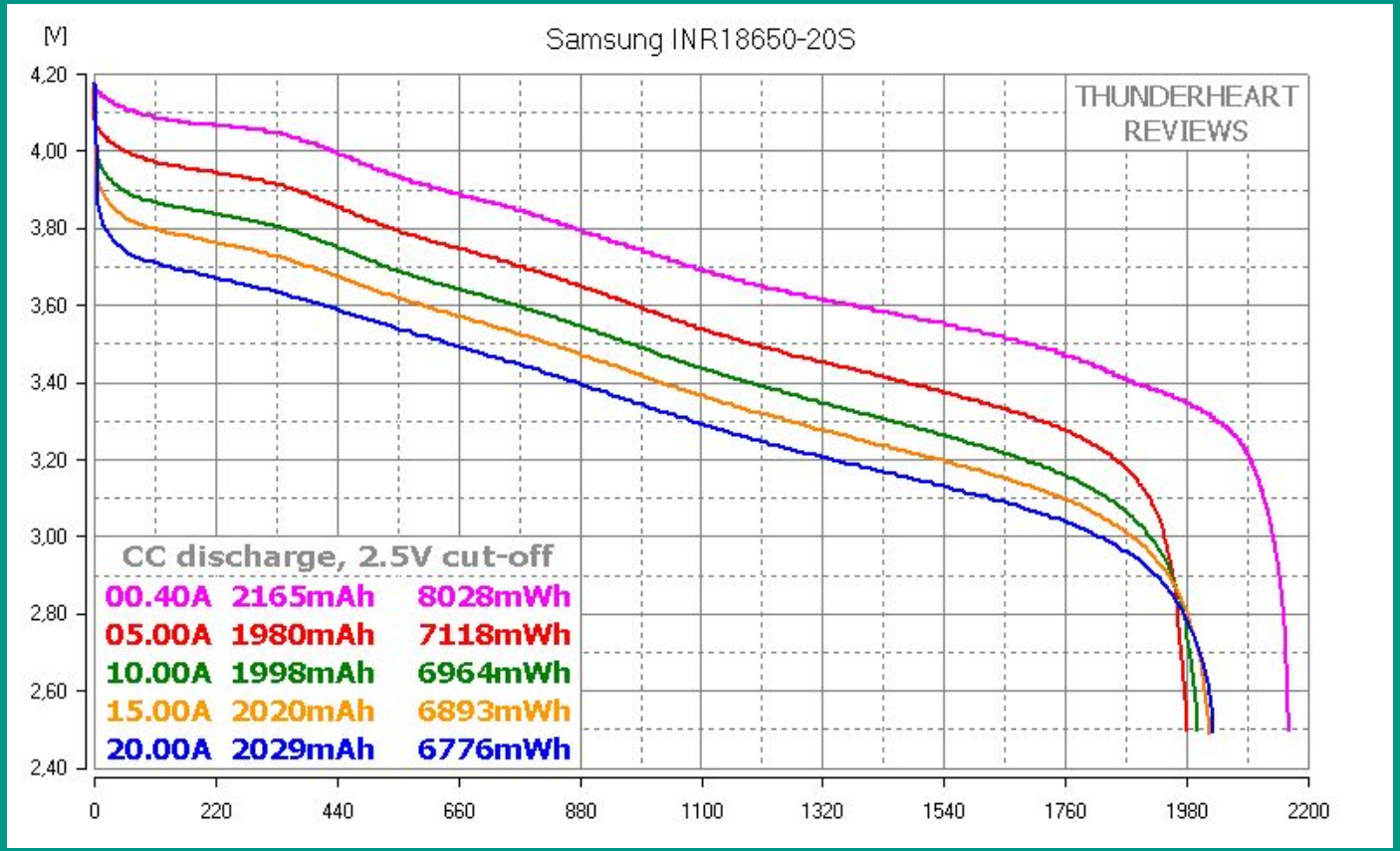
Julian Yerger
Electrical

Hardware Part Selection: Battery

Selected the Samsung 20S

Tested very well

Rated for 30A per cell, will only see 2500/(135*3)= 6A



Julian Yerger
Electrical

Hardware Part Selection: Transistors

- 70 options for GaN FETs, all but 4 intended for 600V
- At low frequency $R_{DS\text{-}On}$ is more important than gate charge

Model Name	Maximum Voltage (V)	$R_{DS\text{-}On}$ (milli-ohms)	Gate Charge (nC)	Price (x12)
GS61004B	100	22	3.3	$6.64
GS61008T	100	9.5	8	$11.09
GAN3R2-100C	100	3.2	12	$3.68
GAN7R0-150L	150	7	7.6	$2.76

Julian Yerger
Electrical

Hardware Part Selection: Capacitors

- Design Conditions: 55.5V average, $10V_{Pk\text{-}Pk}$ ripple, 50A, 10 kHz
  - $R_{Load} = 55.5/50 = 1.11$ ohms
  - $V_{Ripple} = V_{Peak} / (f*R*C)$
  - $C = V_{Peak} / (f*R*V_{Ripple}) = 55.5/(10000*1.11*10) = 500\ \mu F$
- Use two 260 µF polypropylene capacitors each rated to 23A ripple current

Grace Tuomala
Computer

Software Comparison: Display Options

	LCD With Dedicated MCU	LCD Connected to Central MCU	Smartphone App
Number of Microcontrollers	3	2	2
Languages Used	C only	C only	C, along with a development language such as JavaScript, Dart, or Kotlin
Number of IDEs	1-3	1-2	2-3
Learning Opportunities	Embedded programming only; display interfacing	Embedded programming only; display interfacing	Embedded programming and app development

Fouad Braimoh
Computer

Software Selection: Display MCU

	Operating Voltage	Clock Speed	Memory	Useful Features	Price
Arduino Uno	5V	16 MHz	32 KB Flash, 2 KB SRAM	USB connection, Power jack	$27.60
Arduino Mega	5V	16 MHz	256 KB Flash, 8 KB SRAM	USB connection, Power jack	$48.40
ESP 32 WROOM	3.3V	240 MHz	448 KB ROM, 520 KB SRAM	Low power options, Bluetooth connection, Wi-Fi, USB connection	$8.00
STM 32	1.8-3.6V	120 MHz	1 MB Flash, 128 KB SRAM	Low power options	$13.52
MSP 430	1.8 – 3.6V	25 MHz	512 KB Flash, 32 KB SRAM	Ultra-low power mode	$7.93

Grace Tuomala
Computer

Software Selection: Development Platform

	Flutter	Thunkable	React Native
Language	Dart	Codeless	JavaScript
Support Community	Support groups on Discord, Slack, Stack Overflow, Reddit, and Google Developer	Thunkable Community Forum with about 20 posts/day	Multiple Discord groups, Slack; tagged content on Medium, Hacker News, and Reddit
Industry Relevance	Some skills may be applicable to industry	Little to none	Highly applicable to industry (JavaScript/frontend development)
Setup Requirements	Need separate IDE and Android Studio; multi-step installation process	Online interface and live testing app downloaded to phone	Need separate IDE
Limitations to free access	N/A (Open-source)	100MB storage and 2 download/month limit	N/A (Open-source)

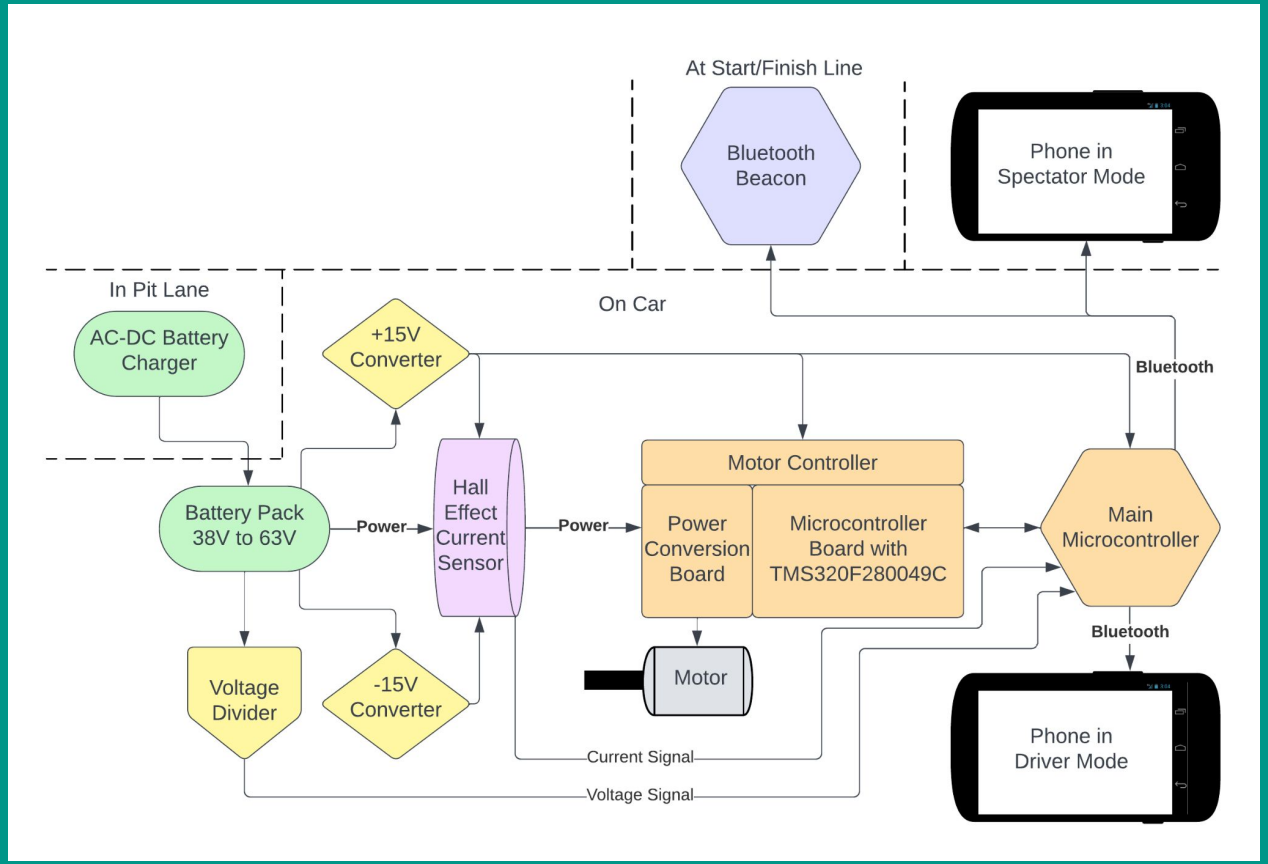
Fouad Braimoh
Computer

Software Selection: Motor Controller MCU

Model	ARDUINO UNO (with FLIPSKY ESC)	TMS320F280049C
Clock Frequency	16MHz	100MHz
Flash Memory	32KB	256KB
RAM	2KB	100KB
Processing (MIPS)	16	200
Notable Features		CLA, FPU, TMU (trigonometric accelerator), InstaSPIN-FOC
Unit Price	$27.60	$10.17

