

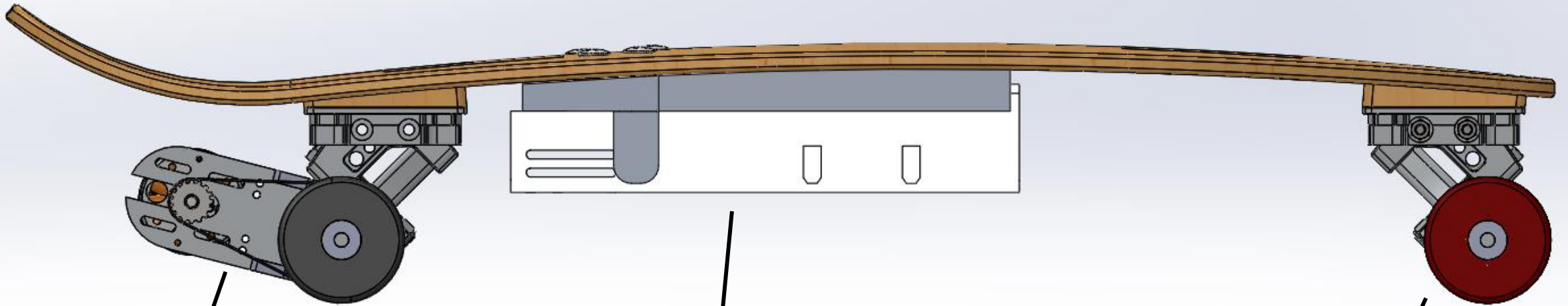
L2AHTB1: Electric Skateboard

P.M. Toby Ashton, Jacob Black, Haydn Lisk, Hugo McCartney, Edward Street, Sam Sutcliffe

Introduction

- Retrofit for wide range of available boards
- Commuting and recreation
- Predicted Load: 120kg
- High performance
- Maximum Range: 15km
- Top Speed: 15m/s on flat, 8m/s on max gradient
- Weight: 8kg

Board



Rear Trucks with integrated
motor and drivetrain

Electrical components
casing

Symmetrical front trucks

Board Analysis

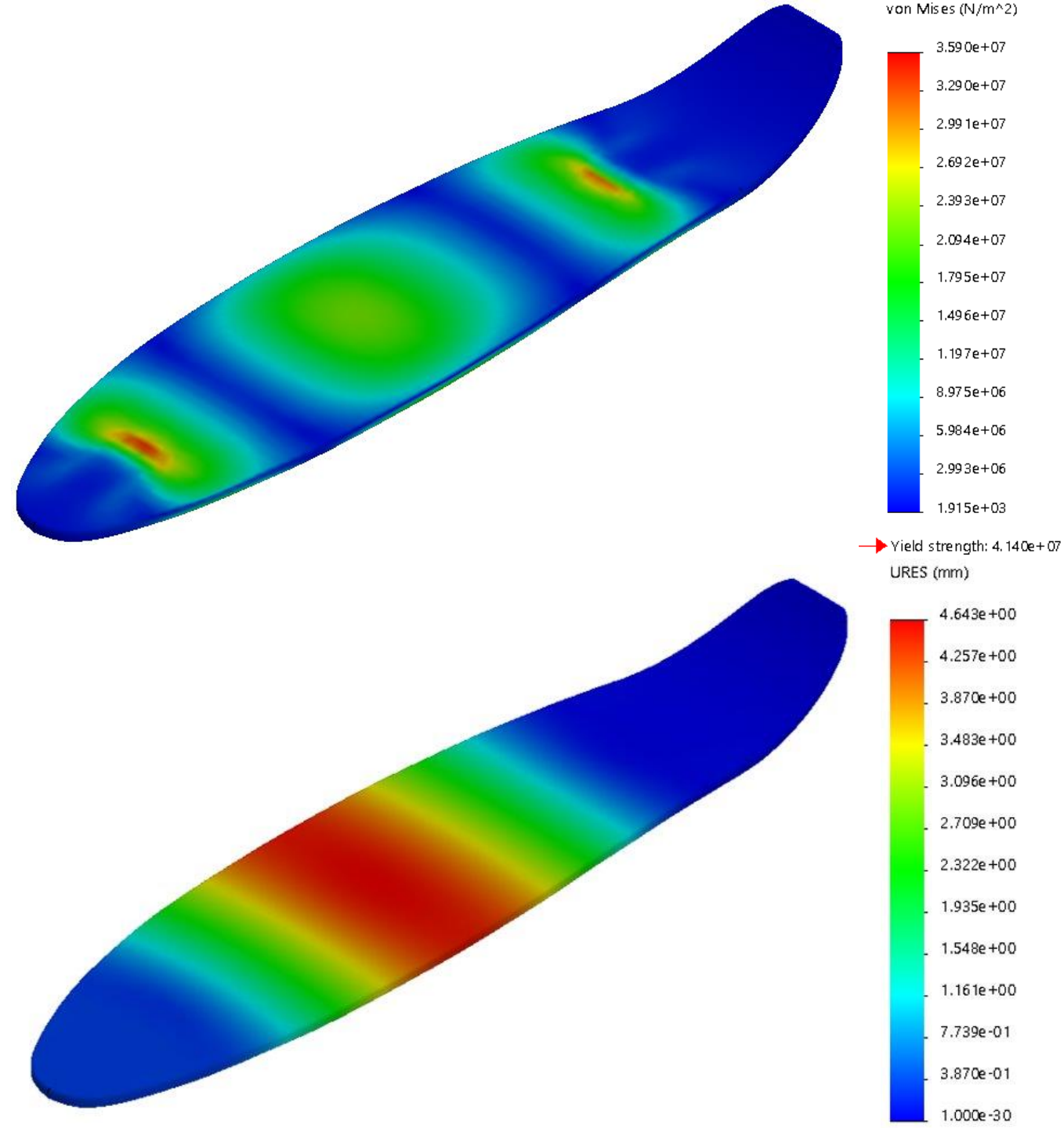
Stress Analysis

FEM analysis

- 120kg user load concentrated at centre
- Approx. 4.5kg components
- High stress at truck fixtures and center of board
- 35.9MPa maximum compressive stress
- Does not exceed compressive yield stress

