Electrical System Form FS2018

Revision 4

Technical University of Denmark, car #133

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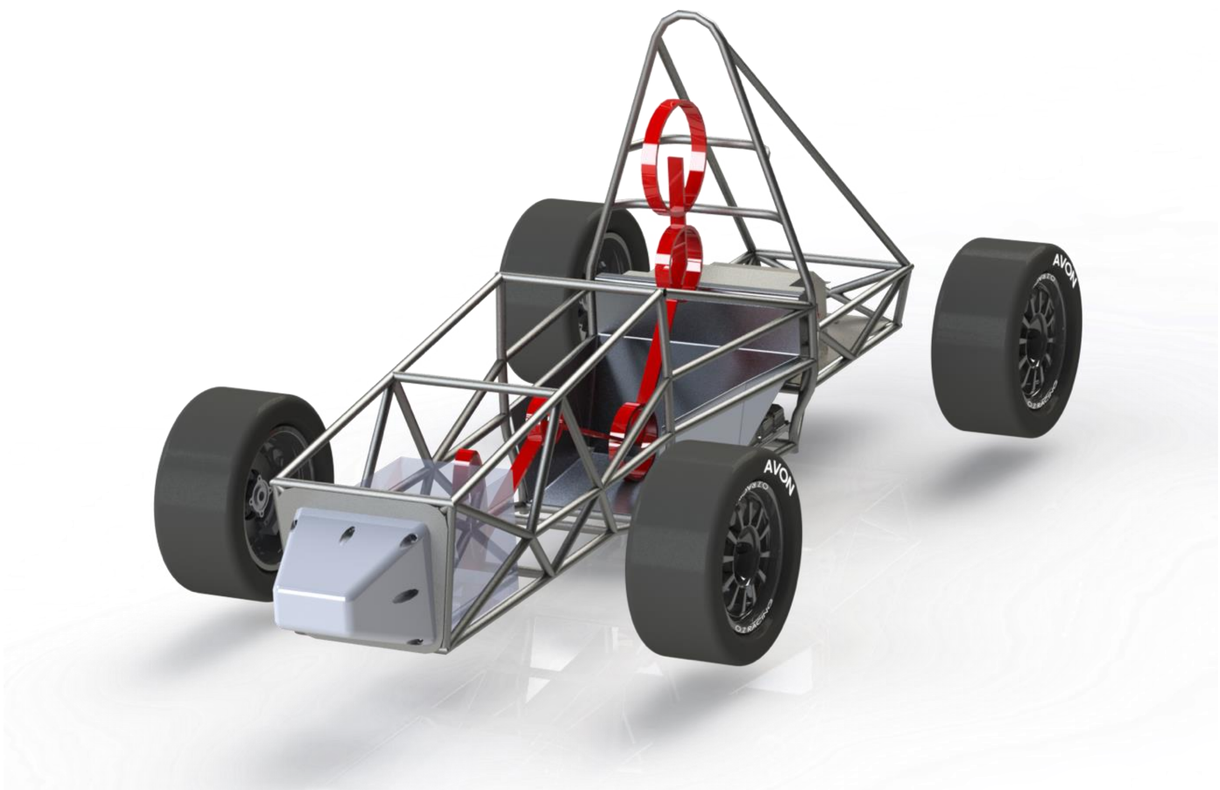

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III List of Abbreviations

1. LiPo: Lithium Polymer
2. BMS: Battery Management System a.k.a. Accumulator Management System / AMS

Additionally the abbreviations present in the rules are inherited.

1 System Overview

The electrical system consists of a high voltage tractive system and a low voltage control system. The high voltage system consists of 2 130V Emrax 228 motors, each connected to a back wheel. These are controlled by 2 Emdrive500 drives which are supplied by a 100V LiPo accumulator through a safety shutdown system. The low voltage control system consists of National Instruments cRio as master controller and a battery management system from Lithium Balance that monitors the high voltage accumulator. The software, the pedals and driver input systems, the cooling system and the Audio/visual system are all designed in-house. The low voltage system supplied 12 and 24 volts through its own LiPo pack, independent of the high voltage accumulator.