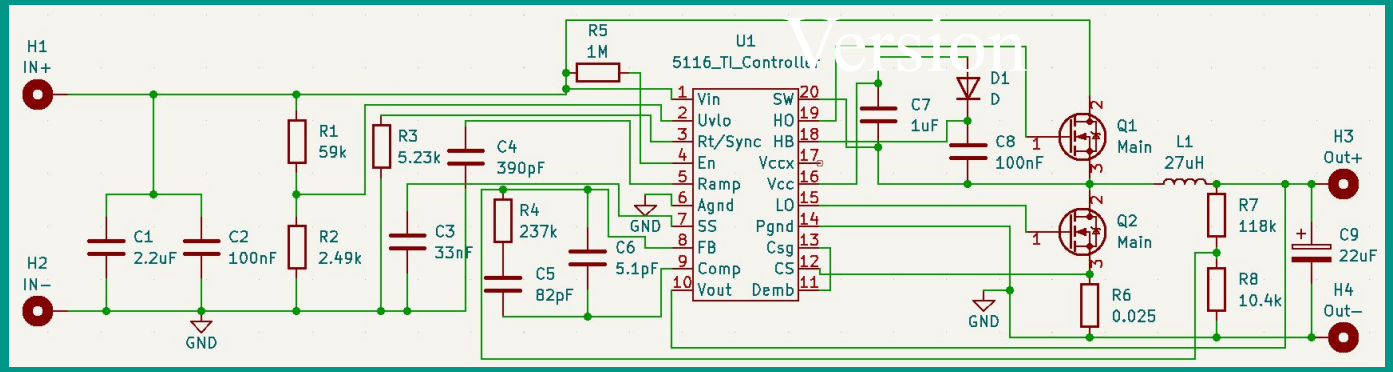
Julian Yerger
Electrical

Hardware Design: Block Diagram

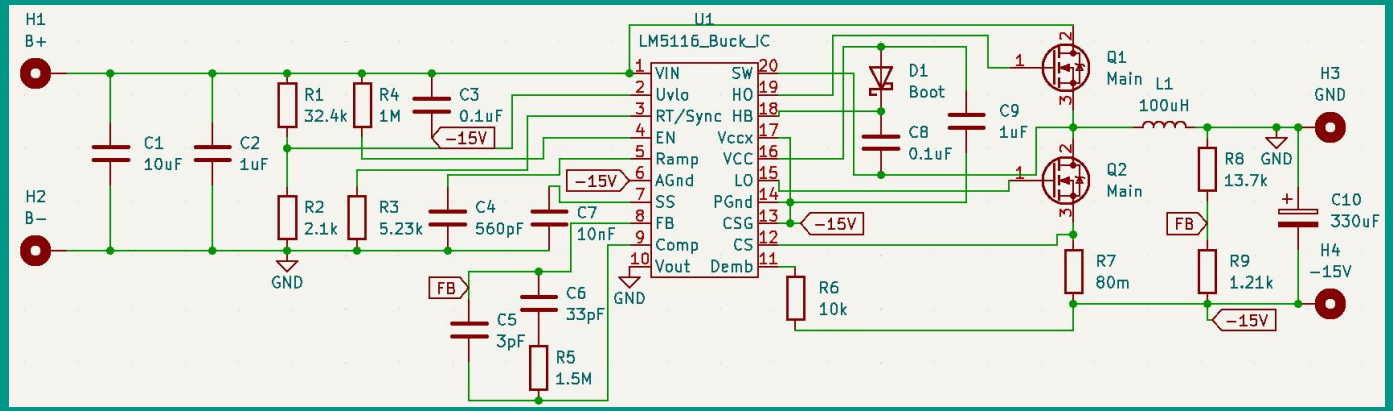


Hardware Design: +/-15V Regulators First

Julian Yerger
Electrical



+15V Regulator
I_{Out} = 2A max

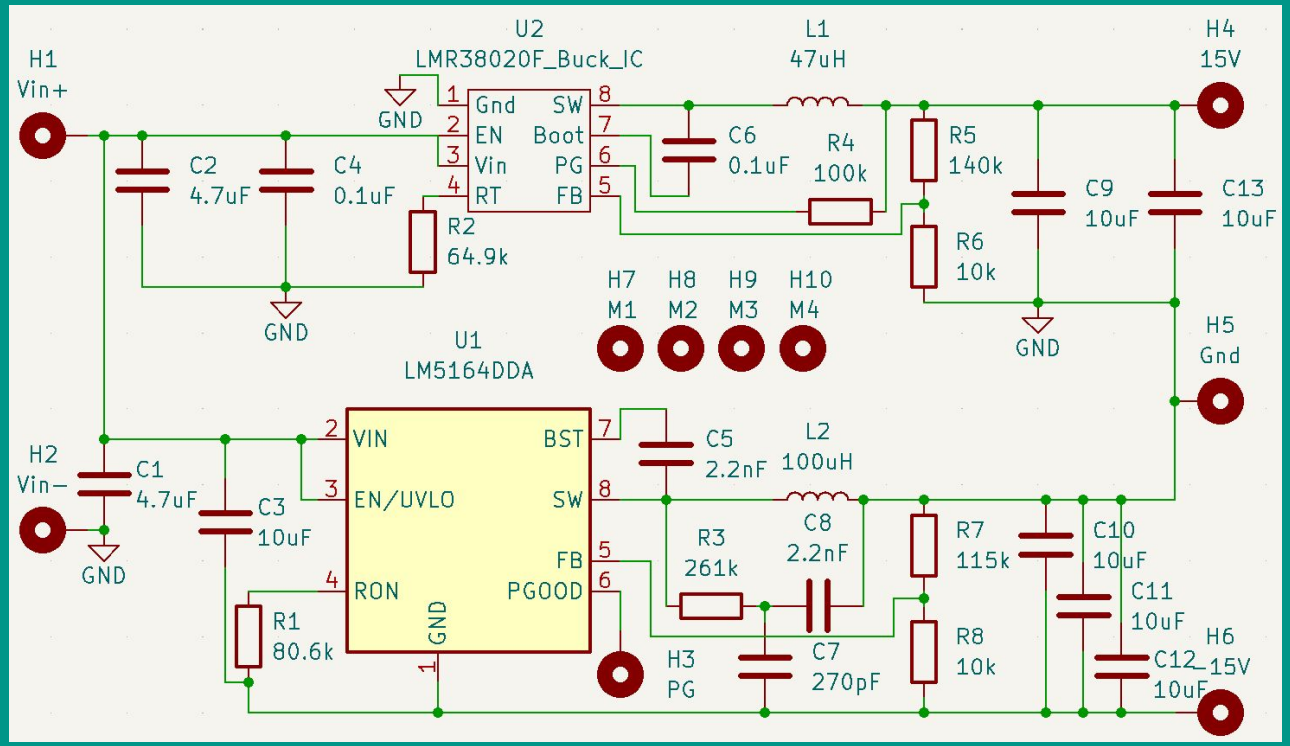


-15V Regulator
I_{Out} = 0.5A max

Hardware Design: +/-15V Regulators

Second Version

Julian Yerger
Electrical



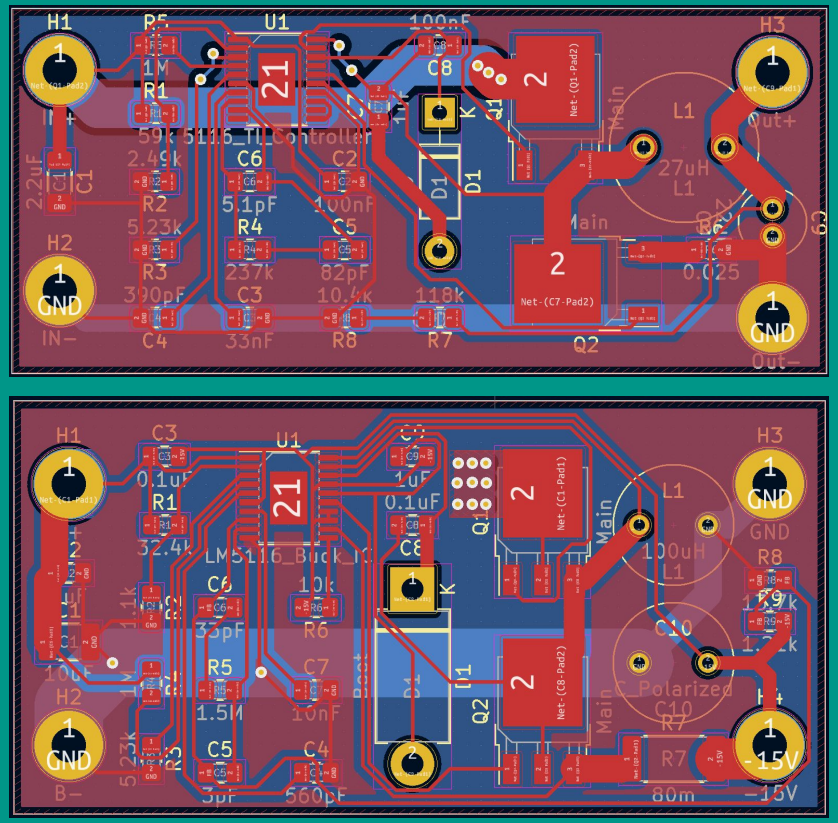
+15V Regulator
I_{Out} = 2A max

-15V Regulator
I_{Out} = 0.5A max

Julian Yerger
Electrical

+/-15V Converter PCB

First Version

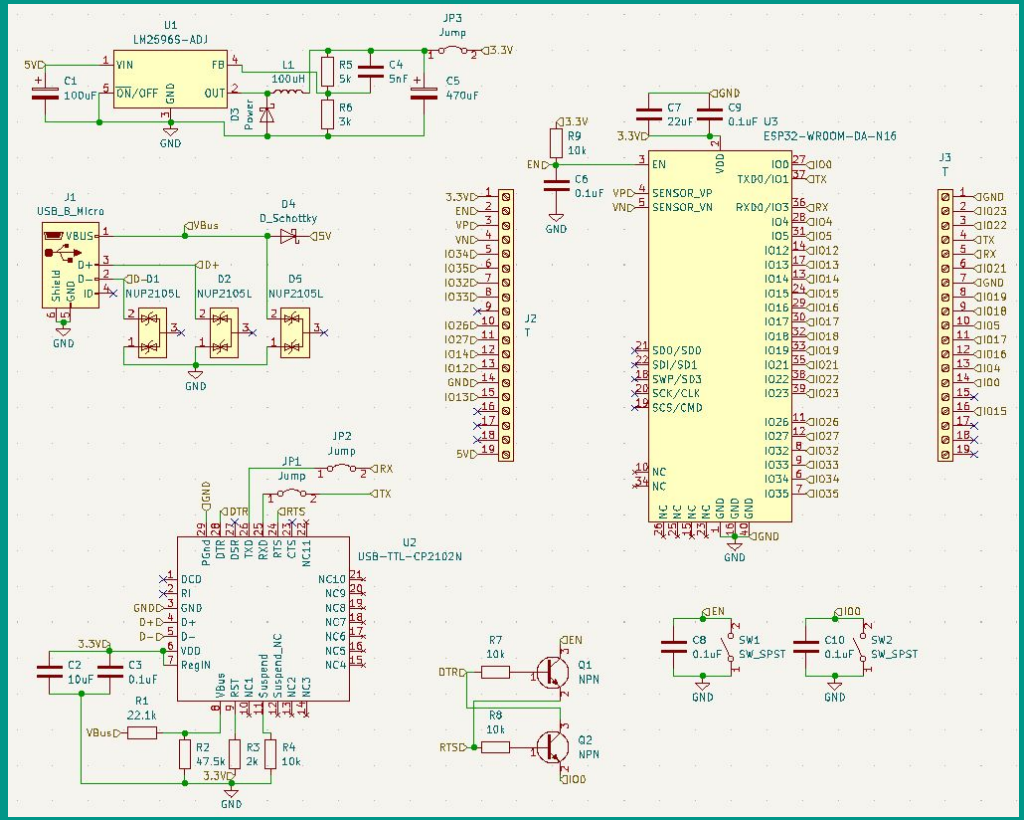


Second Version

Julian Yerger
Electrical

Hardware Design: ESP32 Version 1

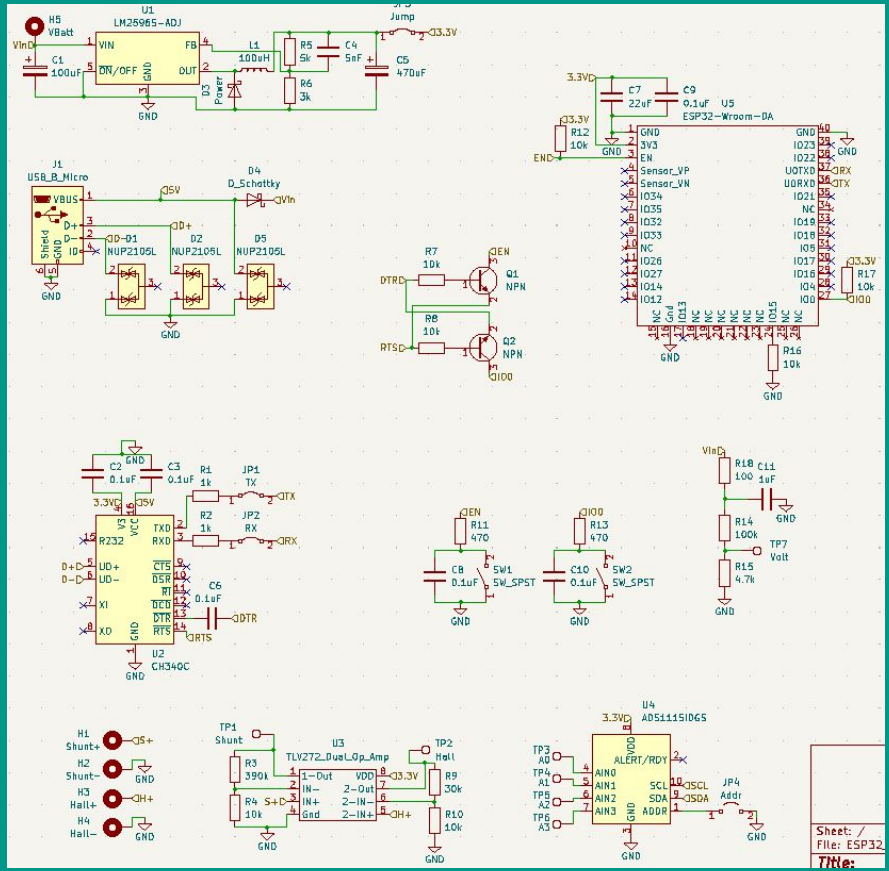
- Main microcontroller board, contains ESP32 in same form factor and pinout as V3 Devkit
- Plugs into female header pins in perfboard, then 22 gauge wires go to throttle, speed, and current sensors