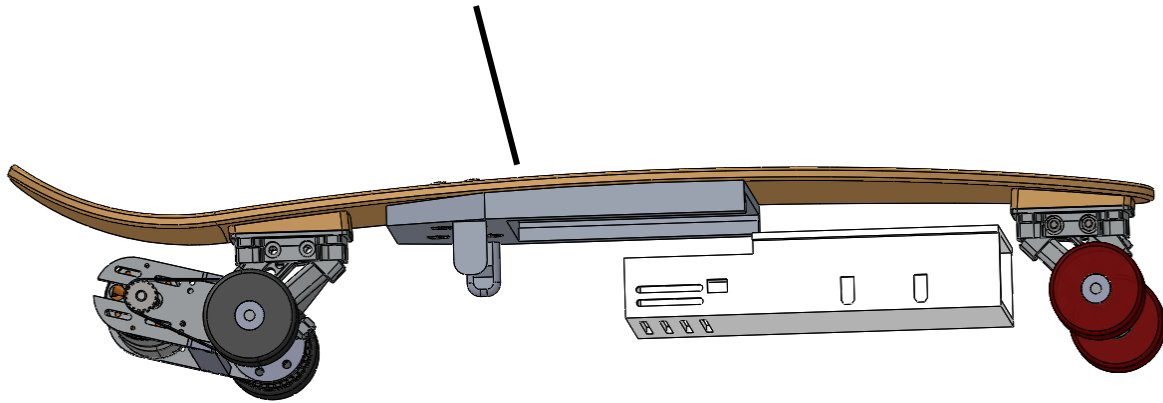
Displacement Analysis

- 4.6mm maximum deflection



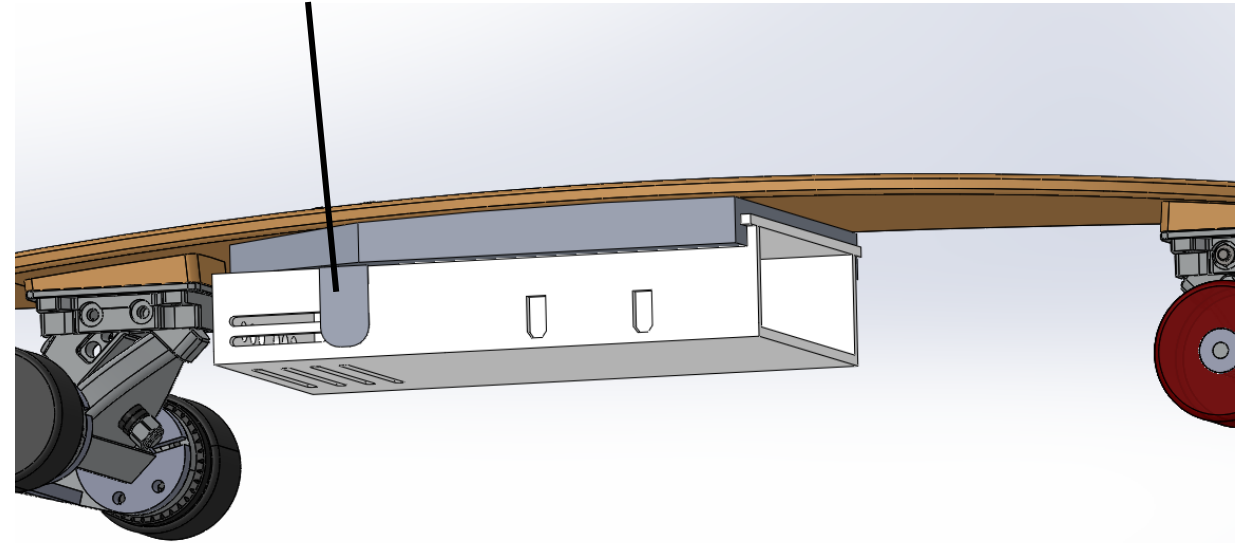
Electronic Components

Fixed railing



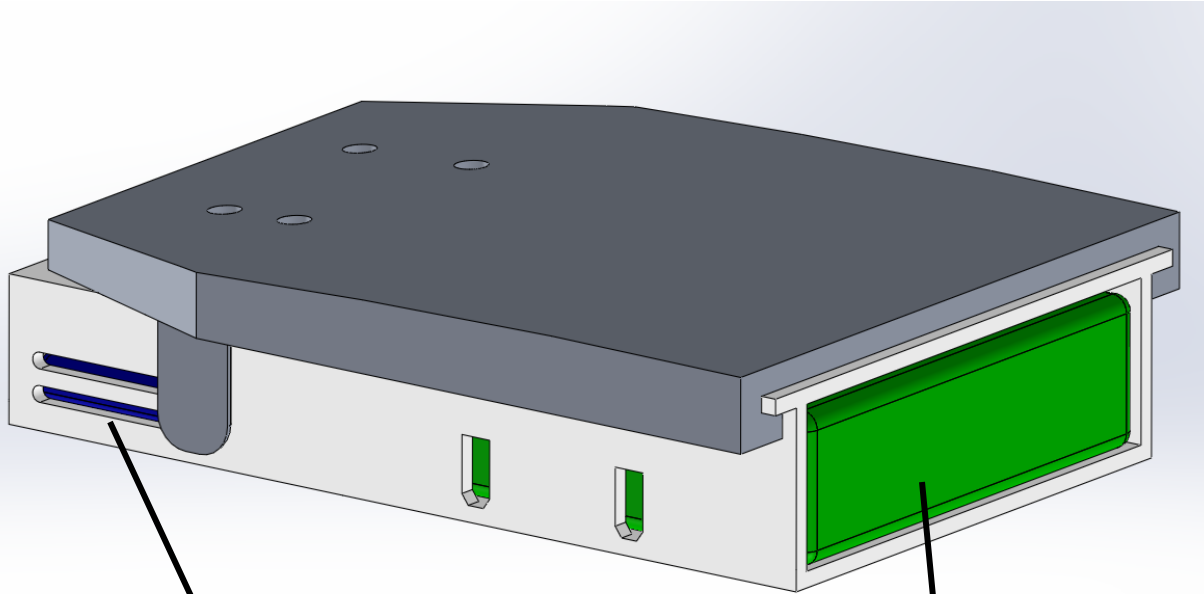
Detached

Quick-release
clamps



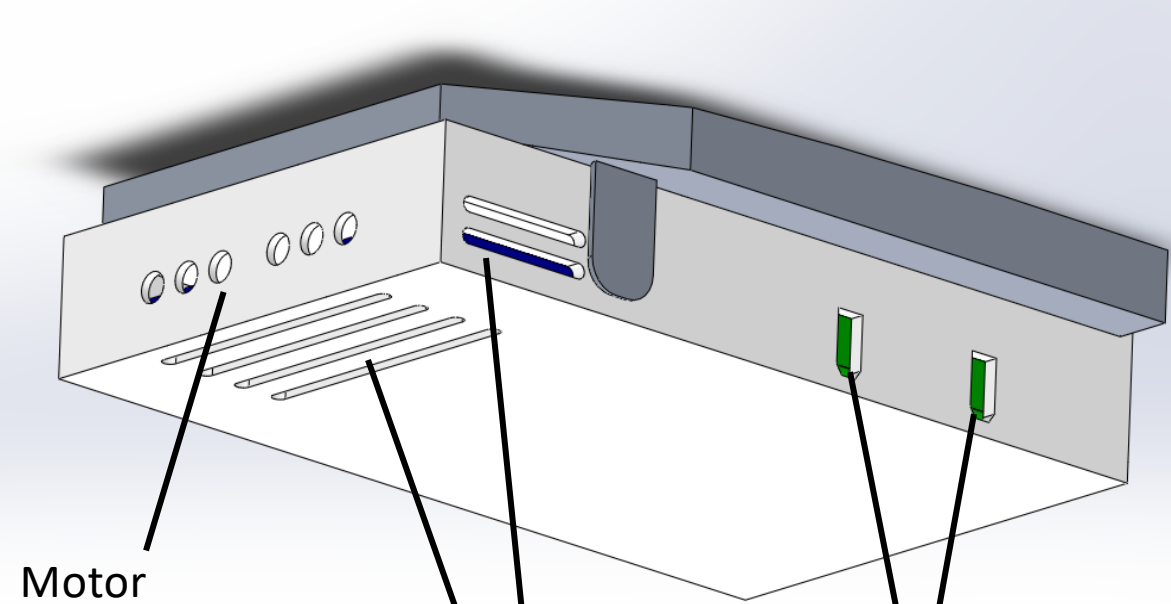
Attached

Battery Box



Control Electronics:
ESC, Microcontroller

Batteries



Motor
connections

Ventilation
Slots

Charging Port

Material Selection

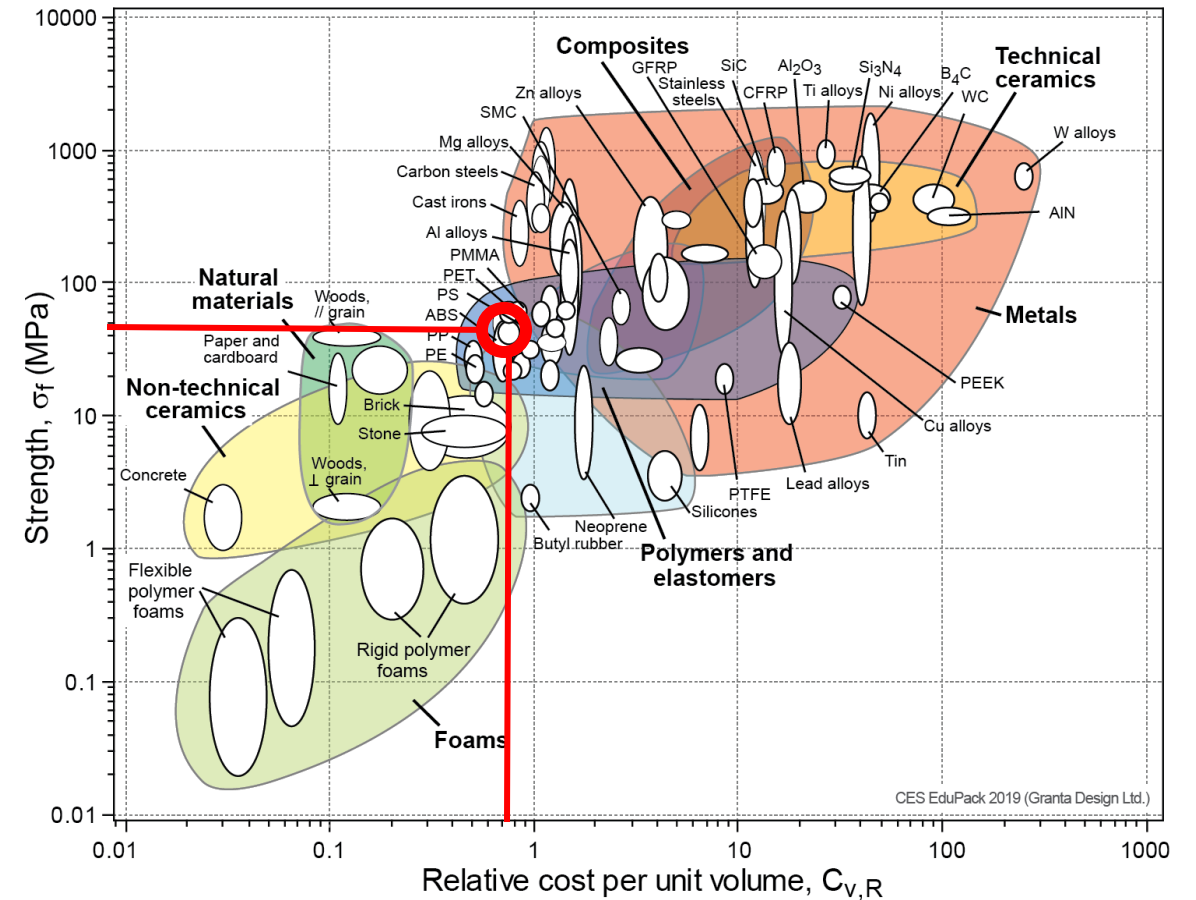
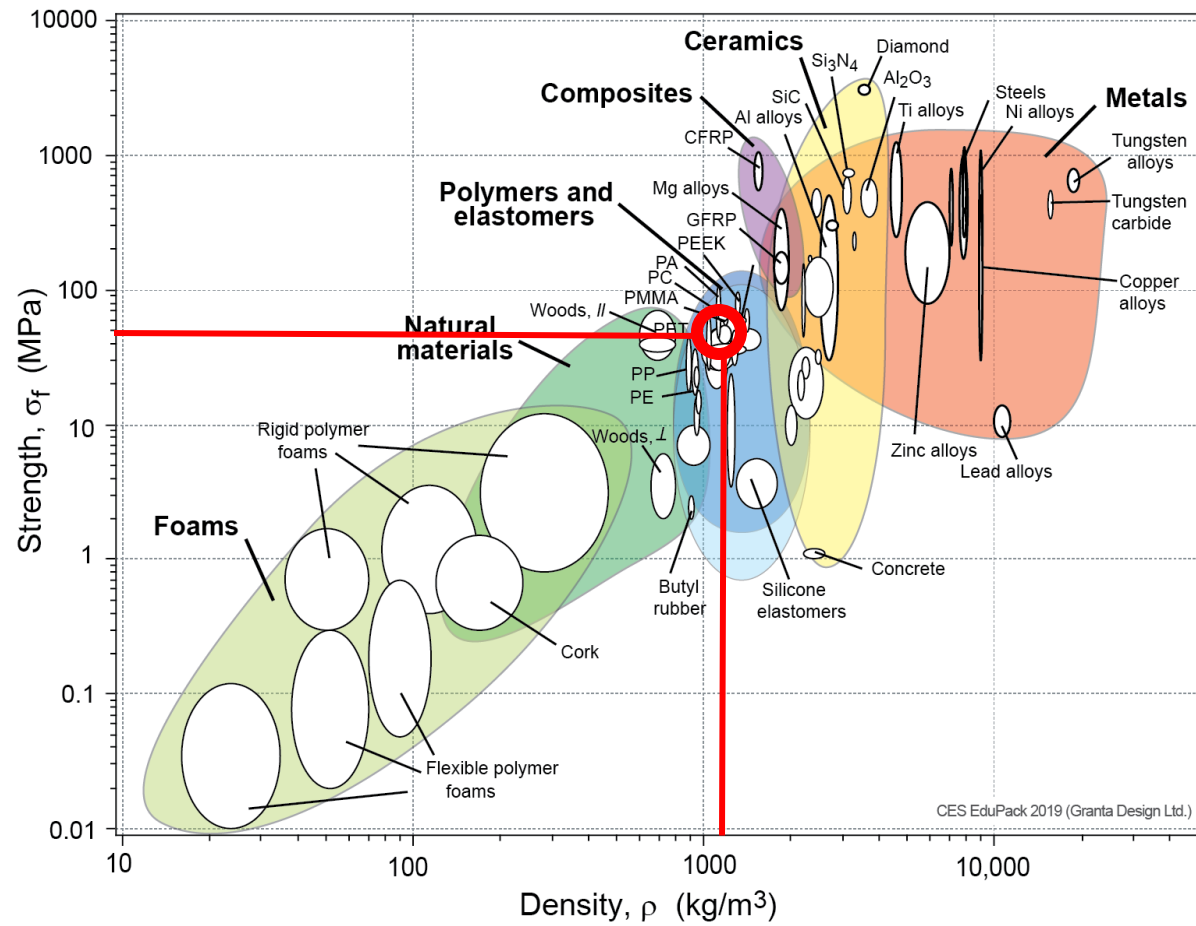
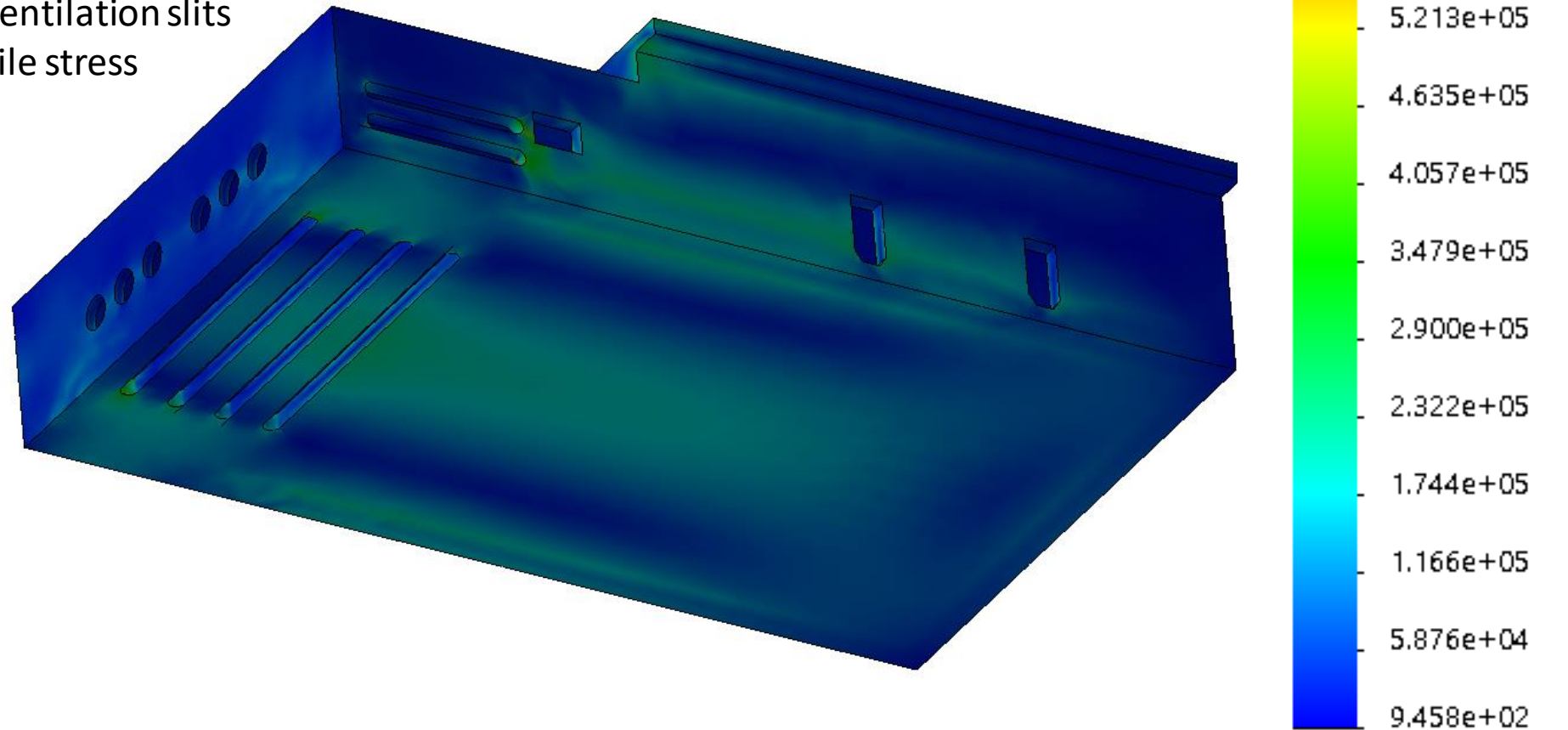


Chart created using CES EduPack 2018, Granta Design Ltd.