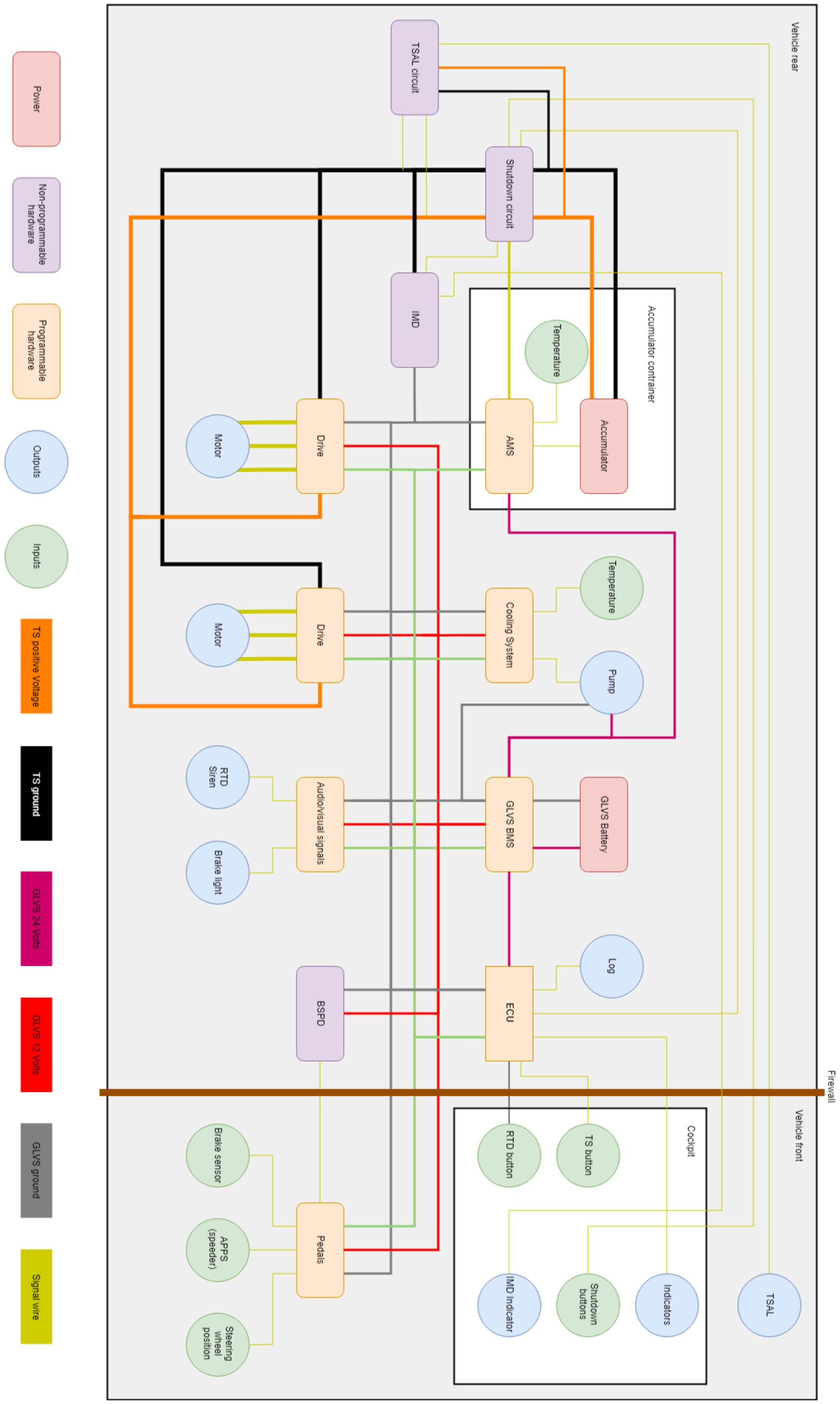


Figure 1.1: System diagram

Maximum Tractive-system voltage:	120VDC
Nominal Tractive-system voltage:	100VDC
Control-system voltage:	12VDC, 24VDC
Accumulator configuration:	28s6p
Total Accumulator capacity:	60Ah
Motor type:	Permanent excitated synchronous motor
Number of motors:	Total 2, one per back wheel
Maximum combined motor power in kW	160