- All pins broken out for maximum software flexibility



Julian Yerger
Electrical

Hardware Design: ESP32 Versions 2-3

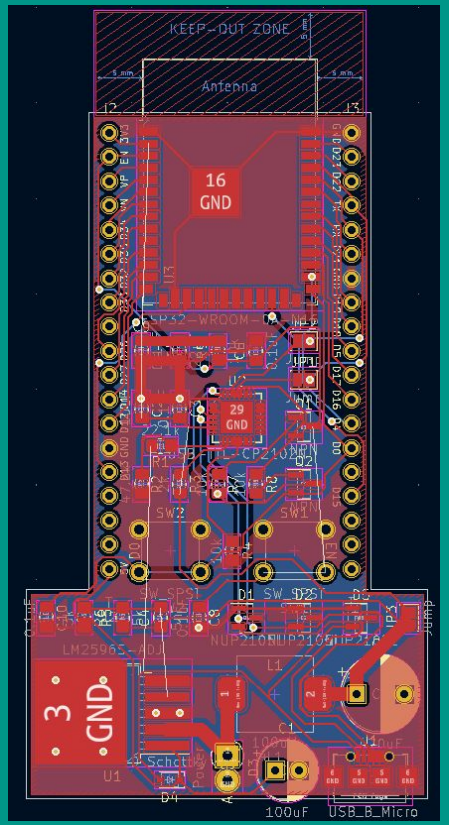
- Devkit pinout not standardized, so it uses a single PCB with ESP32 module, ADS1115 ADC, and TLV272 pre-amplifier
- LM2596 only rated to 40V, so receives 15V from converter
- Mk-II had disconnected I2C pins and error at low current, so Mk-III has NCS210 shunt monitor



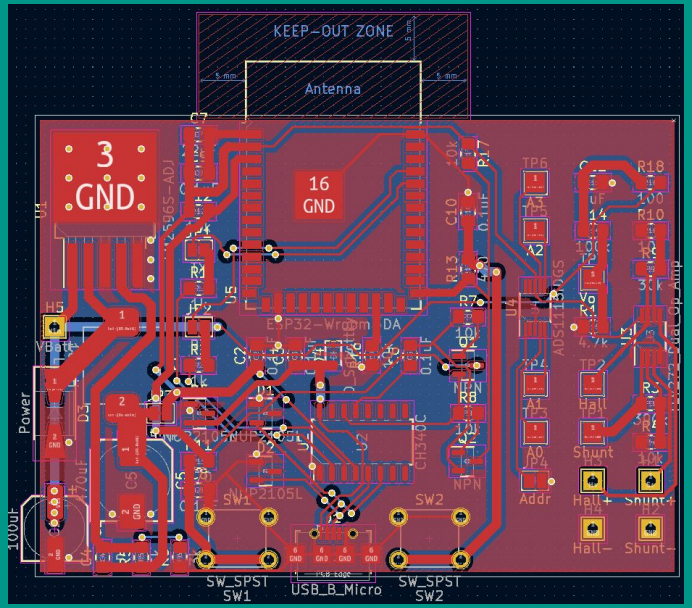
Julian Yerger
Electrical

ESP32 Sensor & Control PCB

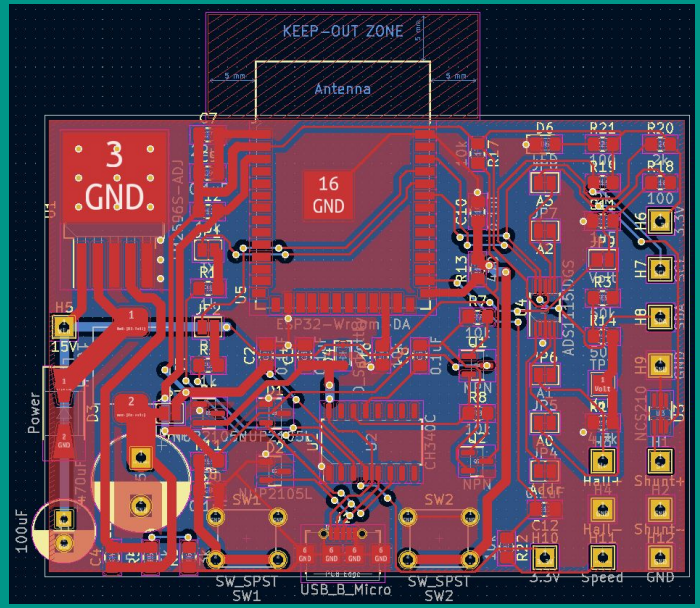
First Version



Second Version

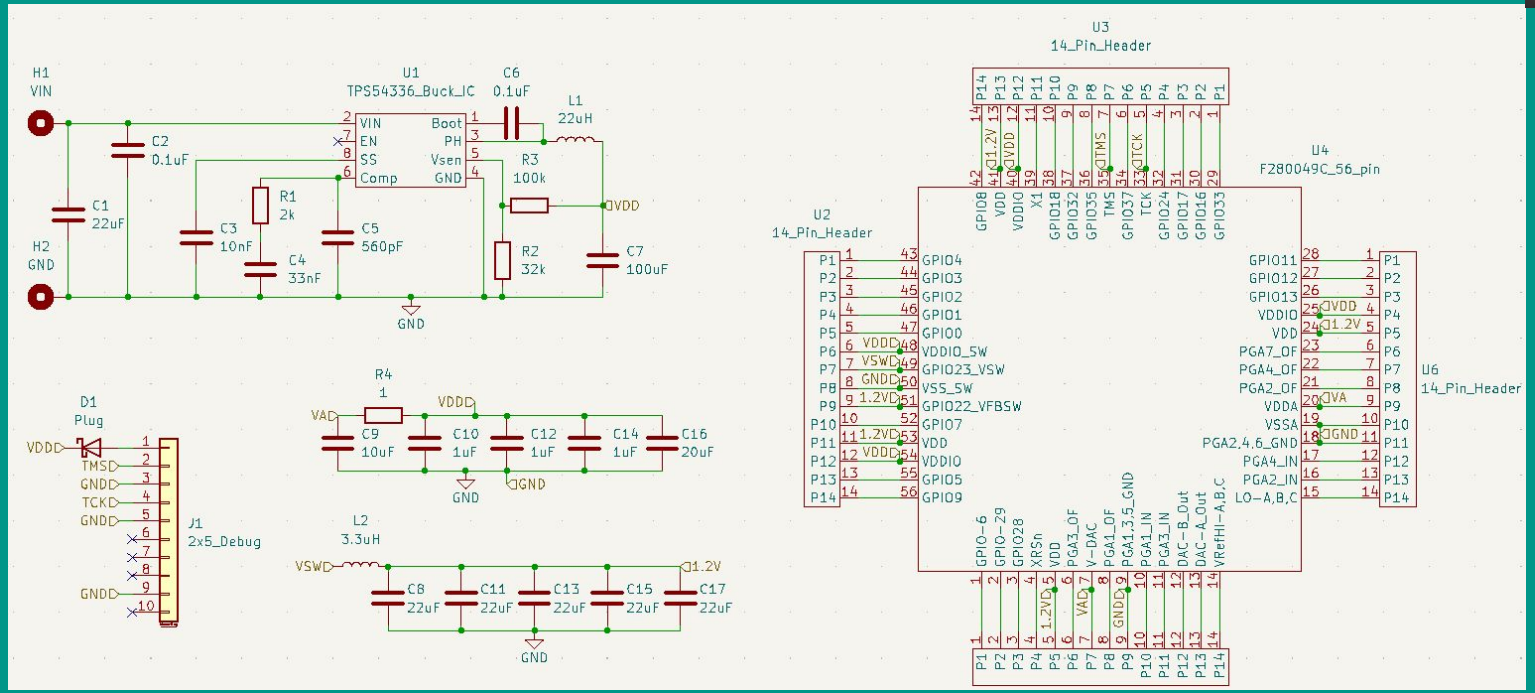


Third Version



Hardware Design: First Motor Controller

Julian Yerger
Electrical



- Motor controller MCU on a daughterboard for easy replacement
- F280049 is nominally 3.3V, but the core runs on 1.2V