Battery Box

Stress Analysis

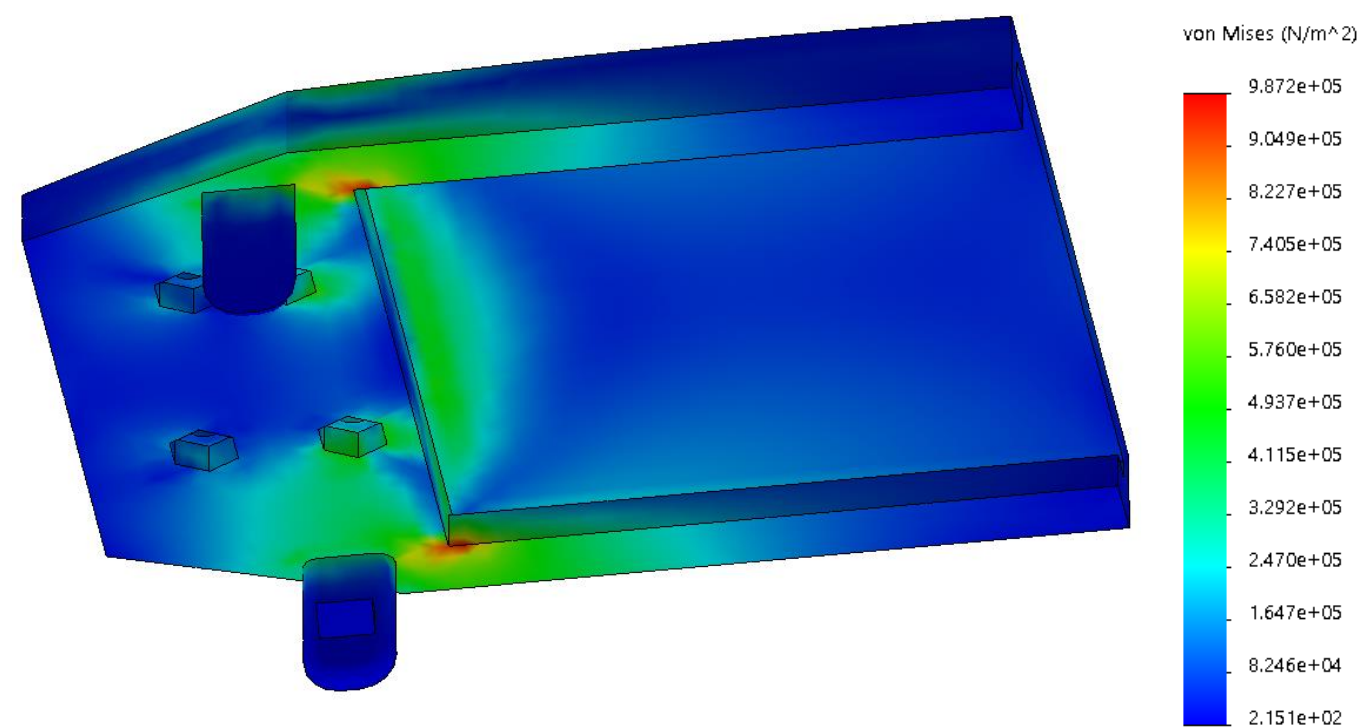
- Mounted on railing with electronic components
- Stress concentrations at ventilation slits
- 0.695MPa maximum tensile stress



Railing

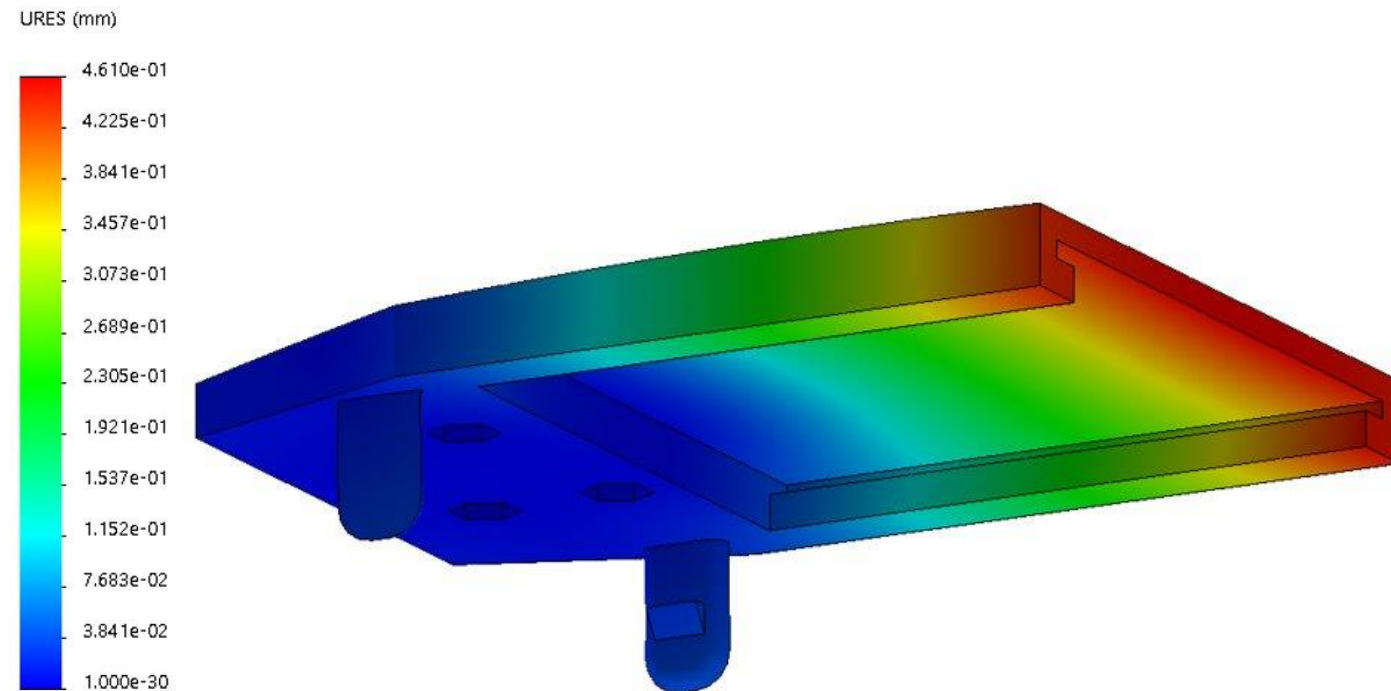
Stress Analysis

- Attached battery
- Stress concentration at inner corners
- 0.987MPa maximum compressive stress



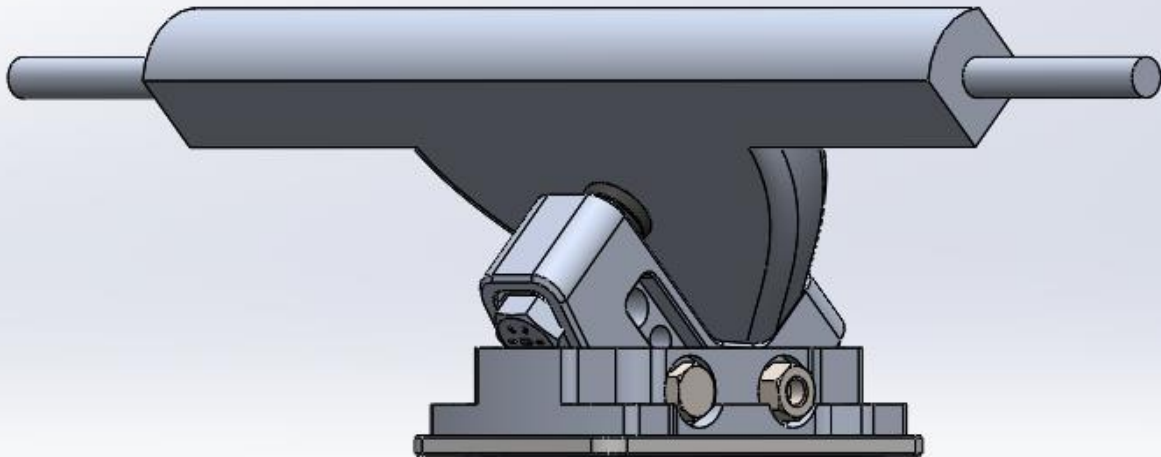
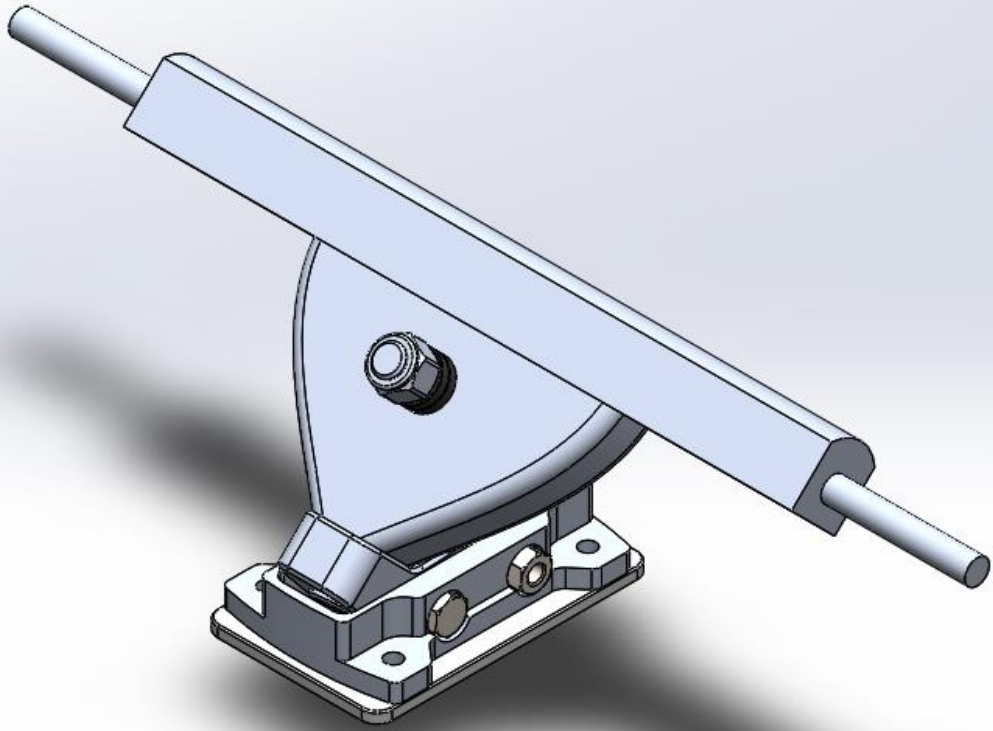
Displacement Analysis

- Approx. 0.46mm maximum deflection
- Total ground clearance = 6.5 cm when loaded