Table 1.1: General parameters

2 Electrical Systems

2.1 Shutdown Circuit

2.1.1 Description/concept

The shutdown system is made to make sure the electrical system is shut down when faults are detected. Every part of the shutdown system either connected to a relay or is a relay. Both the IMD, AMS and the BSPD switches are latched and needs to be manually reset before the system can start again. The positive and negative AIR coils are turned on when both the shutdown system is closed and the BMS control registers no faults. All the relays of the shutdown system is located on the power systems board as well as the connectors to the respective parts of the shutdowns system. Besides the parts required by the rules the shutdown system also include a normally open relay which can be opened and closed by the master controller.

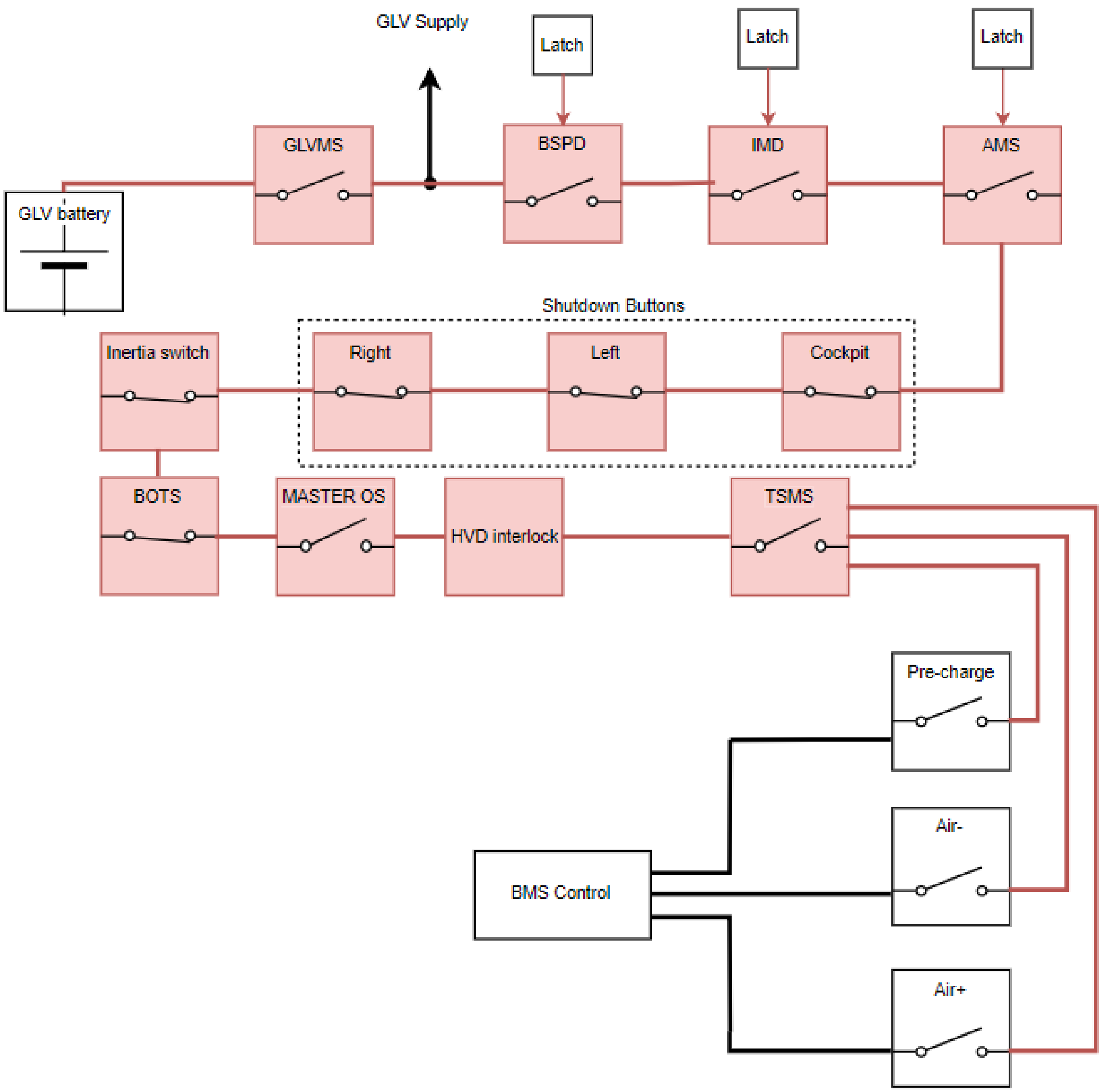


Figure 2.1: Shutdown Circuit

Part	Function
Main Switch (for control and tractive-system; CSMS, TSMS)	Normally open
Brake over travel switch (BOTS)	Normally closed
Shutdown buttons (SDB)	Normally closed
Insulation Monitoring Device (IMD)	Normally open
Battery Management System (BMS)	Normally open
Inertia Switch	Normally closed
Interlocks	Closed when circuits are connected
Brake System Plausibility Device	Normally Closed

Table 2.1: List of switches in the shutdown circuit

2.1.2 Wiring / additional circuitry

See previous section.

Total Number of AIRs:	2
Current per AIR:	0.33A
Additional parts consumption within the shutdown circuit:	24-30W
Total current:	1A
Cross sectional area of the wiring used:	0.205 mm²

Table 2.2 Wiring – Shutdown circuit

2.1.3 Position in car

The circuit controlling the shutdown functionality is located in the accumulator container. See Figure 3.4 for location of accumulator in the vehicle