Hardware Design: First Motor Controller

Julian Yerger
Electrical

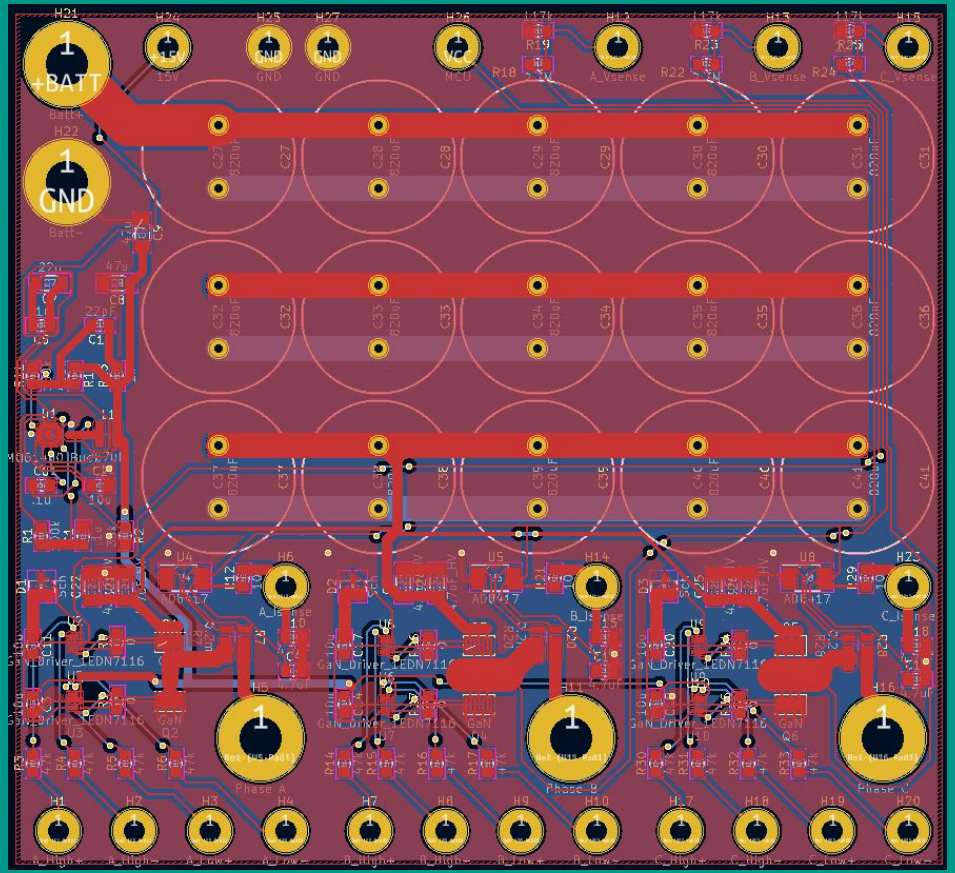
GaN instead of Si power FETs

EDN7116 drivers use differential sensing, no optocoupler so more reliable timing

LMQ61460 buck IC has ultra-low quiescent current, efficiency of 91% at 1mA and 77% at 0.1mA