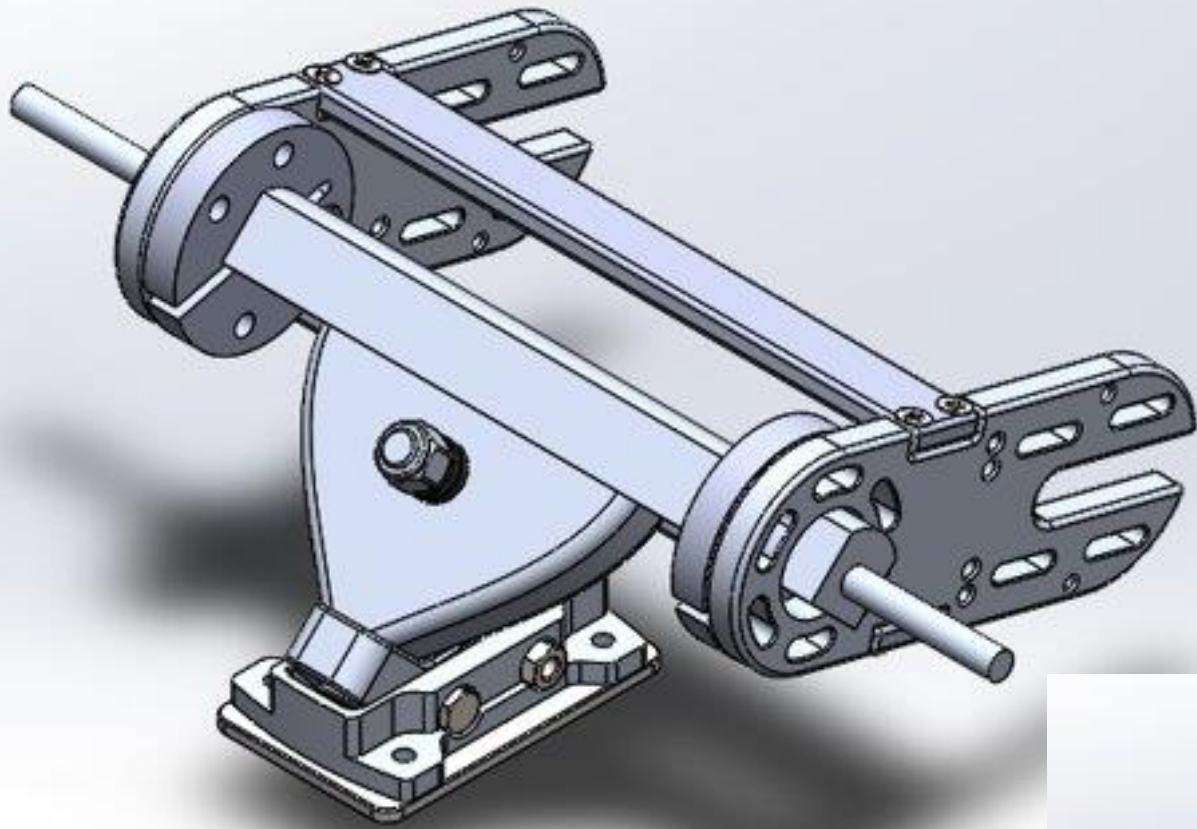


Trucks

- 218mm wide hanger
- 314mm including axles
- Cast aluminium construction

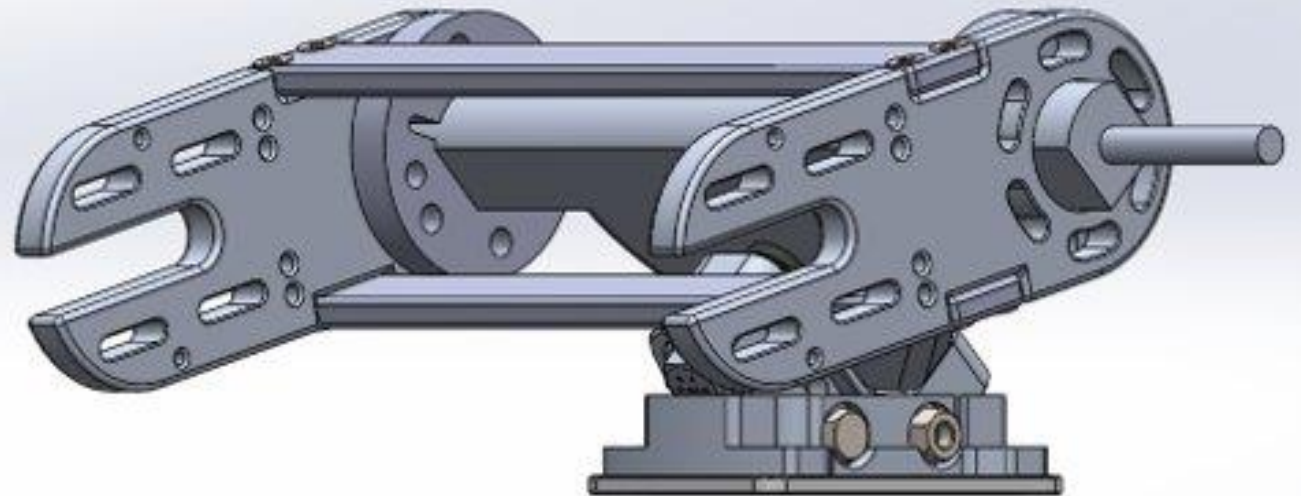


New Longboard Trucks
Image from Torque Boards



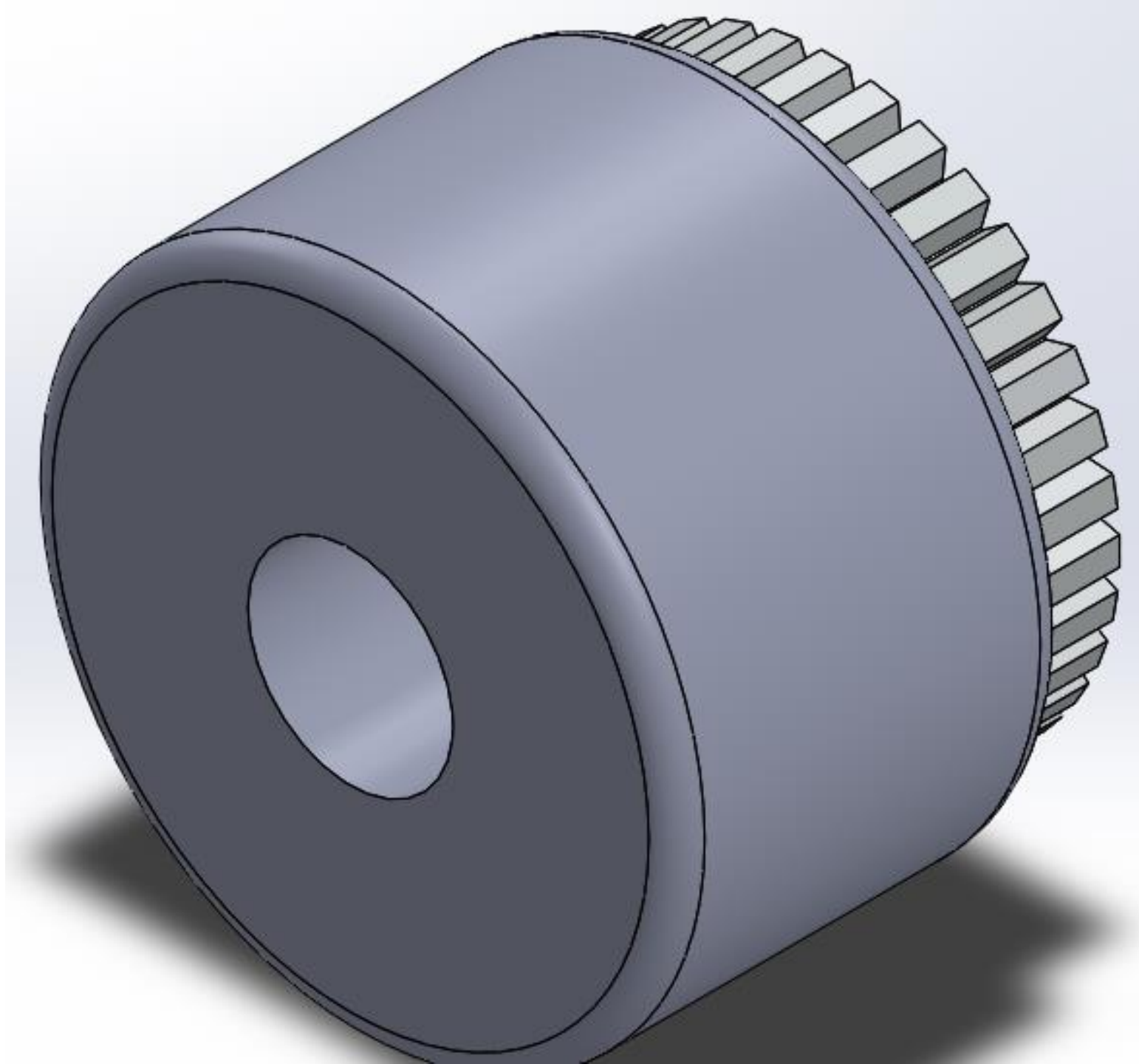
Motor Mount

- Weight of both trucks and mount: 1.5kg
- CNC milled Aluminium



Wheels

- Wheel Dimensions
- Wheel Materials
- Bearing Materials
- Wheel-Gear Attachment



Wheel Materials

Material	μ -rolling	μ -static	Cost (£/wheel)
Polyurethane	0.02-0.04	0.2	2.50-37.50
Rubber	0.02-0.04	0.35-0.45	3.80
Conclusion	Both acceptable for non-driven	Rubber provides 75-125% in μ -static, better for driven wheel	Greater variation in polyurethane, customer's preference

Bearing Materials

Material	σ_{UTS} (MPa)	Brinell Hardness (kg/mm ²)	Specific Heat Capacity (kJ/kgK)	Approximate Cost (£)
Steel: SAE-AISI 52100	590-2100	180-210	0.475	15
Titanium: ASTM Grades 7	550	200	0.554	25
Ceramic: Silicon Nitride	170	1479 (converted from Vickers' hardness)	0.673	70-115

Wheel -Gear Adhesives

Estimated Minimum Tensile Strength Required $\sigma \sim 0.15\text{N/mm}^2$

Adhesive	Tensile Strength (N/mm ²)	FOS	Cost (£/mm ²)	Cost (£/per wheel)
Weicon GMK 2410 Rubber Metal Contact Adhesive	0.54	3.6	3.72×10^{-5}	0.0954
Cole-Parmer Silicone Rubber Bonding Cement: DOWSIL™ 732 Multi-Purpose Sealant	2.3	15.3	4.101×10^{-5}	0.1052
Loctite Super Glue ULTRA Gel Control	21.12	140.8	4.869×10^{-4}	1.249

Drive System Configuration

Category	Weighting (/5)	FWD Belt	FWD (2x Hub)	RWD Belt	RWD (2x Hub)	AWD Belt	AWD (4x Hub)
Weight Distribution	3	1	1	4	4	3	3
Handling	3	3	3	3	3	4	4
Cost	3	4	2	4	2	3	1
Manufacturability	4	4	3	4	3	2	2
Safety	4	4	4	4	4	5	5
Control Complexity	4	4	2	4	2	3	2
Transmission Efficiency	4	3	4	3	4	2	5
Total		84	70	93	79	78	80

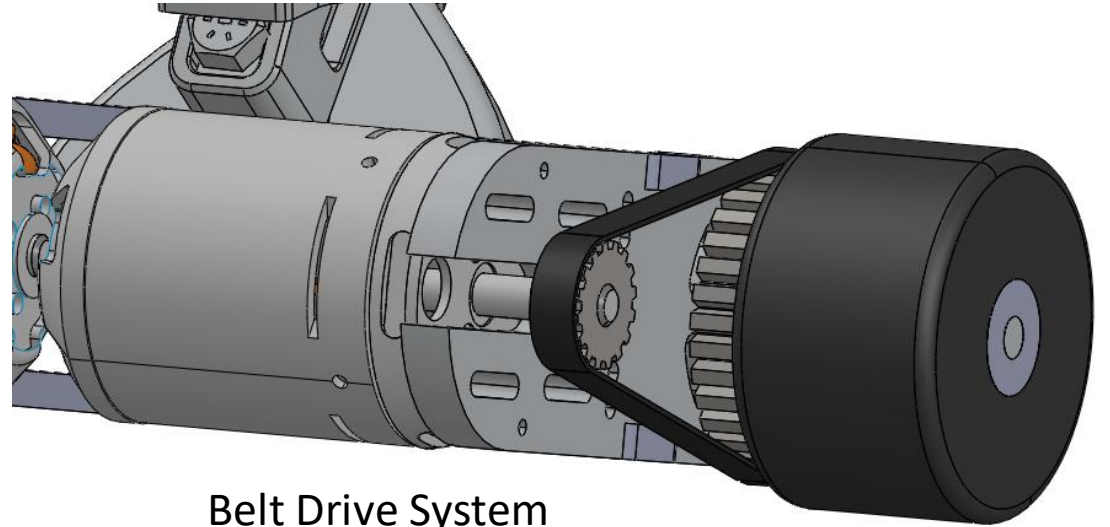
Drivetrain Requirements

- High Torque
- High Speed
- Efficient Power Transmission
- Quiet
- Compact
- Affordable

Drivetrain Types



Direct Attach Motor
Image from MBoards



Belt Drive System

Types of Belt



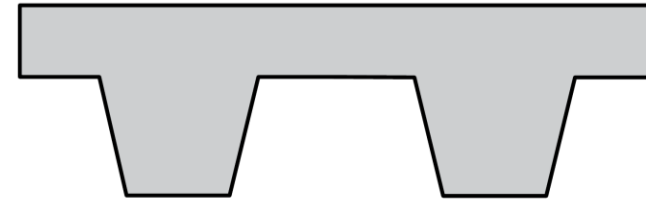
V- Belt

Image from gpr industrial



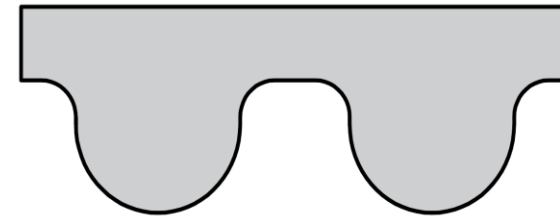
Toothed- Timing Belt

Image from gpr industrial



Conventional Timing Belt

Image from Megadyne



High Torque Belt

Image from Megadyne



High Torque
Motor/ Wheel Pulley

Image from belting online

Motor

AC Induction	Efficient Quiet Hard to control High torque at startup
DC Brushed	Easy Control Inefficient High Speed
DC Brushless	Easy Maintenance Long Lifespan Easy Control Efficient

Drive Circuitry



Torque Boards 6374 190KV Motor:

- Maximum Current: 80A
- Maximum Voltage: 12s (A 12 cell LiPo)
- Maximum Torque: 3.57 Nm
- Integrated Hall Effect sensor.
- Manufacturer Recommended ESC: 12S 120A Car ESC

Image from DIY Electric Skateboard.com

12S 120A Car ESC:

- Continuous Current Rating: 120A
- Burst Current Rating: 1080A (10 sec max)
- Maximum Voltage: 12s
- Forward and reverse capability
- PWM Control



Image from DIY Electric Skateboard.com

Pressure Pad Throttle Control

- Already an existing technology, used on OneWheel
- Measures the weight distribution of the rider
- Lean forward accelerates, lean back decelerates
- Less complex to develop than the handheld wireless remote used by Boosted
- Can detect rider dismount (stop the board)



Image from [Ride&Glide.com](https://rideandglide.com)



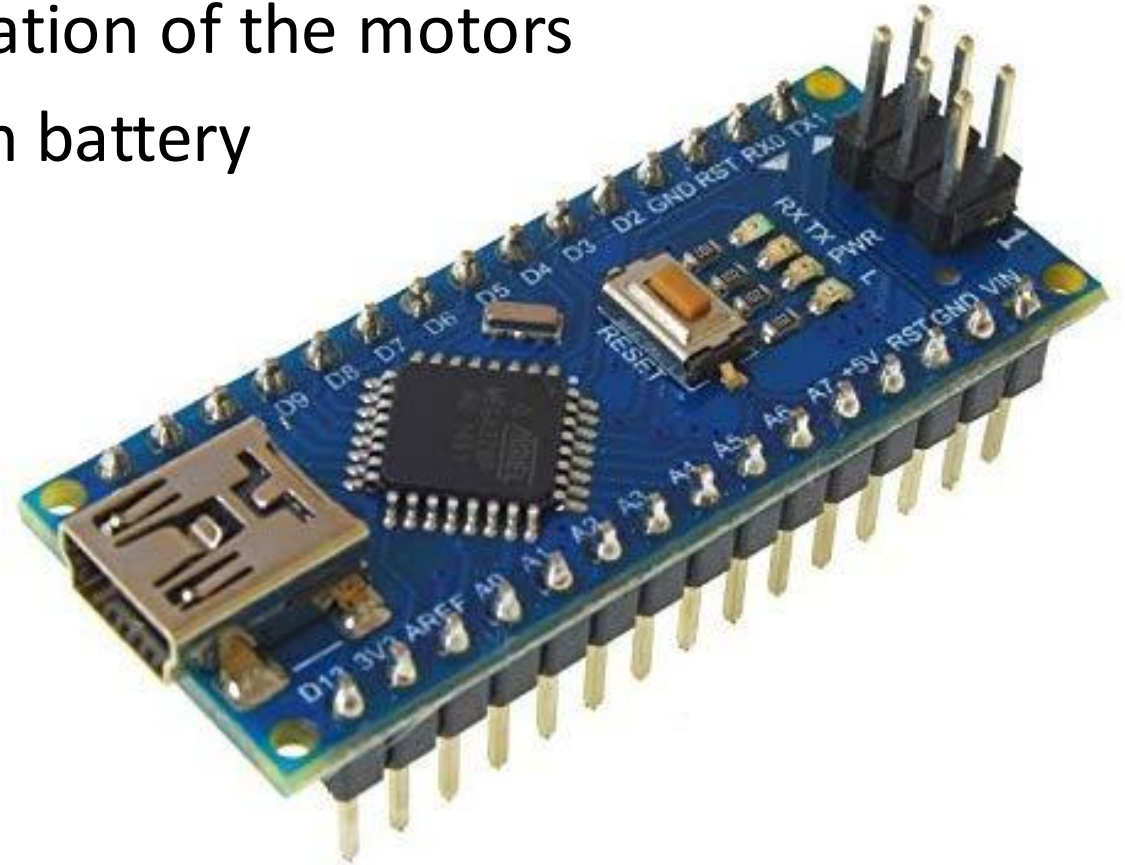
Image from [ArunElectronics](https://arunelectronics.com)