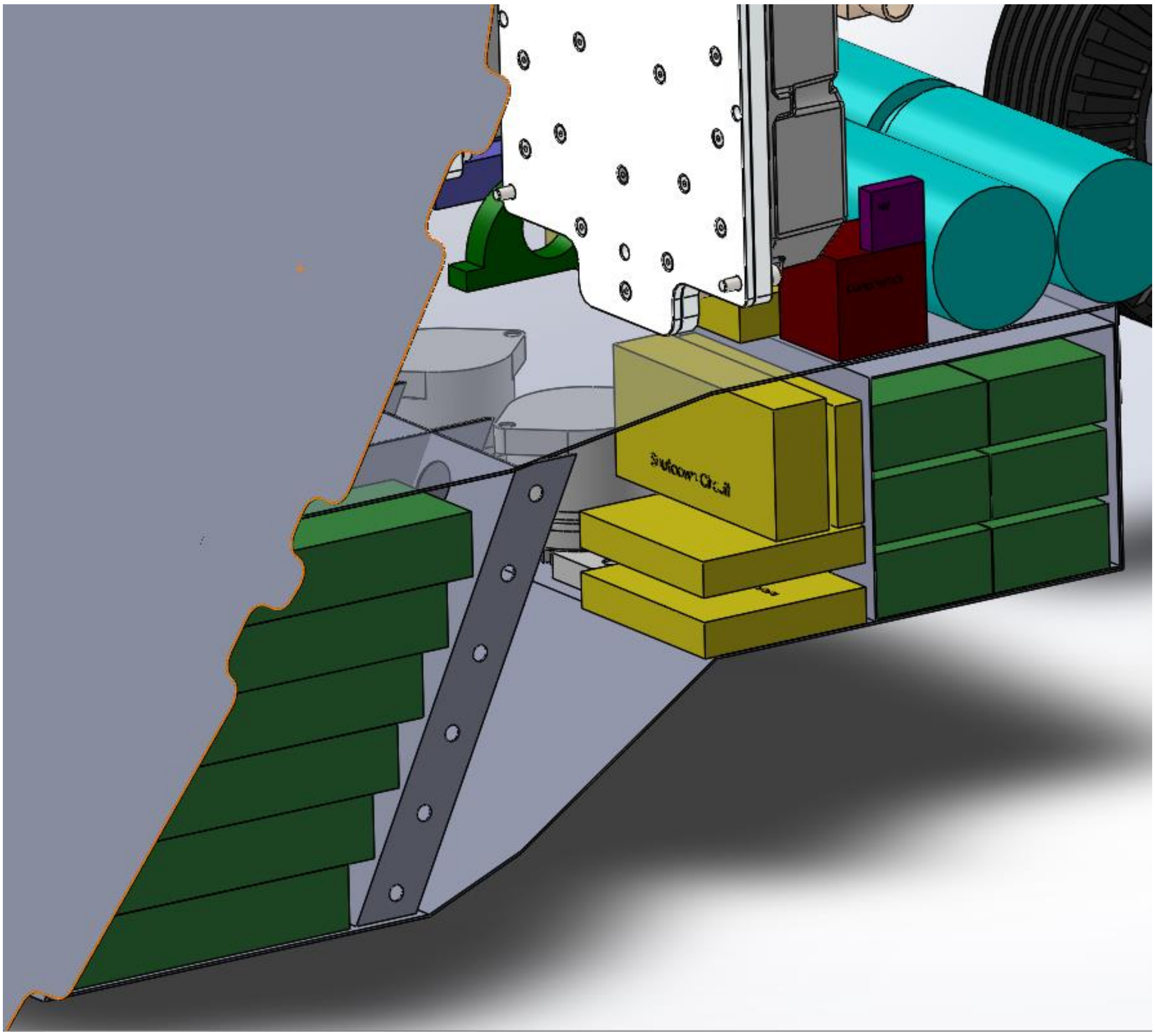


Figure 2.2: Shutdown Circuit position

2.2 IMD

2.2.1 Description (type, operation parameters)

The IMD used is a Bender A-ISOMETER® iso-F1 IR155-3203 the table for the common operation parameters is shown in table 2.3.

The IMD indicator light is turned on when an error is detected. When an error is detected the IMD latch will be activated, this latch will then open the relay and turn the IMD indicator light on. The indicator light will be on and the relay will be open until the latch is manually reset.

Supply voltage range:	10..36VDC
Supply voltage	24VDC
Environmental temperature range:	-40..105°C

Selftest interval:	Always at startup, then every 5 minutes
High voltage range:	DC 84V..1000V
Set response value:	58.8kΩ (500Ω/Volt)
Max. operation current:	150mA
Approximate time to shut down at 50% of the response value:	20s

Table 2.3 Parameters of the IMD

2.2.2 Wiring/cables/connectors/

The figure below shows the wiring of the IMD, pin 1 and 2 will be connected to the tractive system and measure the resistance between the tractive system and ground. Pin 5, 6 and 8 will send data to the master controller. Pin 8 will be used to open the relay through a latch if a fault is detected.