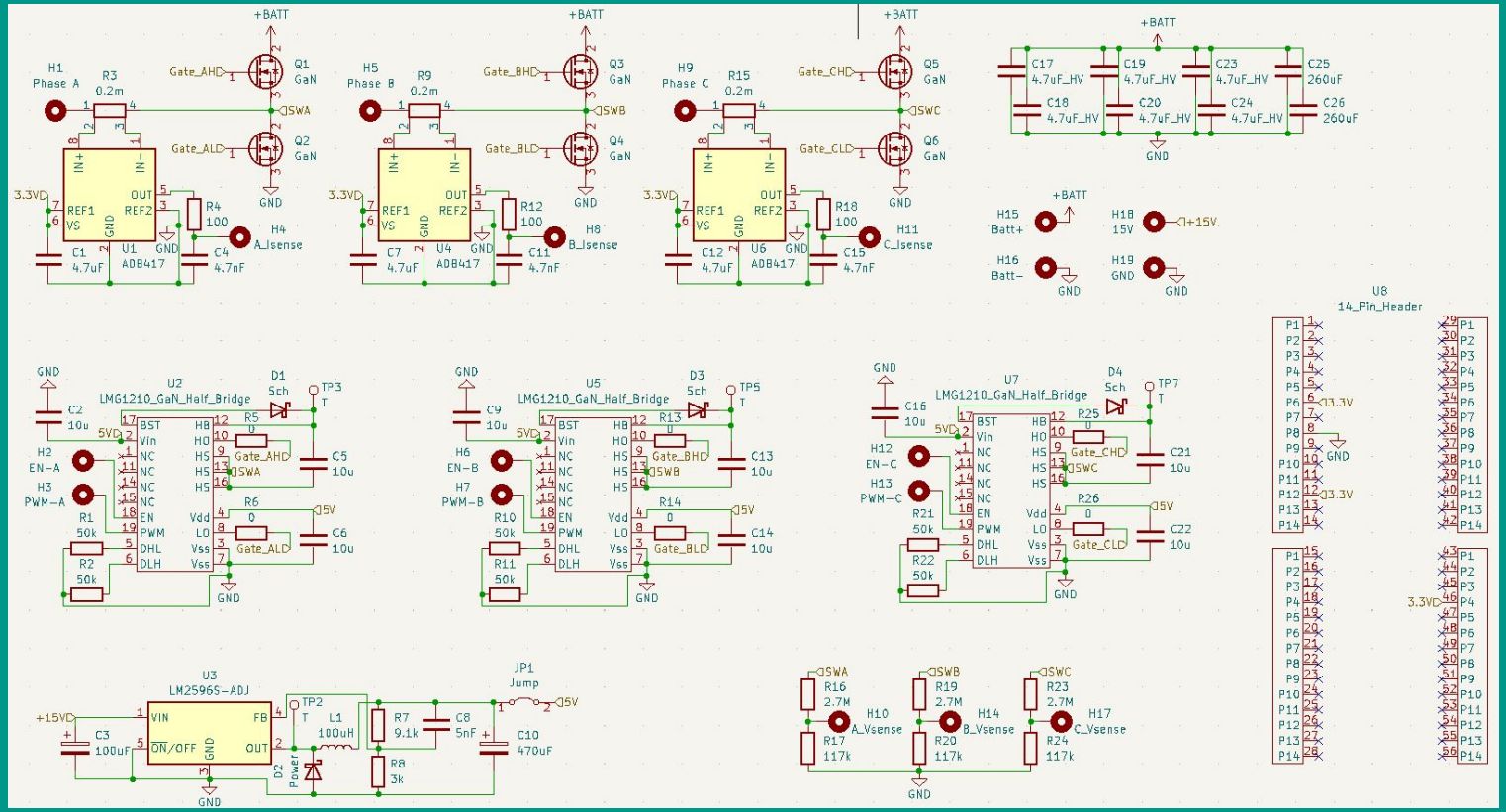
Julian Yerger
Electrical

First Motor Controller PCB Design



Hardware Design: Second Motor Controller

Julian Yerger
Electrical



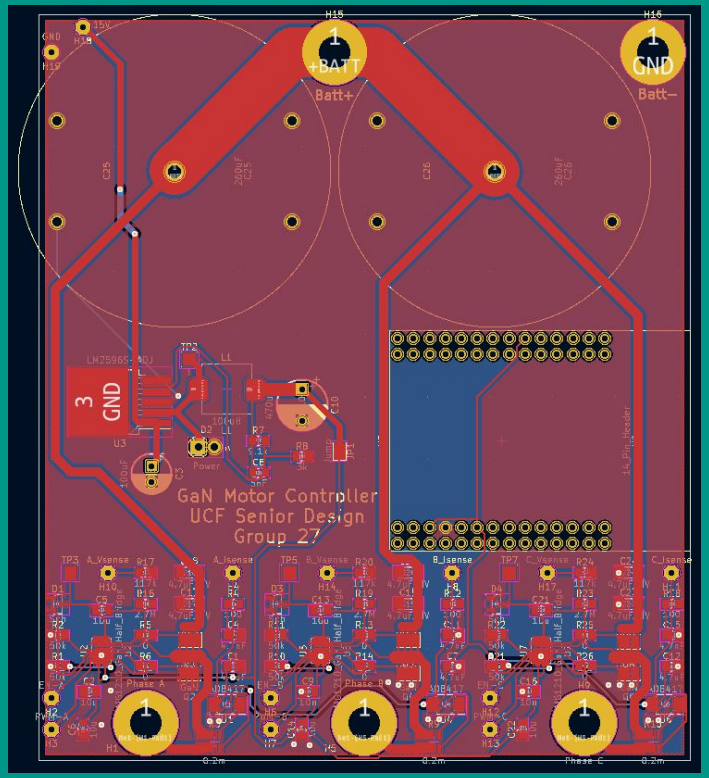
Still using GaN instead of Si FETs

Replaced single EDN7116 drivers with LMG1210 half bridge driver

Replaced buck IC LMQ61460 with LM2596 due to footprint and startup problems

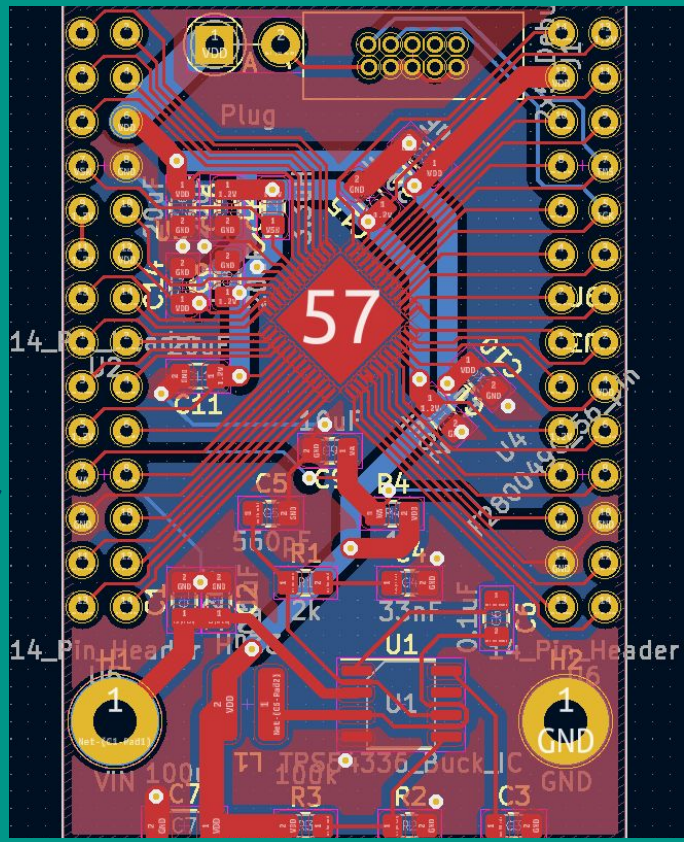
Julian Yerger
Electrical

Second Motor Controller PCB Design



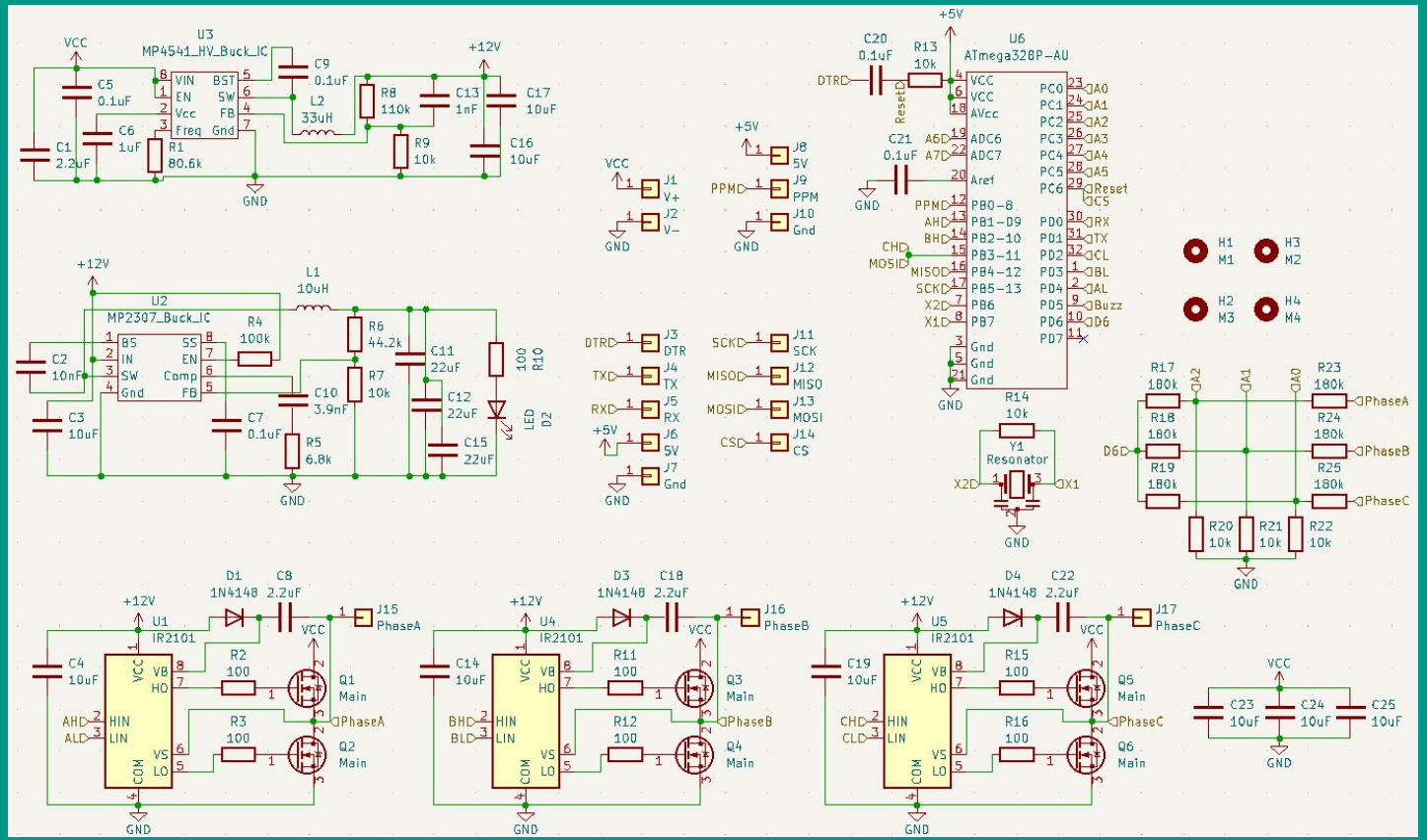
Motor Controller Power PCB

Motor Controller Logic PCB



Hardware Design: Third Motor Controller

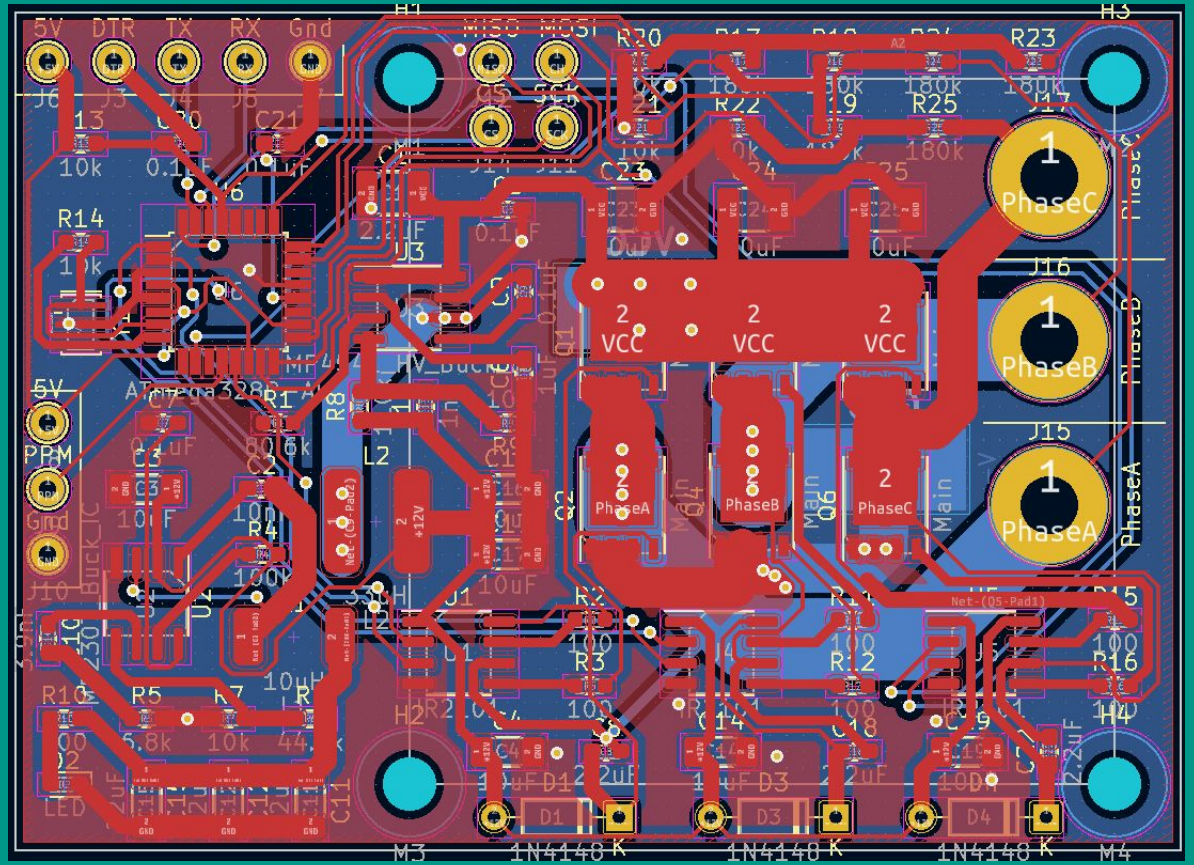
Julian Yerger
Electrical



- Silicon power FETs
- Uses SimpleFOC
- Atmega328P processor
- Virtual ground Back EMF sensing

Julian Yerger
Electrical

Third Motor Controller PCB Design

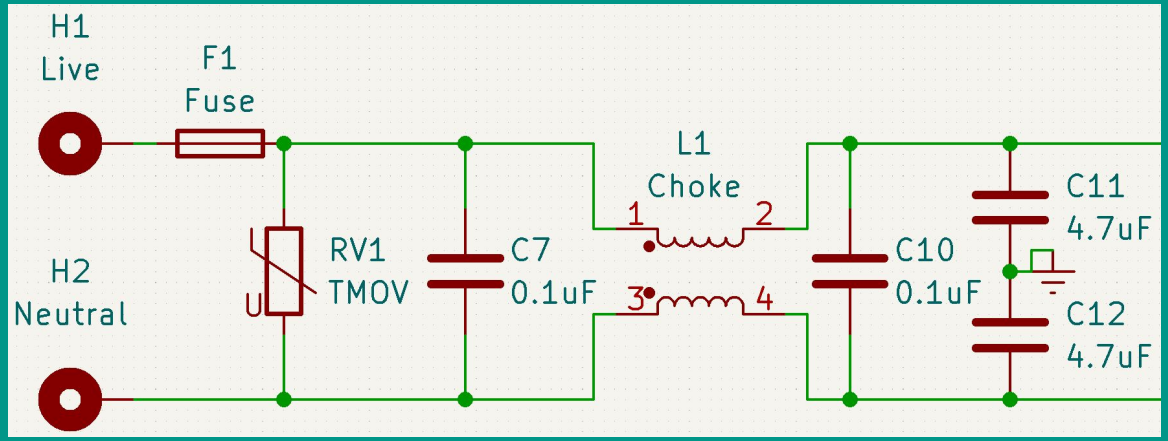


Julian Yerger
Electrical

Hardware Design: AC-DC Converter

EMI Filter

- EN55032 limits differential & common mode noise from 150 kHz to 30 MHz
- Low pass filter, so the binding limit is 60 dBµV at 150 kHz
- Common mode choke and capacitors form a common mode LC filter and a differential mode PI filter