Image from [Tested.com](https://tested.com)

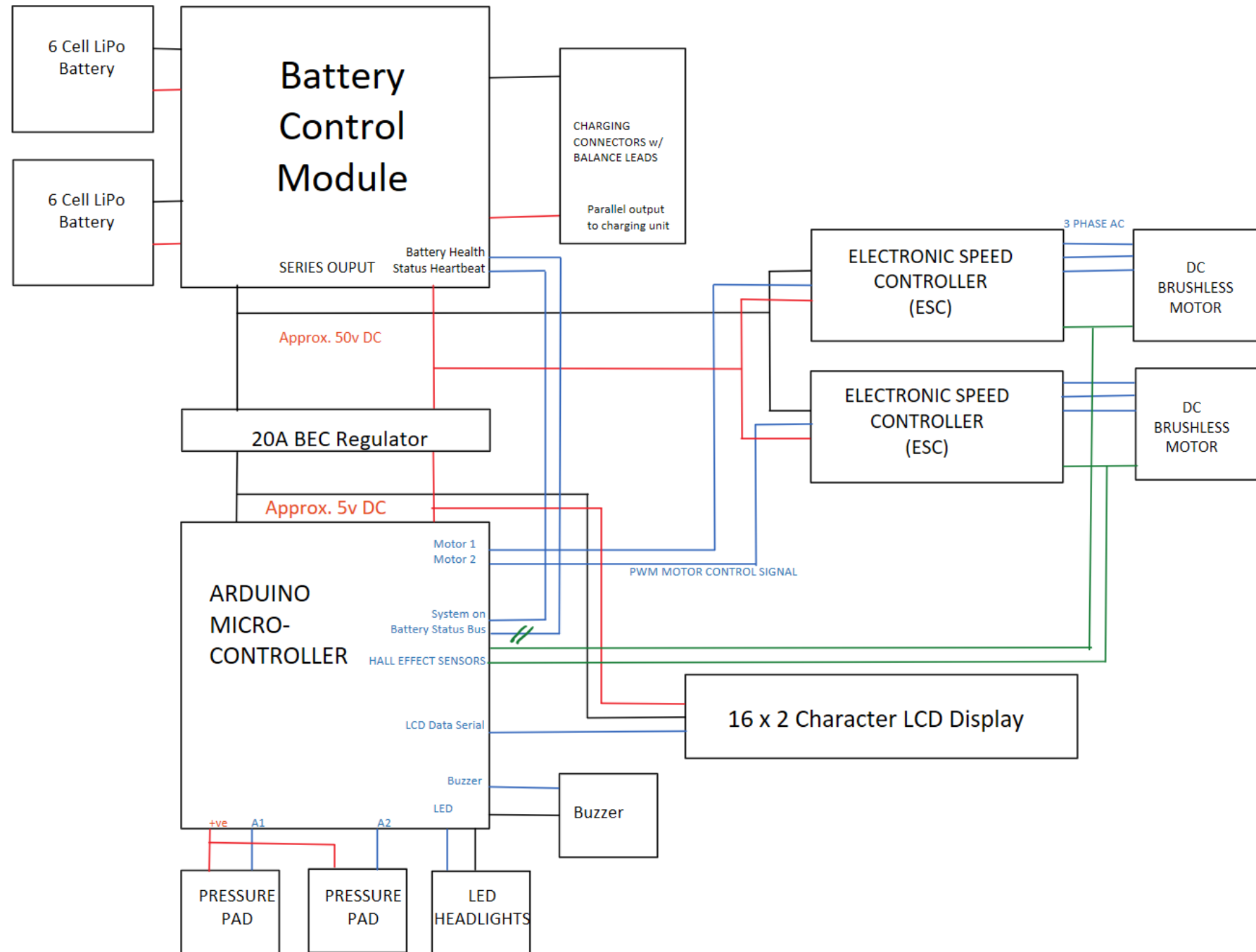
Microcontroller

- Need a system to provide PWM signals to ESCs
- Maps the throttle input to an acceleration of the motors
- Power supply – regulated supply from battery
- LCD monitor – debugging and status



Block Diagram

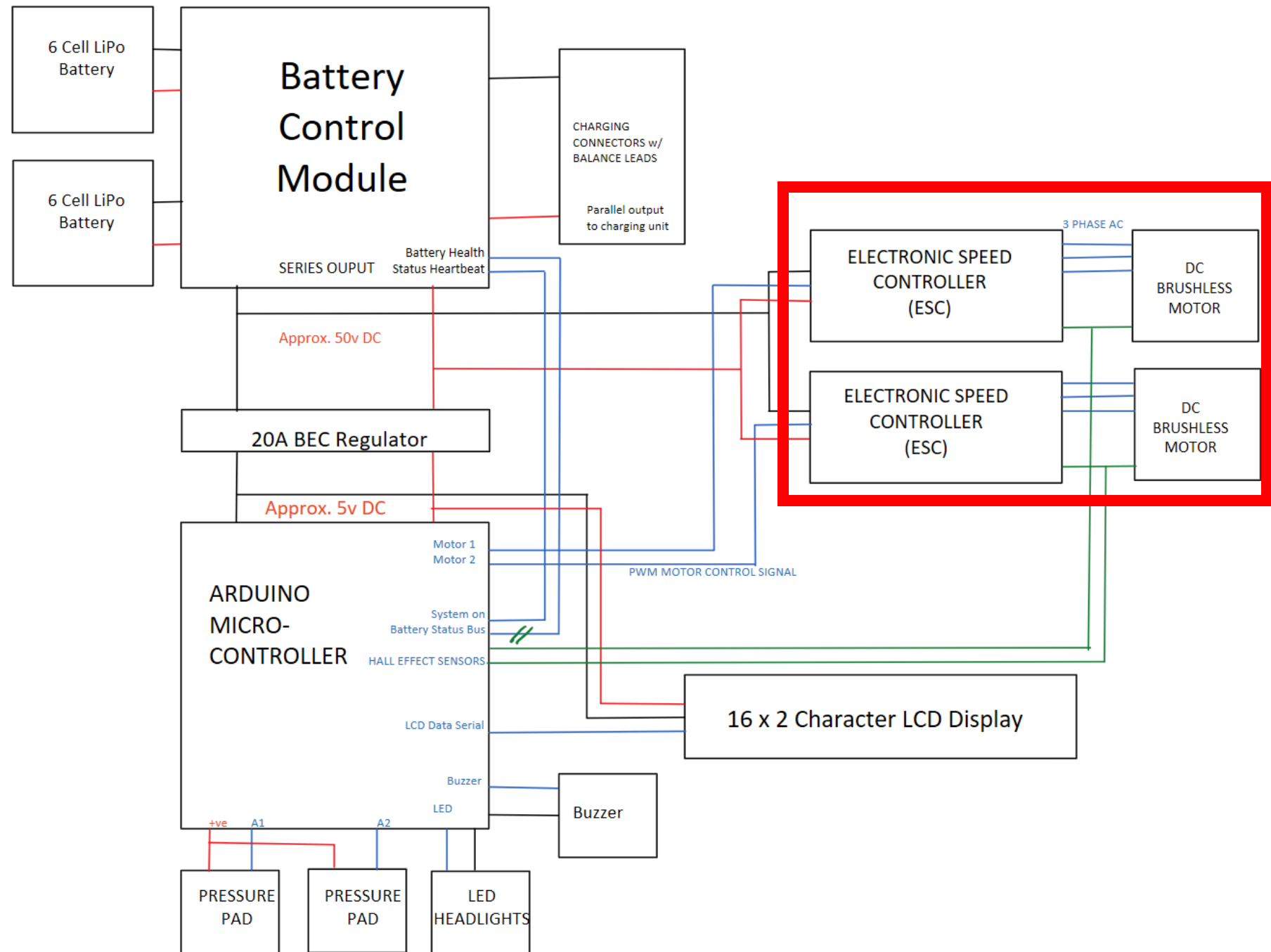
- 50v Supply Rail
- 5v Rectified Supply Rail



Block Diagram

ESC and Motor Module:

- 2 Pairs
- Controlled by PWM Signal
- Hall Effect Sensors to measure rotation speed