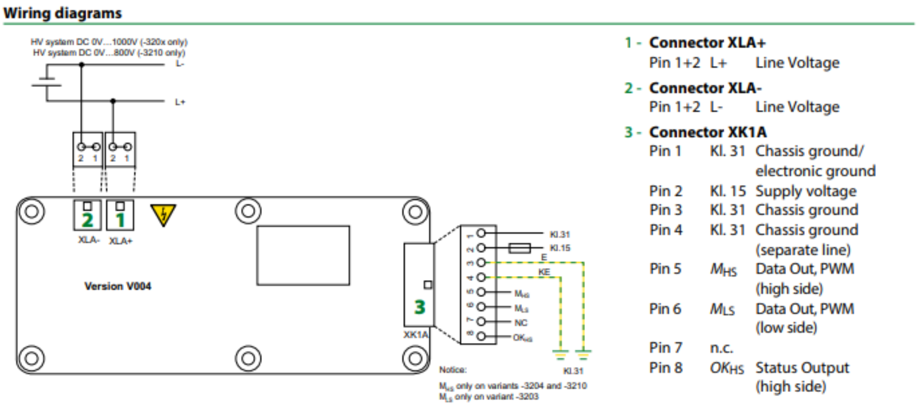


Figure 2.3: IMD circuitry

2.2.3 Position in car

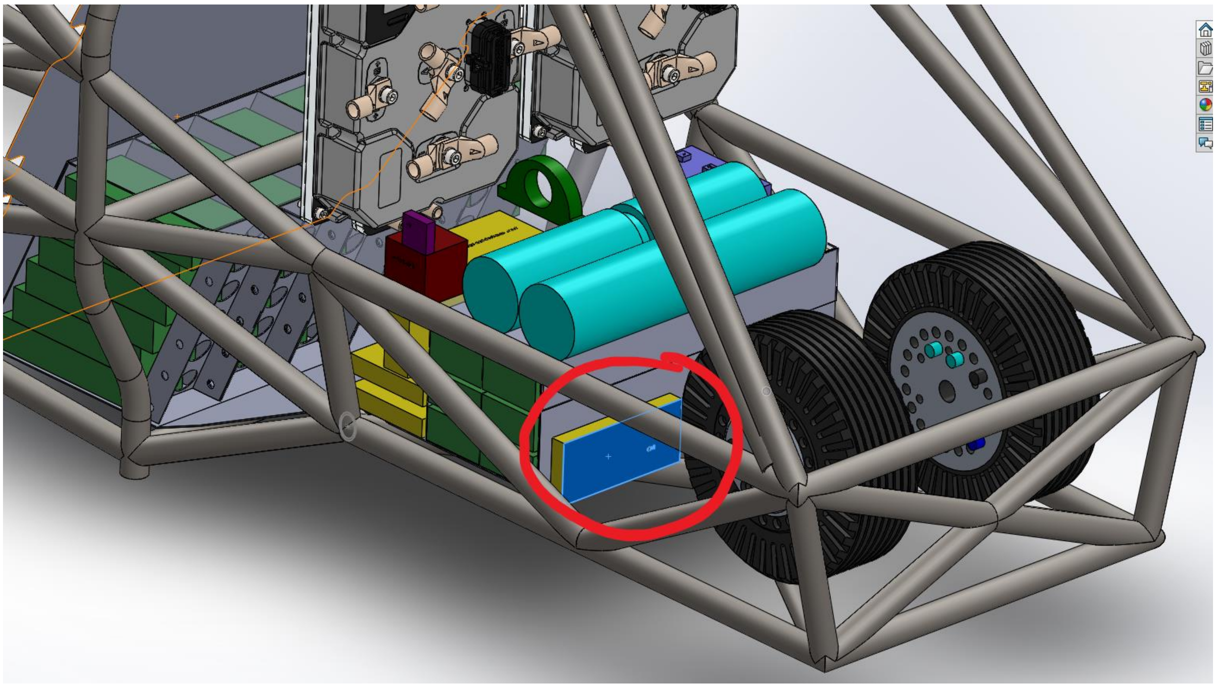


Figure 2.4: Location of IMD in the vehicle

2.3 Inertia Switch

2.3.1 Description (type, operation parameters)

The Inertia Switch is a *Sensata Resettable Crash Sensor*. It works like a switch which will trigger if a high g-force is detected in any direction. The sensor doesn't require to be powered on as it works purely mechanical. If the sensor is tripped, it has to be manually reset before it's possible to turn on the tractive system.

We currently do not have the necessary information on the Sensata Resettable Crash Sensor, but it will be available to us later.

Inertia Switch type:	Sensata Resettable Crash Sensor
Supply voltage range:	Doesn't require a supply
Supply voltage:	Doesn't require a supply
Environmental temperature range:	No data available. It's ISO and TS rated for automotive use, which should be sufficient.
Max. operation current:	10 A
Trigger characteristics:	Shock calibration ranges between 8g and 30g. See datasheet (link: 12.7)

Table 2.4 Parameters of the Inertia Switch

2.3.2 Wiring/cables/connectors

The sensor has a 3-pin connector with a GND, NC and NO pin. The GND and NC will be wired in series in the shutdown system so the AIR coil current is carried through the sensor. If the sensor is tripped, it will break the current to the AIRs and therefore disconnect the accumulator.

2.3.3 Position in car

The inertia switch is depicted by the red box in Figure 2.5.