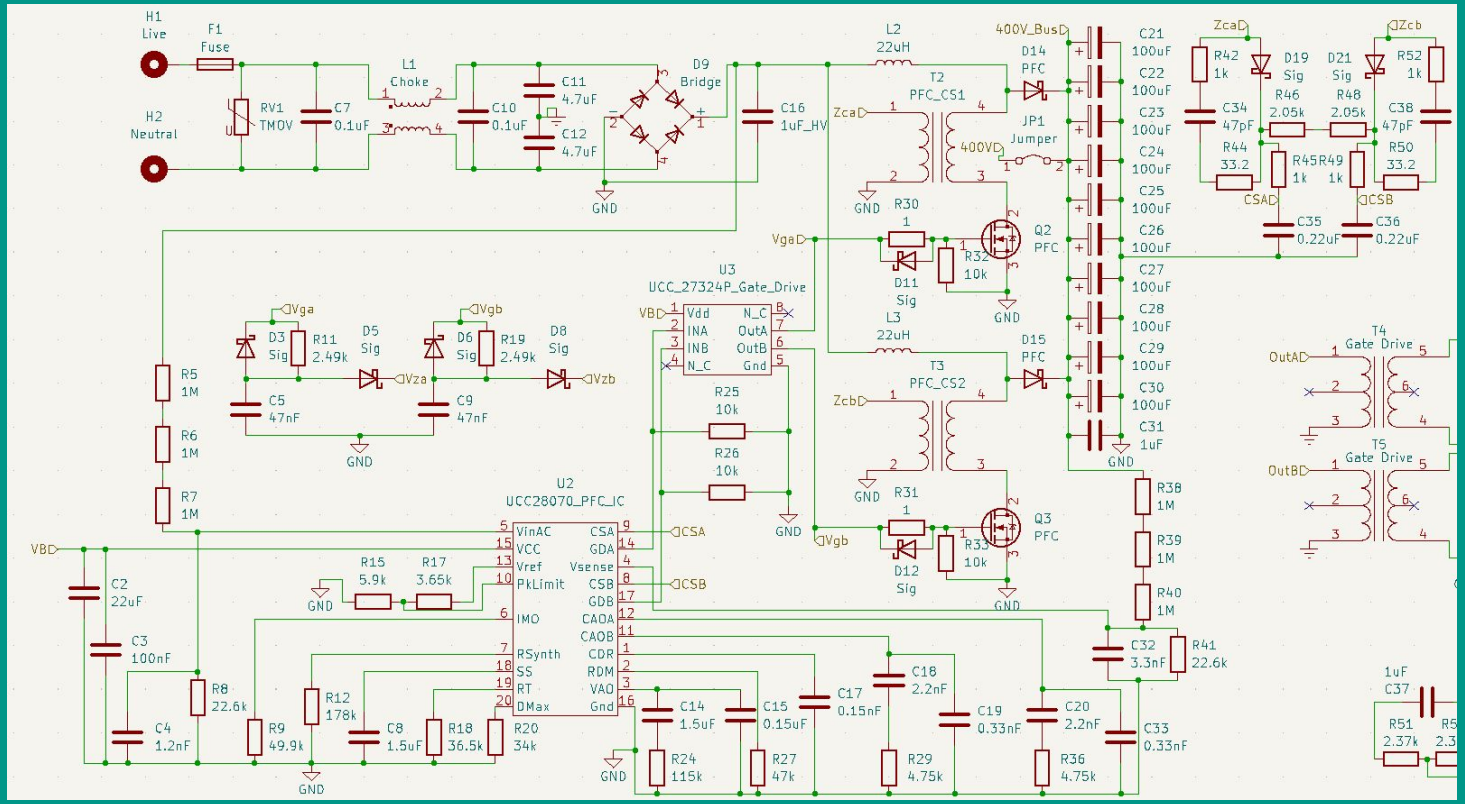
- Capacitors to ground are X2 safety, so more likely to fail open than short
- TMOV clamps voltage spikes (MOV) and thermal protection prevents overheating when clamped

Julian Yerger
Electrical

Hardware Design: AC-DC Converter

Power Factor Correction (PFC) Circuit

- Rectifies AC-DC with PF ~ 1
- Two phase interleaved boost converter for higher power
- Peak current mode control through current transformers

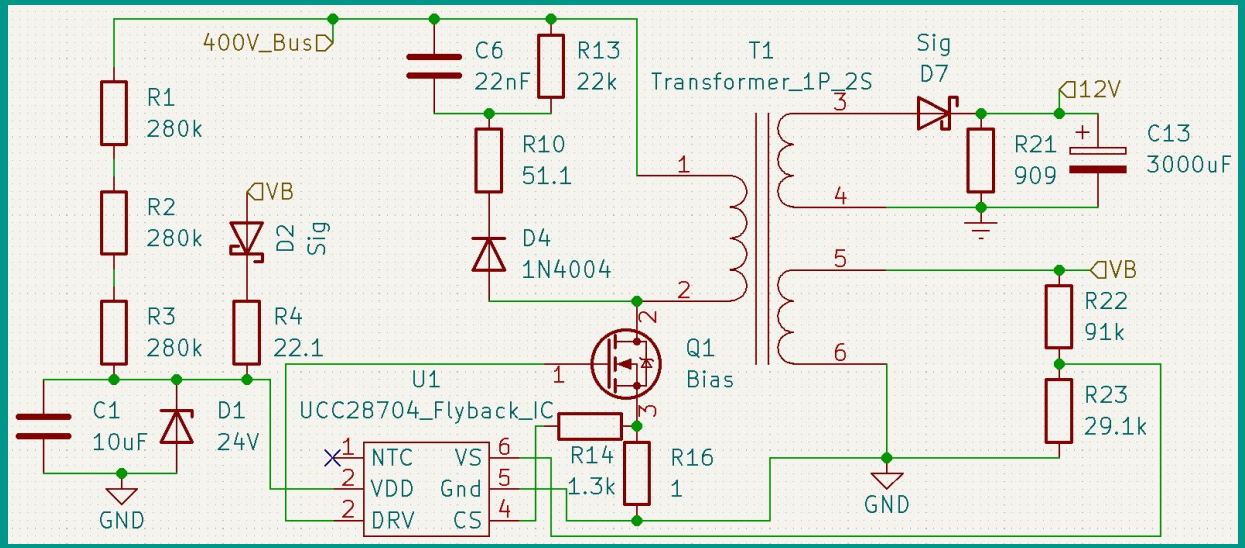


Julian Yerger
Electrical

Hardware Design: AC-DC Converter

12V & 16V Bias Supply

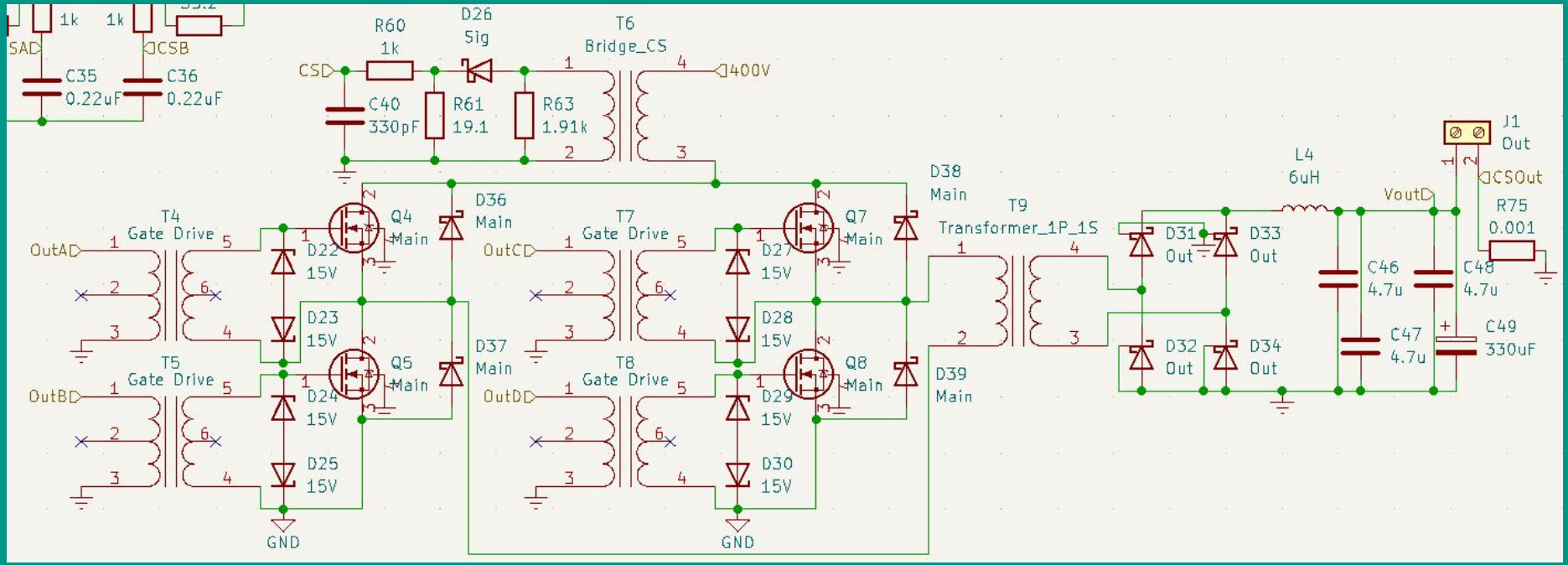
- Powers the gate drive and control circuits within the power supply
- Flyback converter for simplicity
- Non-isolated 16V powers flyback and PFC, isolated 12V powers full bridge IC, gate drivers, and output sensing