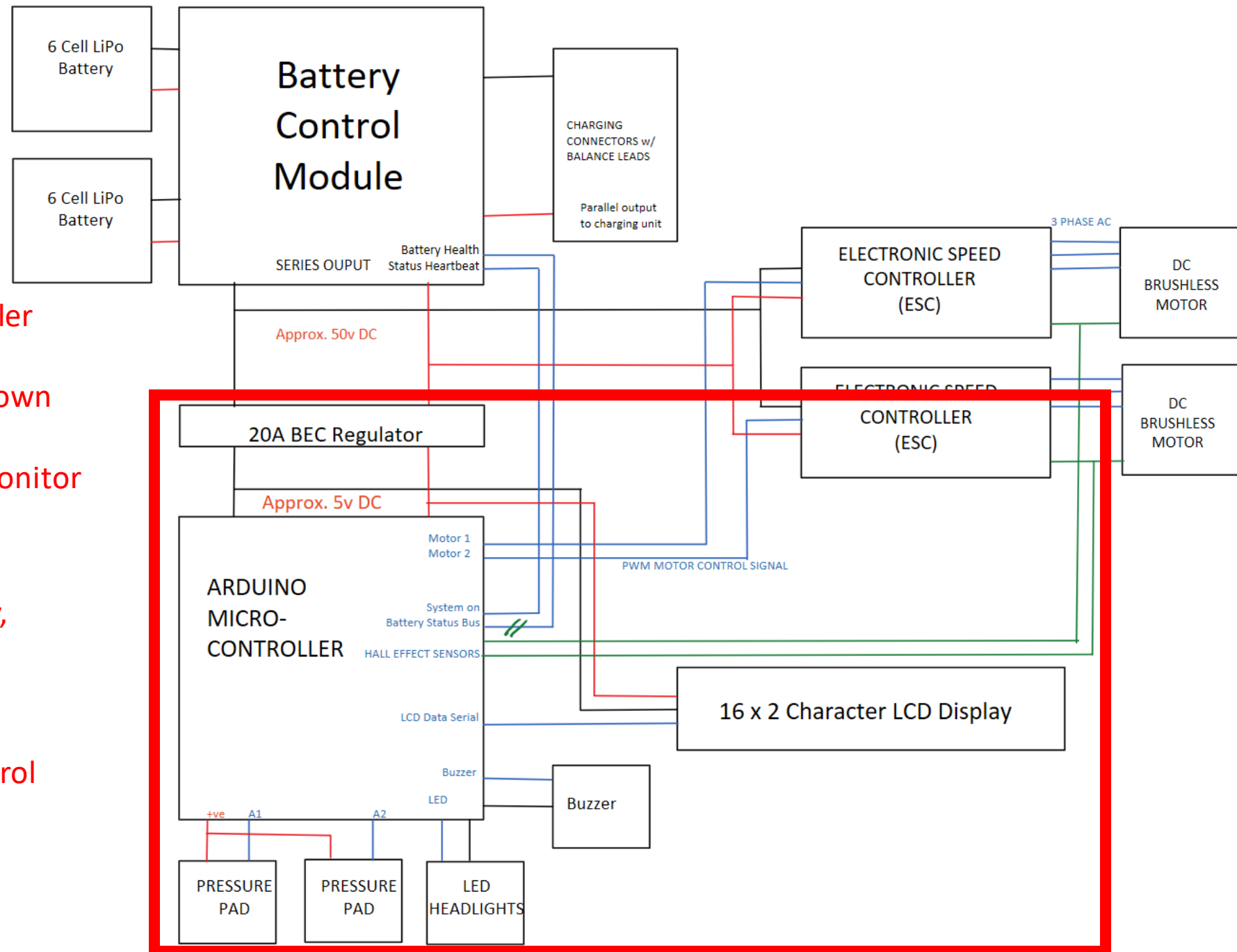
Block Diagram

Regulator and Main Microcontroller

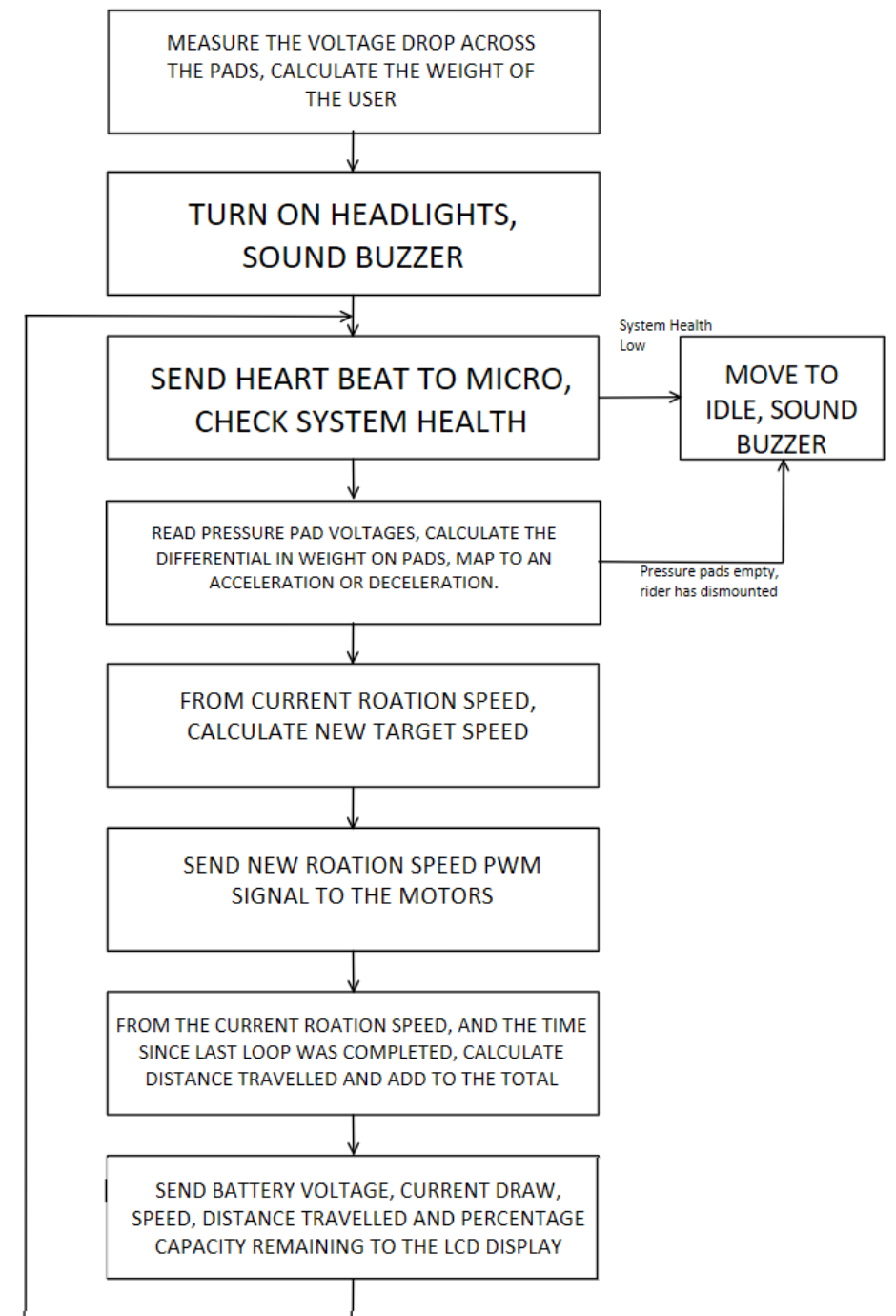
- Runs at 5v
- Uses a 20A regulator to step down from 50v
- Many inputs and outputs to monitor the system

I/O components:

- LCD to display battery capacity, speed etc
- Buzzer to alert the rider
- Headlights for riding at night
- Pressure pads for throttle control



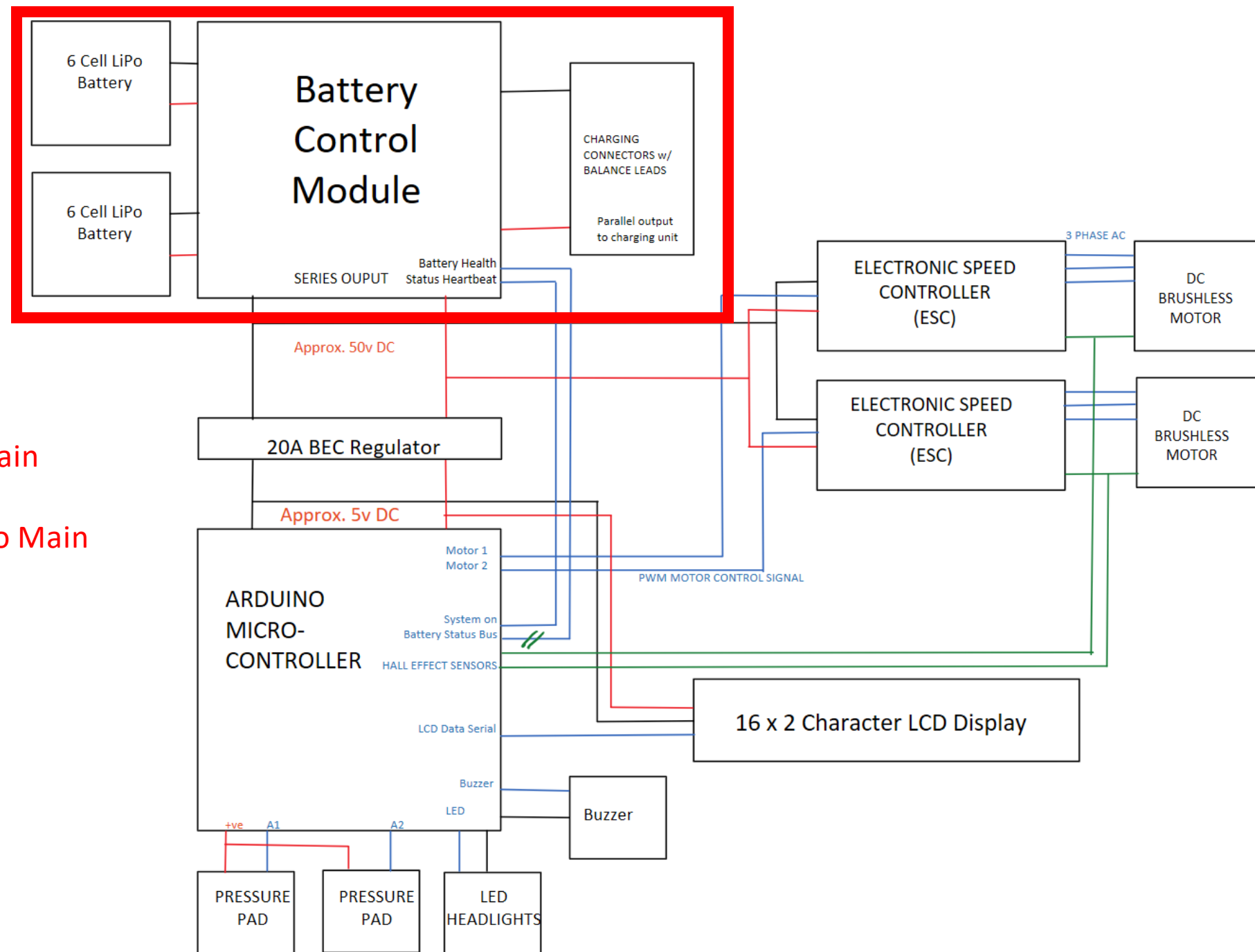
- Calibration Stage
- Main loops sends heartbeat periodically
- Checks for system safety, stopping drive if it falls outside safe bounds
- Reads pressure pads to find the acceleration
- Sends signals to ESCs
- Displays system status to user on LCD



Block Diagram

Battery Control Module:

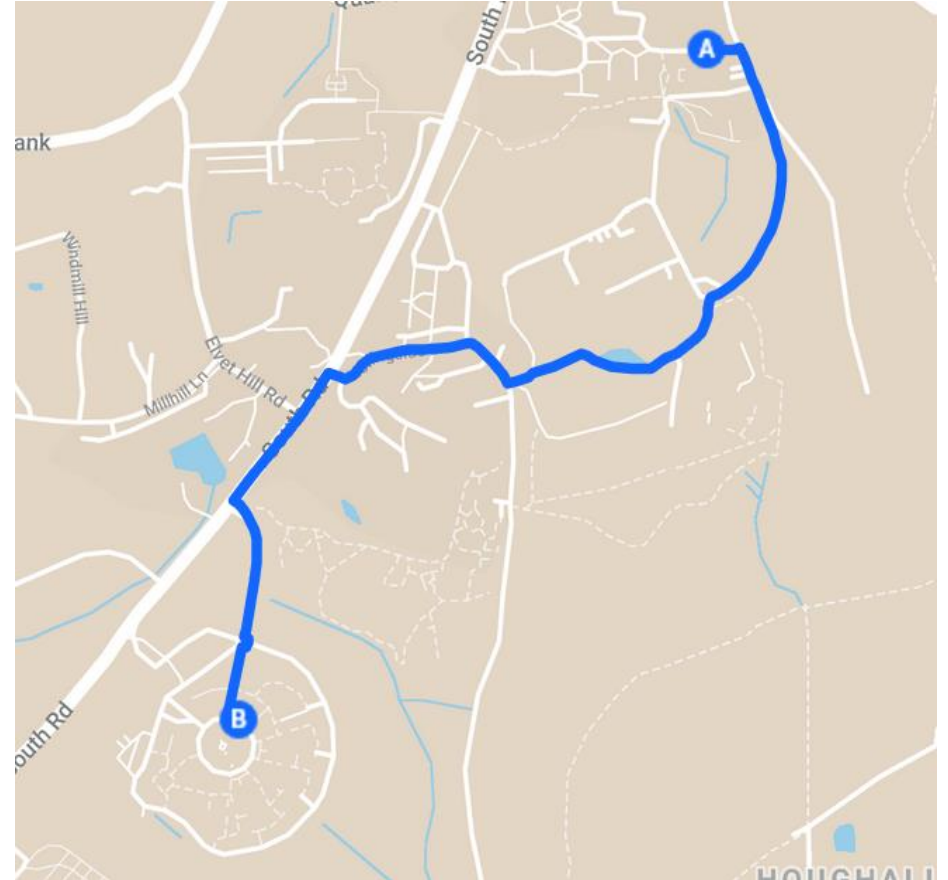
- Receives a heartbeat from Main Microcontroller
- Reports back battery status to Main Microcontroller



Range specification

Specification

- Charge once per week
 - Days in use: 5 days (commute)
 - Distance each day: 3km
 - Estimated vertical distance: 80m
-
- Range on full charge: ~15km
 - Estimated energy per mile: 10Wh/mile
 - Min capacity requirement: ~180Wh



Google maps example commute

Battery specification

Lithium polymer chemistry

- Watt-hour capacity: 180Wh
- Supply voltage: 22.2V
- Amp-hour capacity: 8100mAh
- Mass: 1.24kg
- Supply voltage: 50v
- 2 batteries in series required