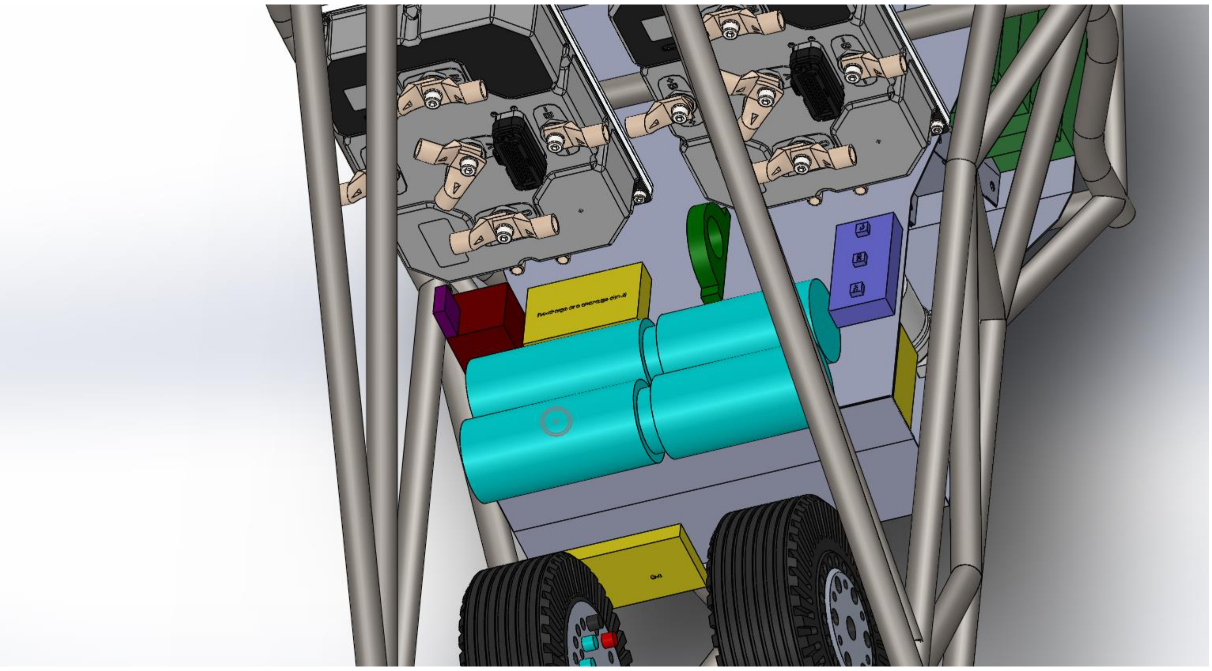


Figure 2.5: Position of Inertia Switch, HVD, TSMP, Energy Meter and Discharge Circuit

2.4 Brake System Plausibility Device

2.4.1 Description/additional circuitry

The electronic hardware brake plausibility device is a nonprogrammable circuit that disables the tractive system incase power is delivered while hard braking occurs. This ensures that the driver will always be able to press the brake pedal hard to stop the car in case of a tractive system failure.

The power delivered to the tractive system is measured using a hall effect open Loop LEM HTFS 800-P current transducer. The brake pedal position is measured using two Bourns potentiometers. Each potentiometer has a different transfer function. If either of the signals show that the pedal has travelled more than 50% while the power delivered to the motor is more than 3kW It will trigger the shutdown circuit after 300ms.

On top of the hardware brake plausibility device the ECU also checks for brake system implausibility. If an implausibility occurs between the values of the brake sensors or the values of the torque encoder for more than 100ms the power to the motors will be shut down immediately. If more than 5% accelerator pedal travel is detected while braking or more than 5% brake pedal travel is detected while accelerating the power to the motors will also be shut down immediately. See section 8.1 for a description of the pedal circuit.

Brake sensor used:	Bourns 53RAA-R25-A15L potentiometer (2x)
Torque encoder used:	Bourns 53RAA-R25-A15L potentiometer (2x)
DC Current measurement used:	HTFS 800-P
Supply voltages:	12V
Maximum supply currents:	25mA
Operating temperature:	-40..105 °C (LEM) 1°C..125°C (Bourns)
Output used to control AIRs:	Open shutdown circuit