Julian Yerger
Electrical

Hardware Design: AC-DC Converter

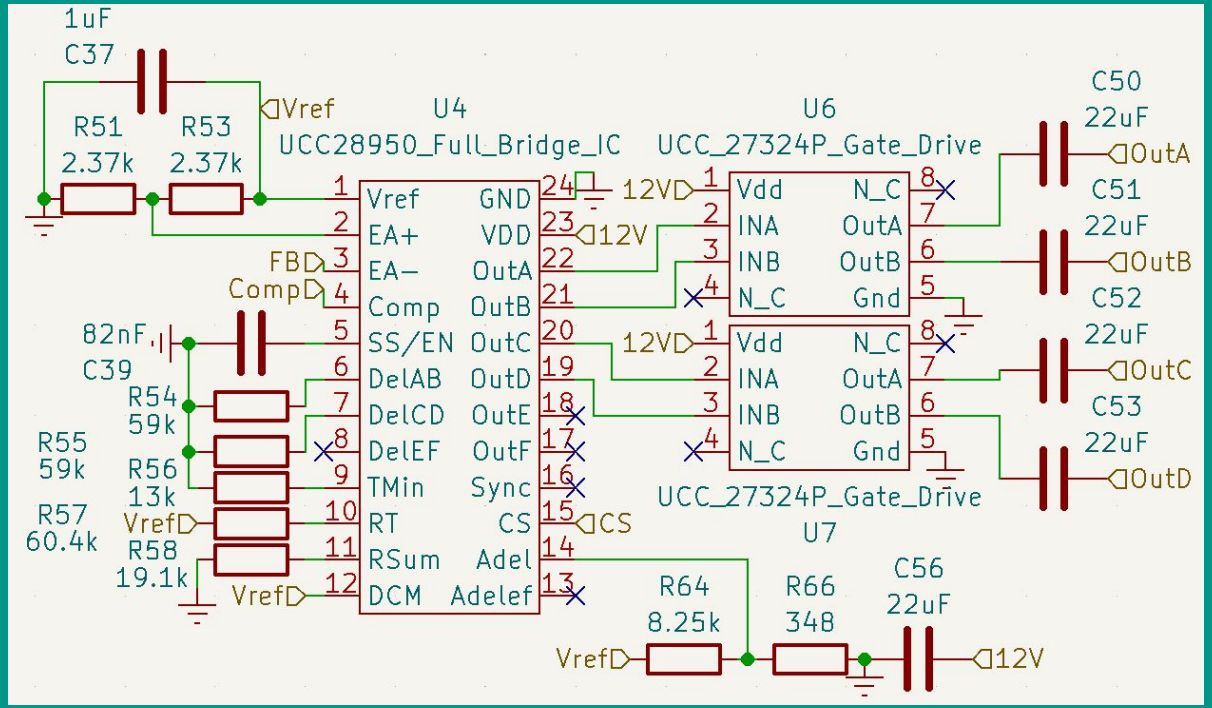
Phase-Shifted Full Bridge Converter

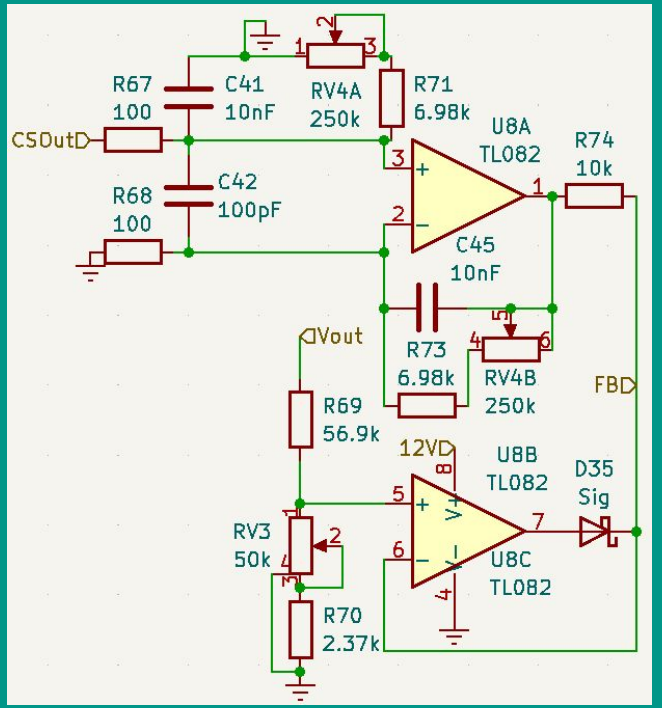


Julian Yerger
Electrical

Hardware Design: AC-DC Converter

UCC28950 Controller IC and CC/CV Regulation





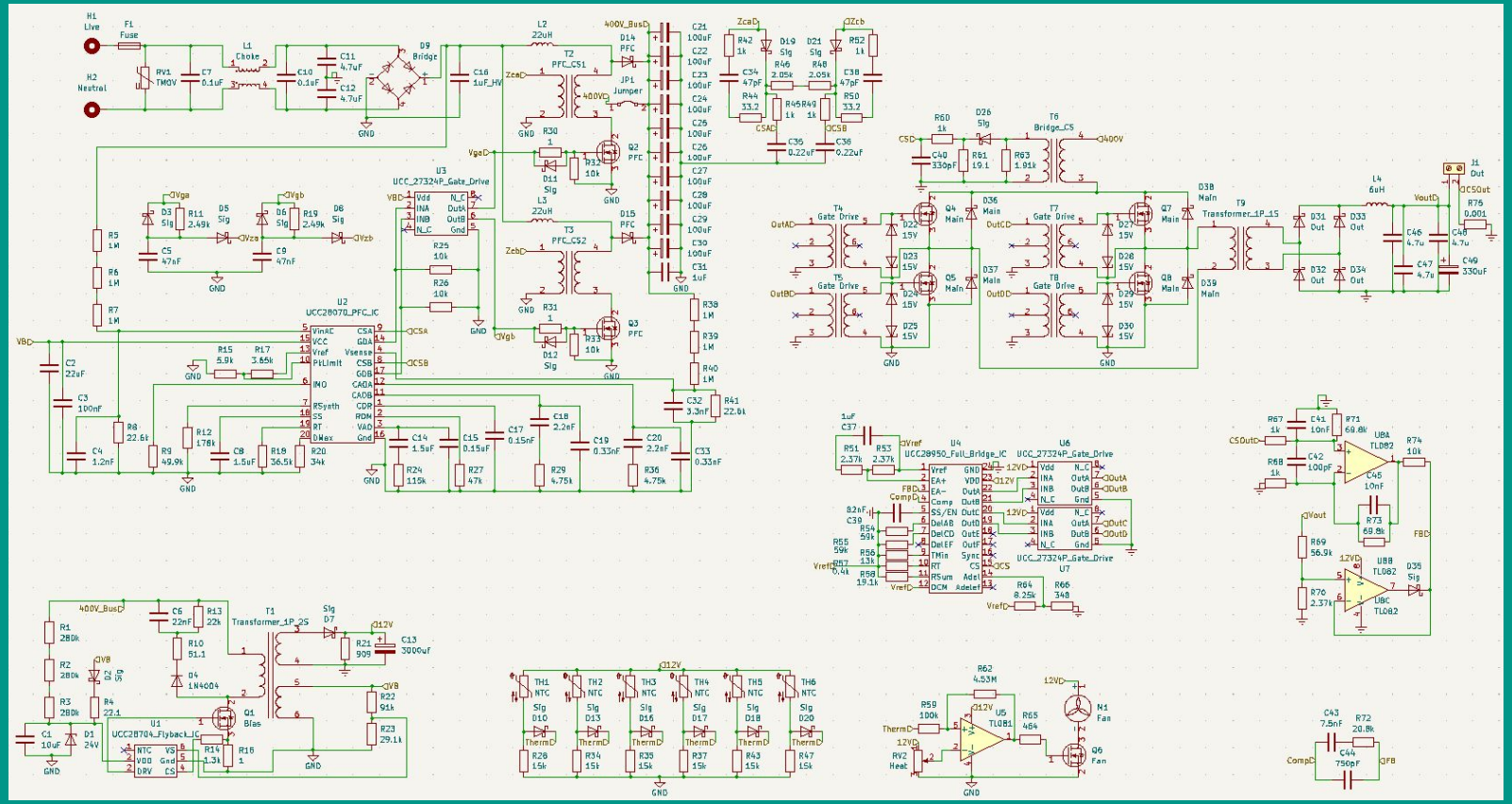
Julian Yerger
Electrical

Hardware Design: AC-DC Converter

Output:
5.2V to 63V
1A to 36A

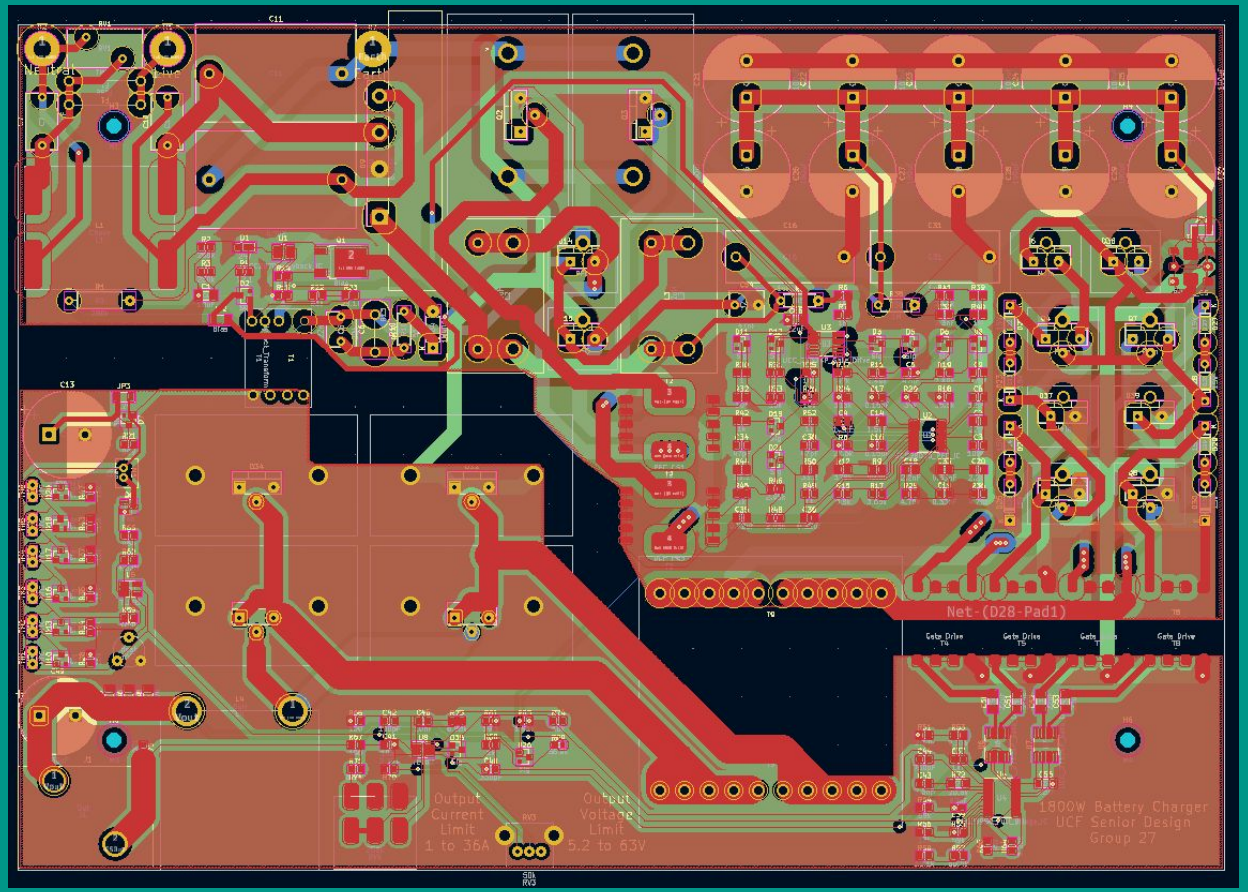
Input:
15A x 120V = 1800W max power

Designed for 15S lithium-ion battery pack



Julian Yerger
Electrical

PCB Design



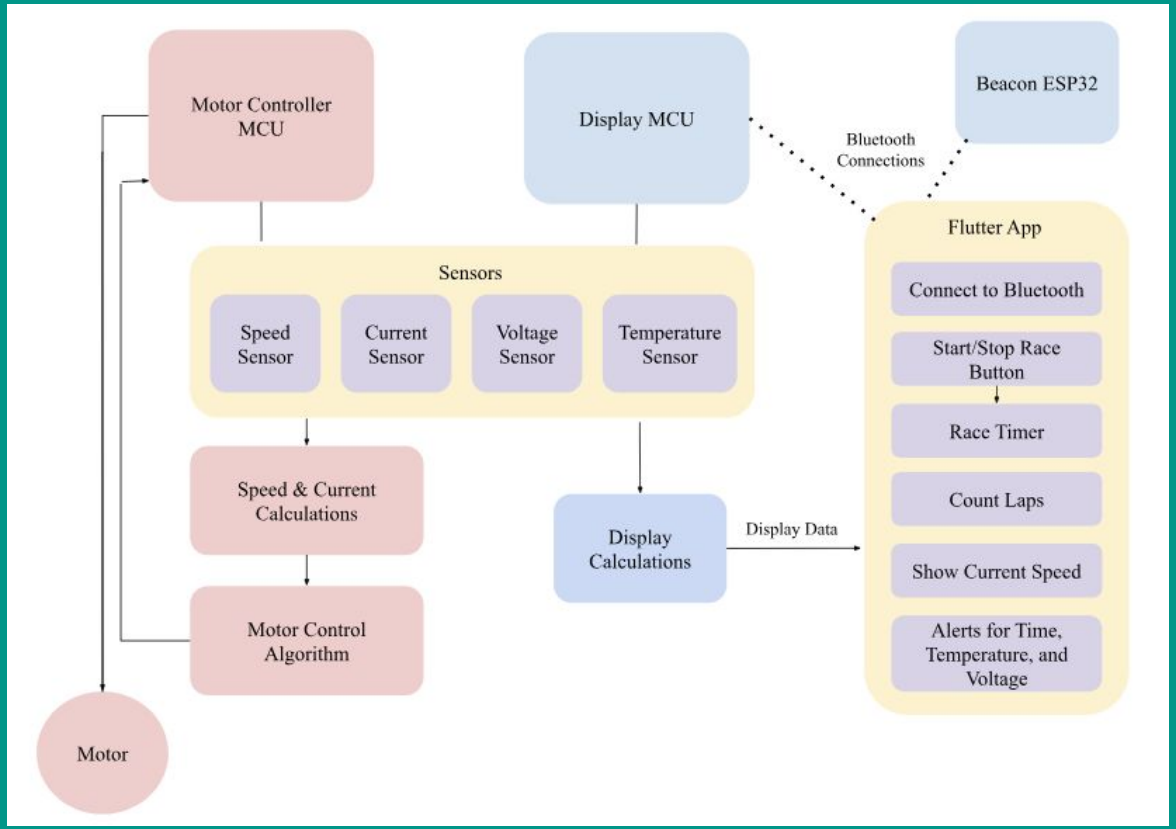
1800W AC-DC
Battery Charger

1.8mm creepage
on HV side

0.7mm creepage
on 63V output side

Grace Tuomala
Computer

Software Design: Overall Flowchart



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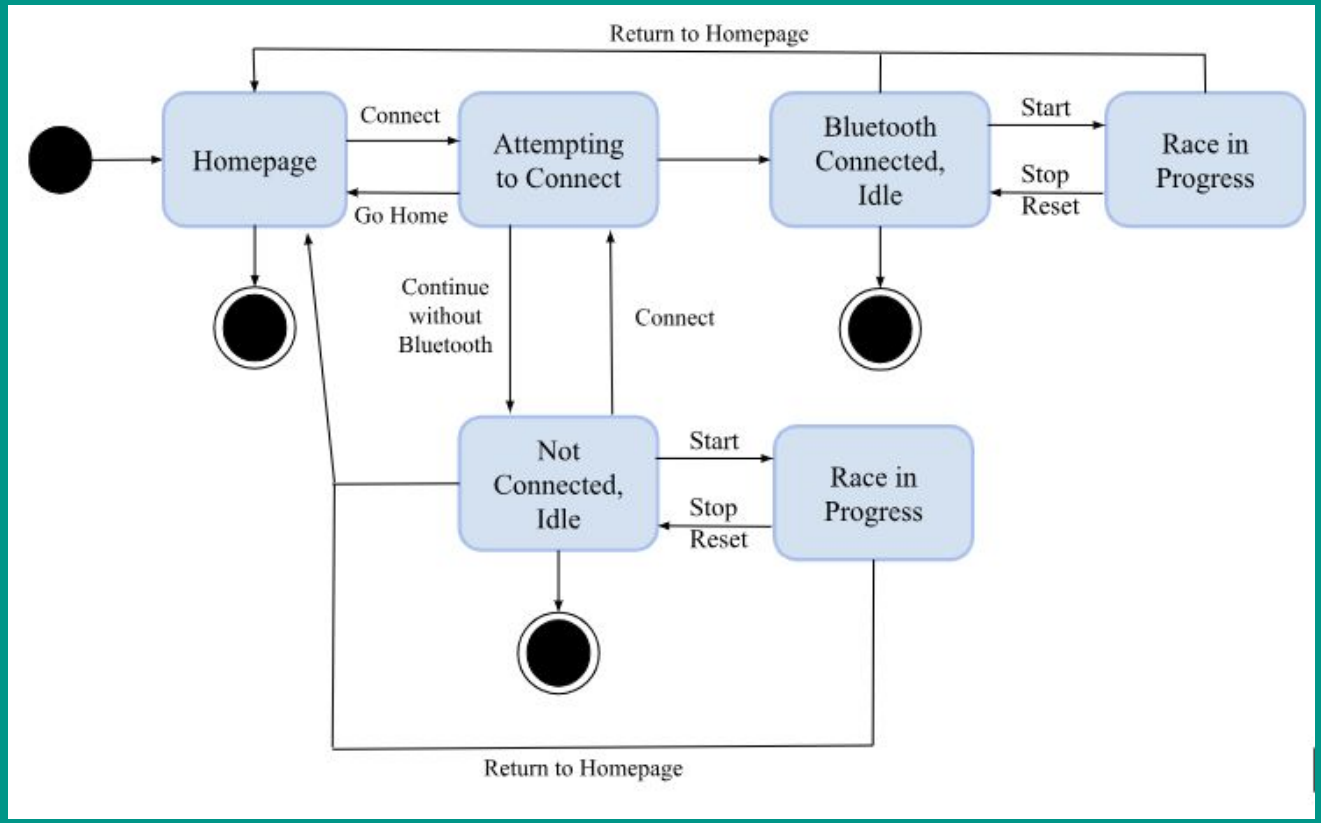
Computer

Software Design: Display App State Diagram



Homepage: Instructs User on How to Connect

Grace Tuomala
Computer

Welcome to JARVIS

Your handy-dandy Electrathon driver assistance app!

Ready to race?

1. Make sure Bluetooth is enabled on your device
2. Pair with "ESP32" if you have not already
3. Press the "Connect" button below
4. Once connected, you will automatically redirected to the main race page

Connect

Grace Tuomala
Computer