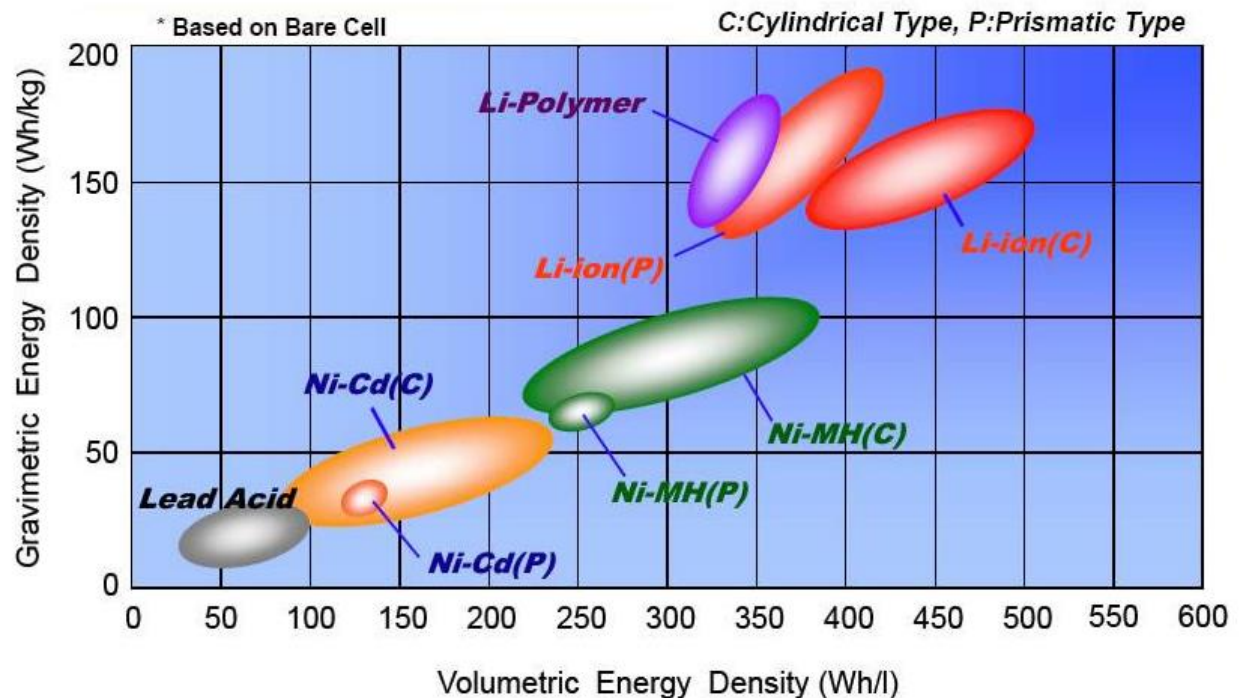


Figure from [Comparison of Energy Density in Battery Cells](#) - NASA

Battery charging

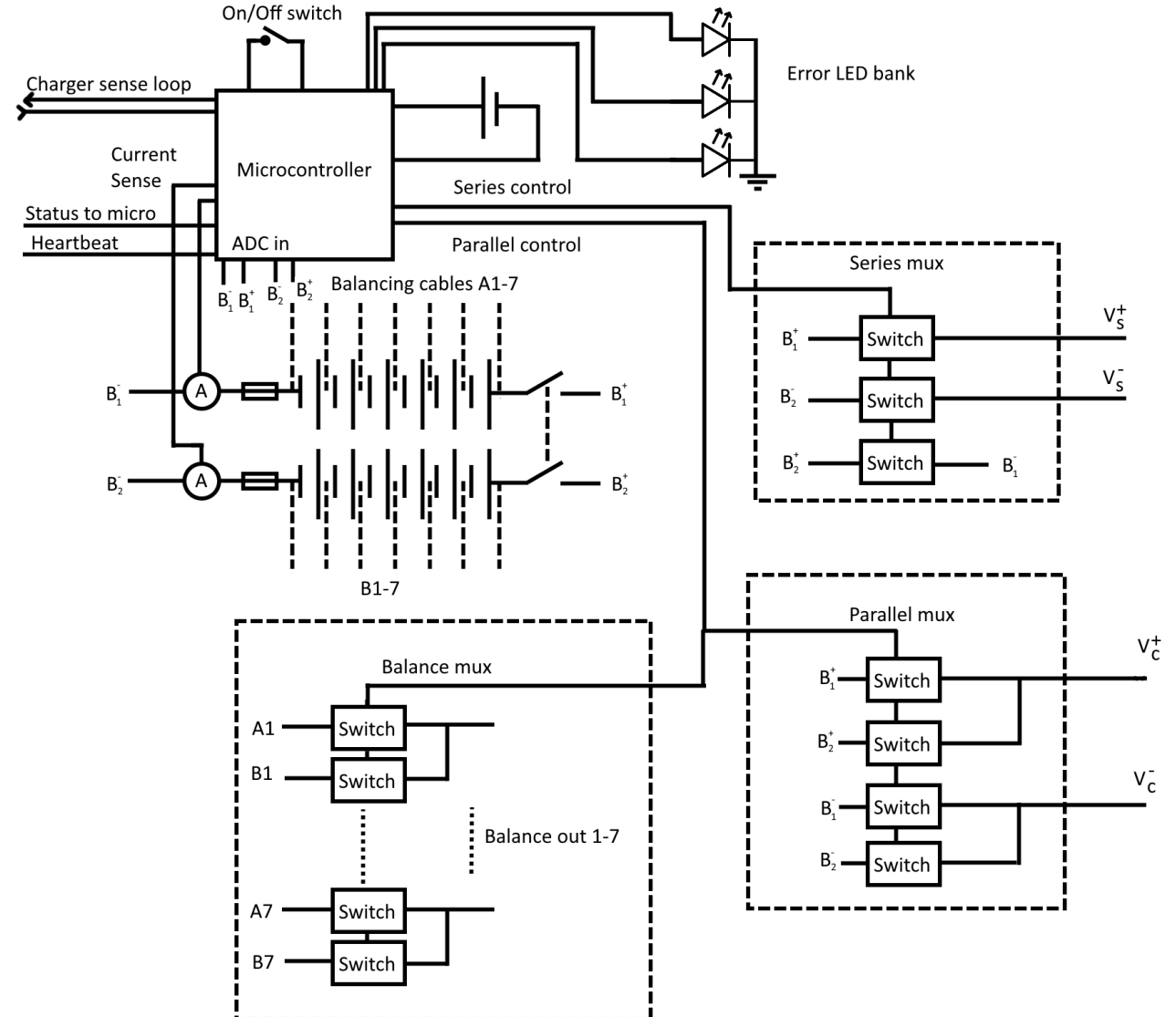
- Lithium polymer can be dangerous:
 - Overcharging
 - Unbalanced charging
 - Use an off the shelf solution
 - Use hobby/RC charger
-
- Charge batteries in parallel
 - System to switch between series and parallel



<https://traxxas.com/products/parts/2994>

Battery control overview

- Battery series/parallel multiplexer
- Microcontroller
- Independent power supply
- Current monitors
- Isolation switches
- Fuses
- Communication bus

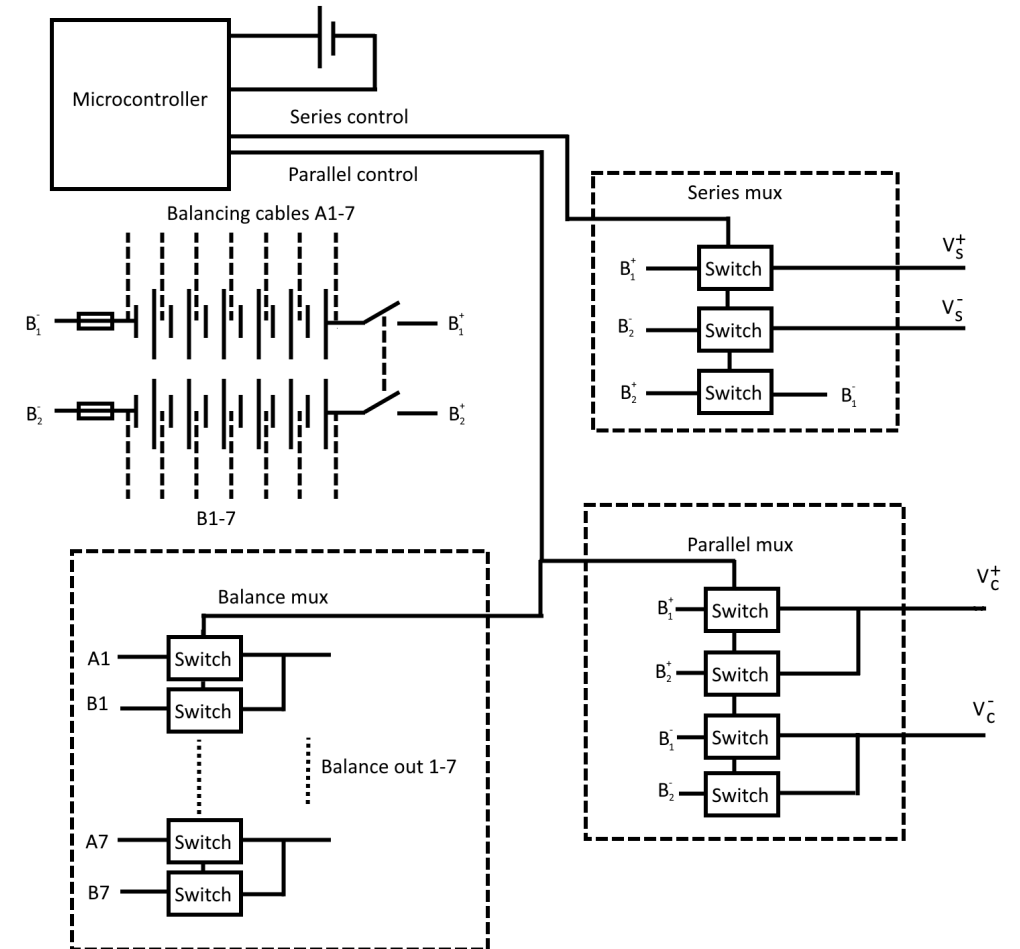


Battery multiplexer (mux)

- Two large batteries

States:

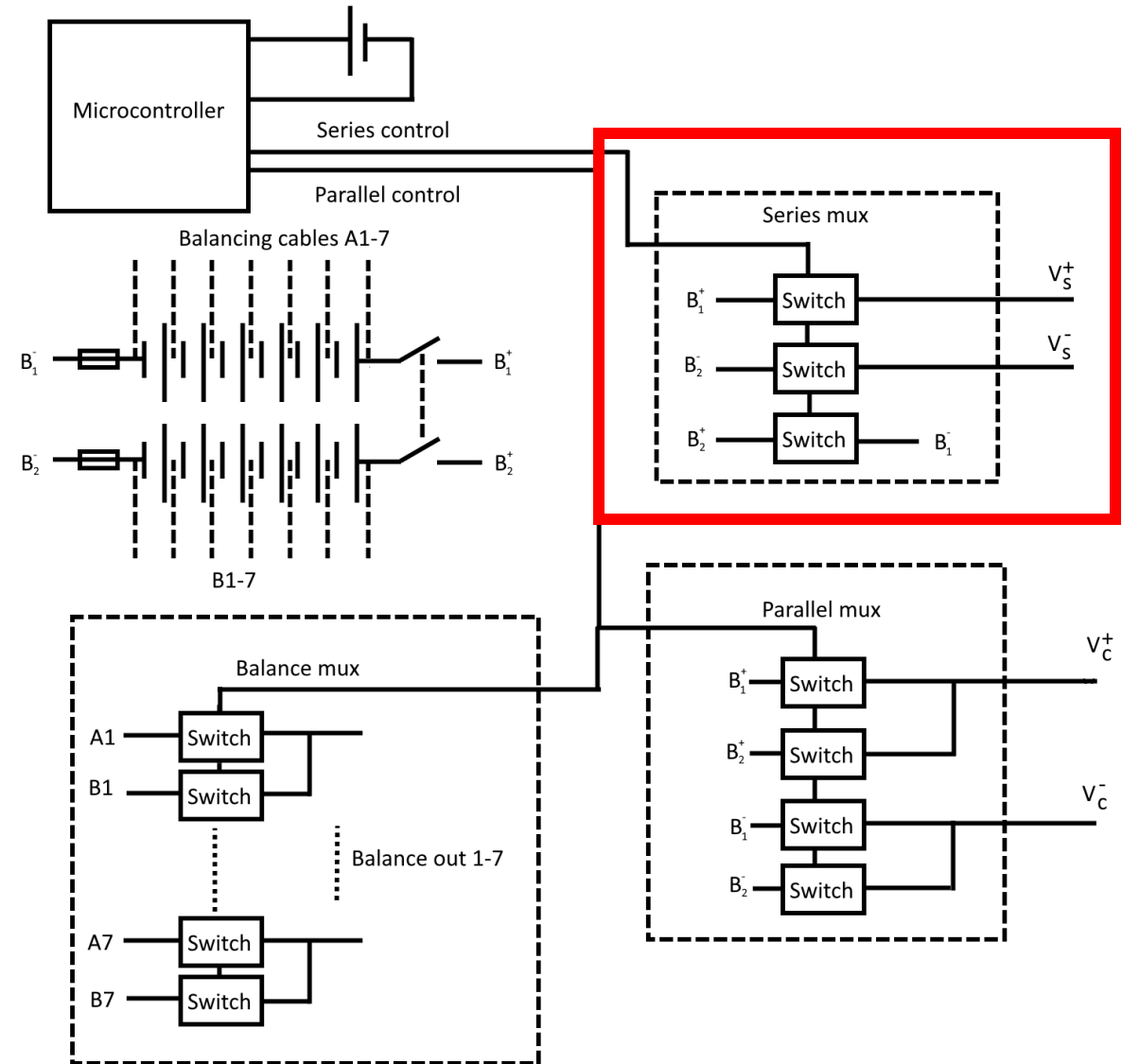
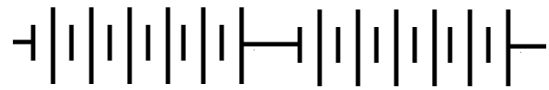
- Charge in parallel
- Discharge in series
- Disconnected
- Electrically controlled path switching
- Vibration resistant
- Short resistant
- Bidirectional current flow (balanced charging)



Multiplexer (cont)

- Discharge

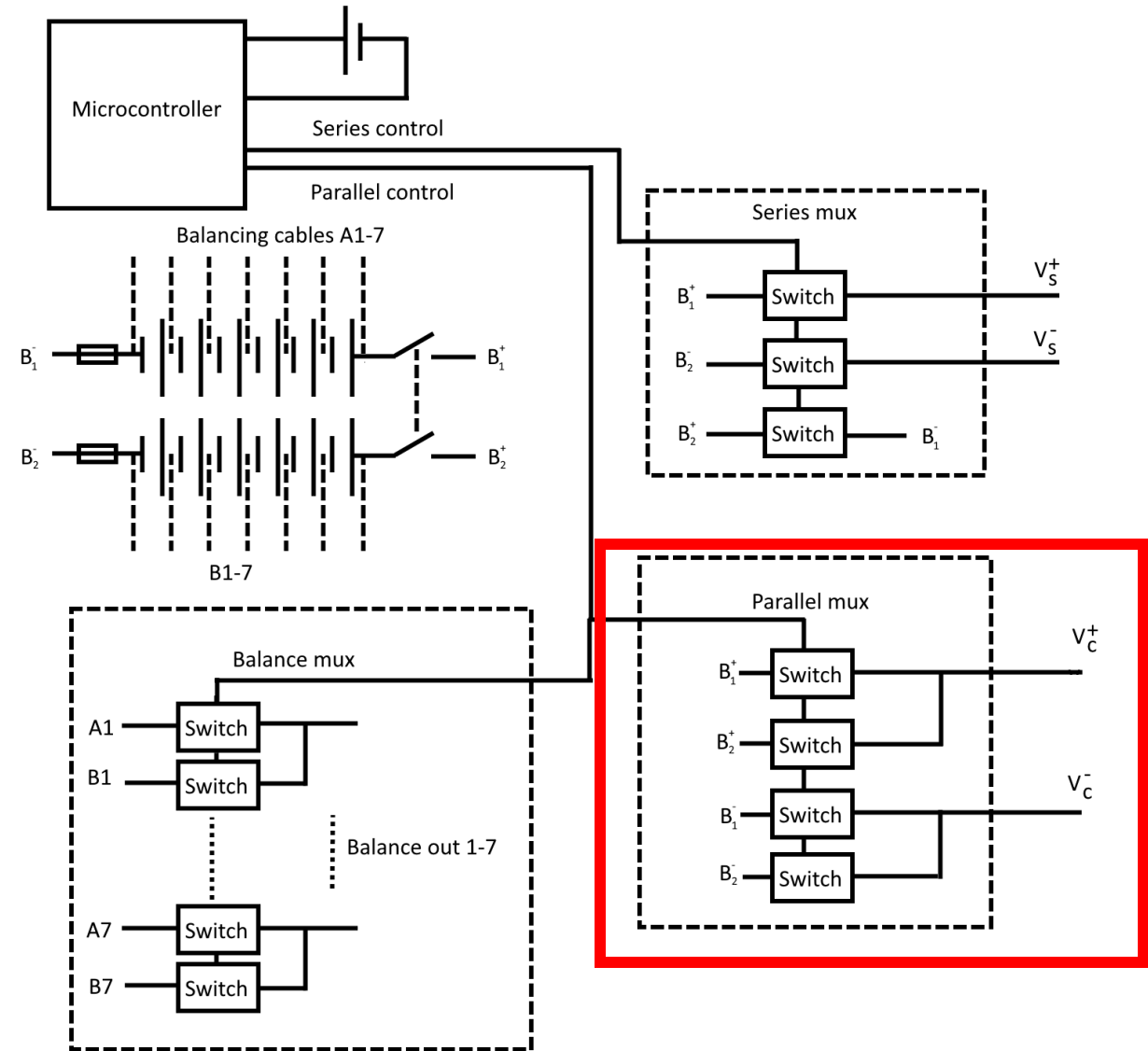
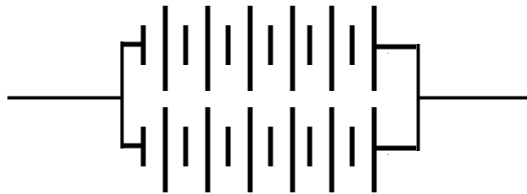
Equivalent circuit



Multiplexer (cont)

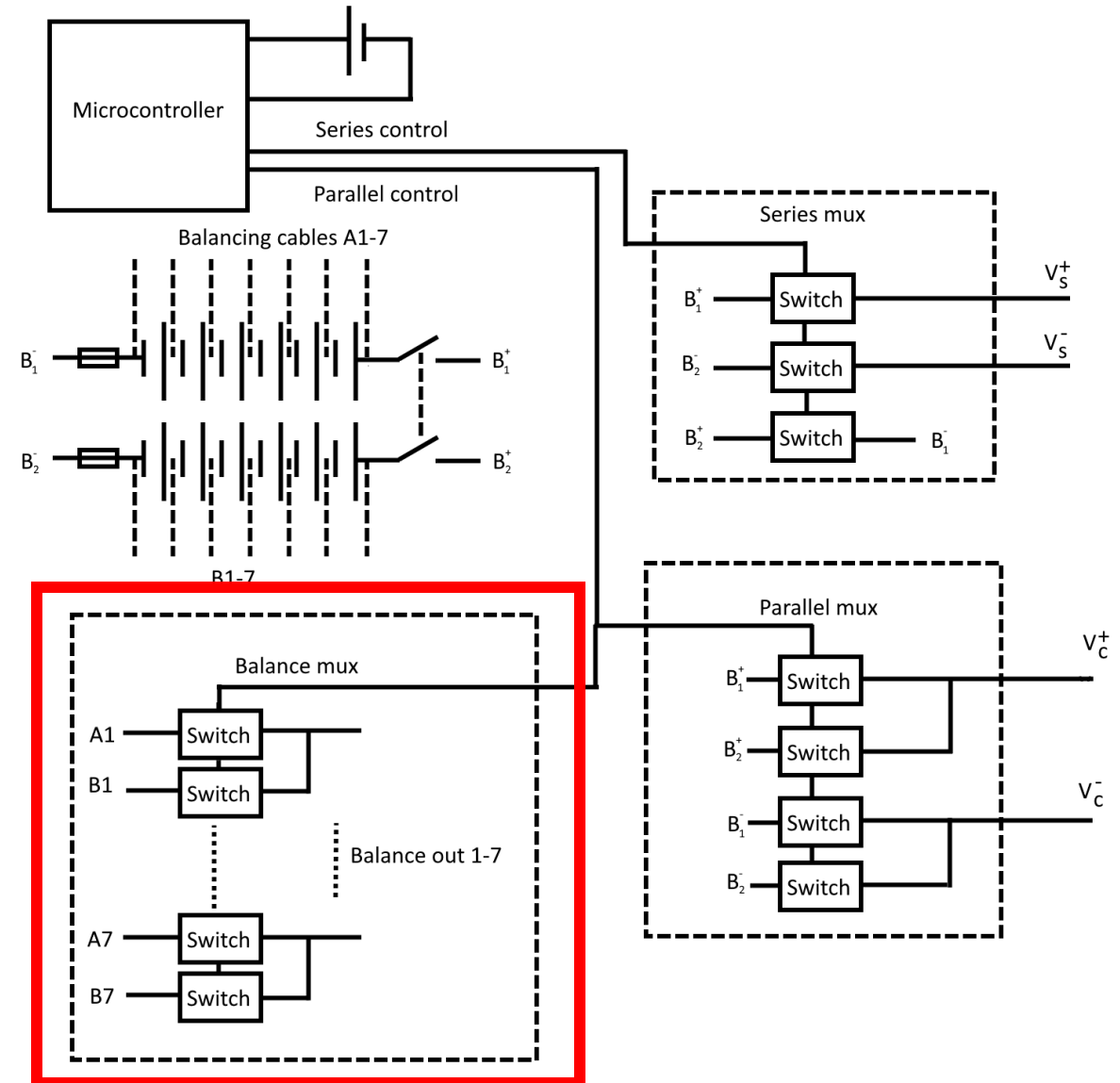
- Charge

Equivalent circuit



Multiplexer (cont)

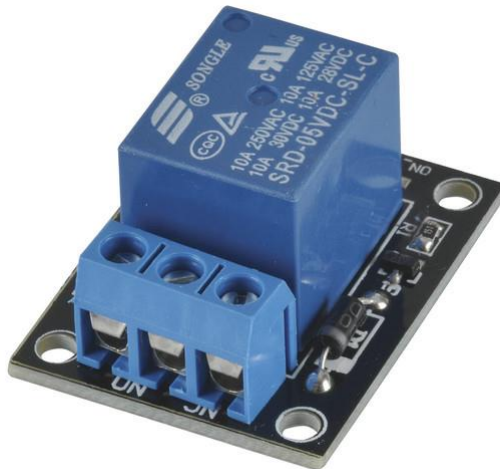
- Charging
- Balance leads in parallel
- Connects to charger



Switching technology

Relay:

- Electro-Mechanical switch
- Very high voltage
- Very high current
- Low standby draw



MOSFET power switch:

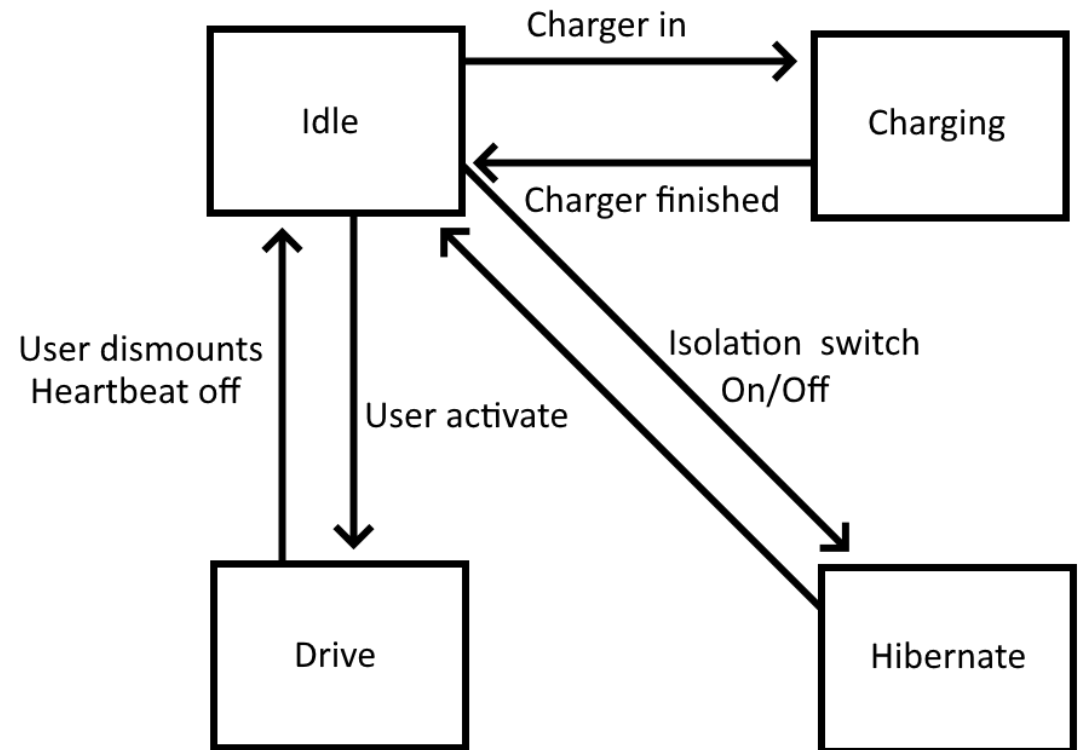
- Solid state system
- Low current
- Higher power dissipation
- Extra drive circuitry



Stock images from
Farnell

Battery embedded controller

- STM8L – microcontroller
- Ultra low power 10 μA sleep state
- Separate battery supply
- Monitors battery health
 - Volts
 - Time
 - Cycle count
- Controls battery mux
- Heartbeat signal from main micro



Safety Measures

- Conducted a Failure Mode Analysis
- Determines edge cases which could lead to system damage/failure
- Plans mitigation factors

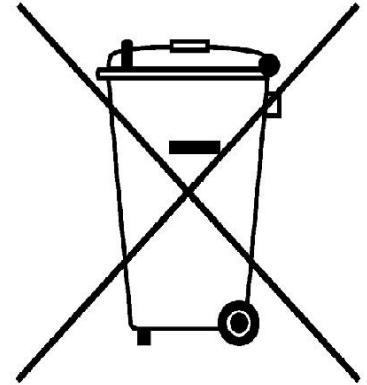
SUBSYSTEM	FAILURE MODE	EFFECT		Severity	MITIGATION
			Likelihood		
Battery Cells	Mechanical Damage	Explodes, fire, capacity reduction	High	Very High	Fuses, Hard Casing, anti vibration (metal fatigue/work hardening)
	Over Charging	Decreased Capacity, fire, explosion, expansion due to c02	High	Very High	Fuses, Smart Charger, detailed user manual, battery health monitor
	Over Discharge	Decreased Capacity, expansion due to c02, metal whisker salt deposits, self discharge leading to remedial charging	Medium	Medium	Fuses, Anti-short connectors, idle mode, battery monitor, hibernation, isolation switch
	Terminal Short	Very Large current draw, heating, fire, all other components down stream lose power	Low	Very High	Use industry standard connectors, isolated contacts, no naked contacts, waterproofing, design to prevent shorts due to circuit failure, fuse in series with battery

Servicing

- Lithium battery take back scheme & disposal
- Replace main batteries and coin battery
- Test and maintain circuitry
- Check mechanical parts for damage
- Replace consumable parts

End of Life

- Lithium Polymers
 - EEE Waste
 - Readily removeable
 - Labelled fully
- ABS plastic and wood are easily recyclable
- Metal can be scrapped



Required Battery Symbol
Image from GOV.uk

Costing

- Material Costs: £880
- Boosted Boards 'Boosted Plus'
 - Retail Price: £1300
- OneWheel's 'XR'
 - Retail Price: £1400

Cost (£)	Item
£50.00	Front and Rear Trucks (Torque Motors)
£72.00	Motor Mount (Torque Motors 'V6')
£7.74	Rubber Driven Wheels (x2)
£12.98	Titanium Bearings (x4)
£0.19	Weicon GMK 2410 Rubber Metal Contact Adhesive
£184.00	6374 DC Brushless Motors (x2)
£20.60	36 Tooth HTD5 Cog (36-5M-09F) (x2)
£5.98	12 Tooth HTD5 9mm Motor Cog (x2)
£21.48	Belt HTD 300-5M-9 Continental (x2)
£126.00	Li-Po Battery (x2)
£0.67	Coin battery CR2032
£5.00	Switch driver LTC7004
£38.00	Battery charger
£13.50	Power switches FDC6324L (x30)
£1.50	Low power micro STM8L 152C6T6
£30.00	Box and Rail ABS cost
£220.00	ESC (x2)
£70.00	Miscellaneous Parts
£879.64	

Questions