Waiting for Connection

Please wait while JARVIS connects to Bluetooth.
If this page persists more than a few seconds, check your connection and try again.

Continue without Bluetooth

Go Home

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Computer

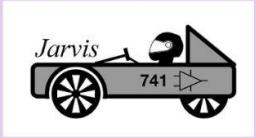
Main Display: Normal Operating Mode

Speed

0.0 mph

Rssi: -29

----Spectator Mode----



Time Remaining

60:00

Start

Reset

Switch to Driver Mode

Laps: 0

Current: 0.00A

Voltage: 4.46V

Temperature: 23C

Murphy's Screen: All Possible Warnings Triggered

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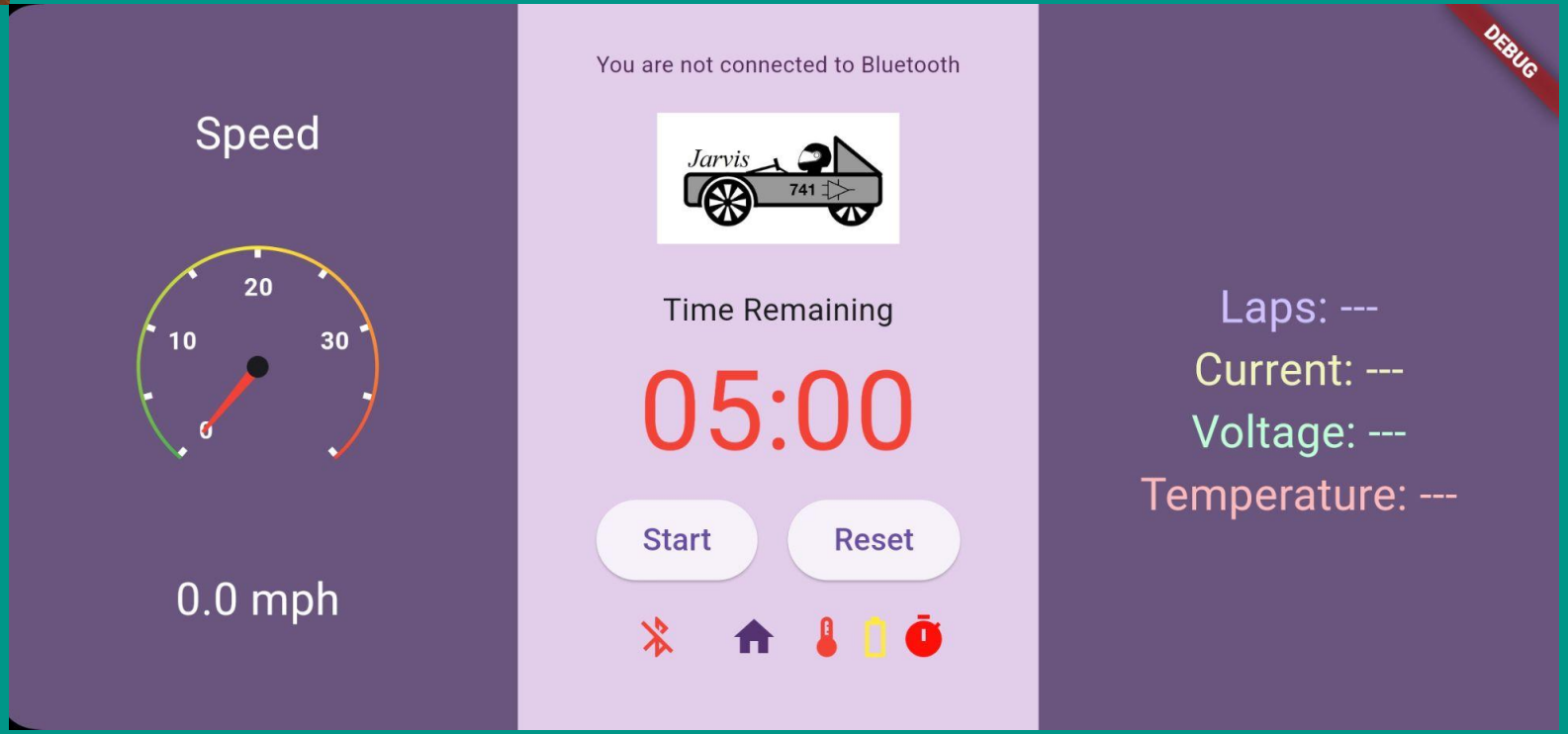
Computer



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Computer

Icons

Bluetooth Connected

Internal Temperature too high

Not Connected or
Connection Lost

Voltage Reading Below Target

Return to homepage

<5 minutes remaining in race

Julian Yerger
Electrical

Budget Estimate

Item	Quantity	Price Estimate	Actual Spending
Samsung 20S battery cell	140	$700	$700
Busbars and cell holders	200	$30	$54
Active cell balancer	1	$21	$23
Hacker A60-18L motor	1	$272	$272
Parts for motor controller	1	$300	$380
Circuit breaker	1	$11	$31
Wires and connectors	8	$50	$172
Main microcontroller	1	$20	$175
Sensors	3	$50	$79
Parts for battery charger	1	$250	$324
Total		$1,704	$2,210