Table 2.5 Parameters of the Brake System Plausibility Device

2.4.2 Wiring

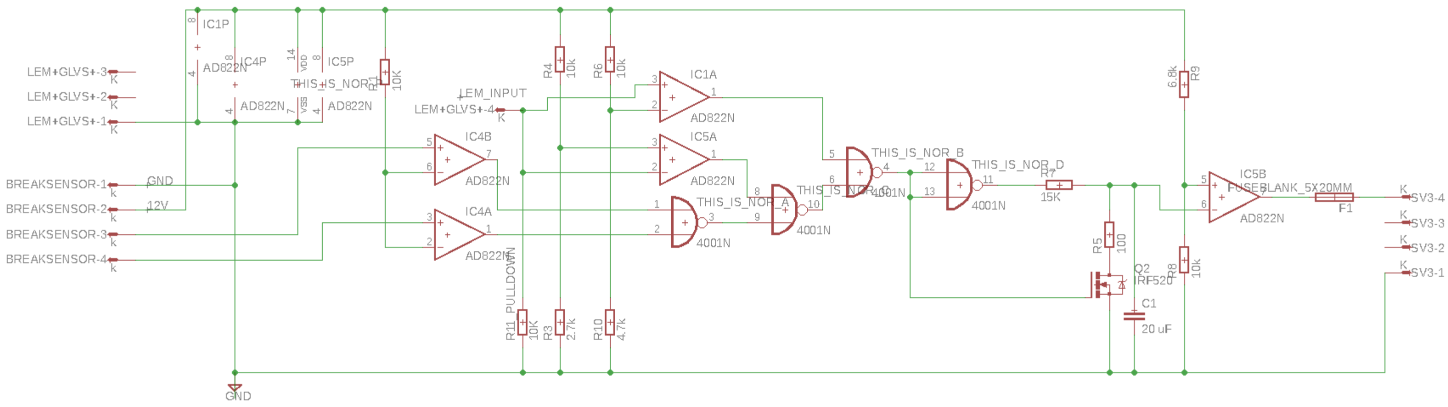


Figure 2.6: BSPD circuit

The circuit is supplied with 12 volts from the GLVS. The LEM current sensor is supplied with 5 volts.

The two leftmost op-amps compare 6 volts from a voltage divider;

$$\frac{10k\ ohm}{10k\ ohm + 10k\ ohm} \cdot 12V = 6V$$

with the brake position signals which vary from 0-12 volts. If either of the brake pedal position sensors signal higher than 6 volts they send high to a NOR gate, meaning that if more than 50% brake is detected on either it will produce a low on the output of the NOR gate. The next op-amp, IC5A, compares the LEM sensor with ~2.625V to see if more than 40A is running through the LEM sensor. If the LEM sensor becomes short circuit to supply another op-amp, IC1A, checks if the signal goes above 3.84V, which indicates either a short circuit or a current larger than the current limit of the batteries. Voltage dividers:

$$\frac{2.7k\ ohm}{2.7k\ ohm + 10k\ ohm} \cdot 12V = 2.55V$$

$$\frac{4.7k\ ohm}{4.7k\ ohm + 10k\ ohm} \cdot 12V = 3.84V$$

The LEM sensor produces a 2.5 – 4.375 volts signal representing a current of 0 – 1200 amperes. 2.625 volt is equivalent to 40 amperes. Calculations are based on the datasheet:

$$\frac{2.625V - 2.5V}{1.25V} \cdot 800A = 40A$$

At a nominal voltage of 100 volts this is equal to 4kW of power. It is designed in such a way that IC1A overrules everything, while a signal from either IC4B or IC4A has to be high while a signal from IC5A has to be low to actually trigger the system. If more than 4kW is drawn while the pedal position is more than 50% or if the LEM sensor is shorted the output on V1/1 goes high and charges a capacitor through a resistor with a time constant of 300ms to make sure that the detected error is persistent and not caused by noise.

$$15k\ ohm \cdot 20\mu\ F\ = \tau = 0.3\ s$$

This means that the capacitor is charged to 63% of 12 volts after 0.3 seconds which is when we want it to trigger. The voltage of the capacitor is compared to a voltage divider of;

$$\frac{10k\ ohm}{10k\ ohm + 6.8k\ ohm} \cdot 12V = 0.63 \cdot 12V$$

A LOW from the last op-amp triggers the shutdown circuit, because the relay is normally opened. Furthermore, the capacitor is immediately drained through a small resistor and an npn transistor when an error is not detected.

2.4.3 Position in car/mechanical fastening/mechanical connection

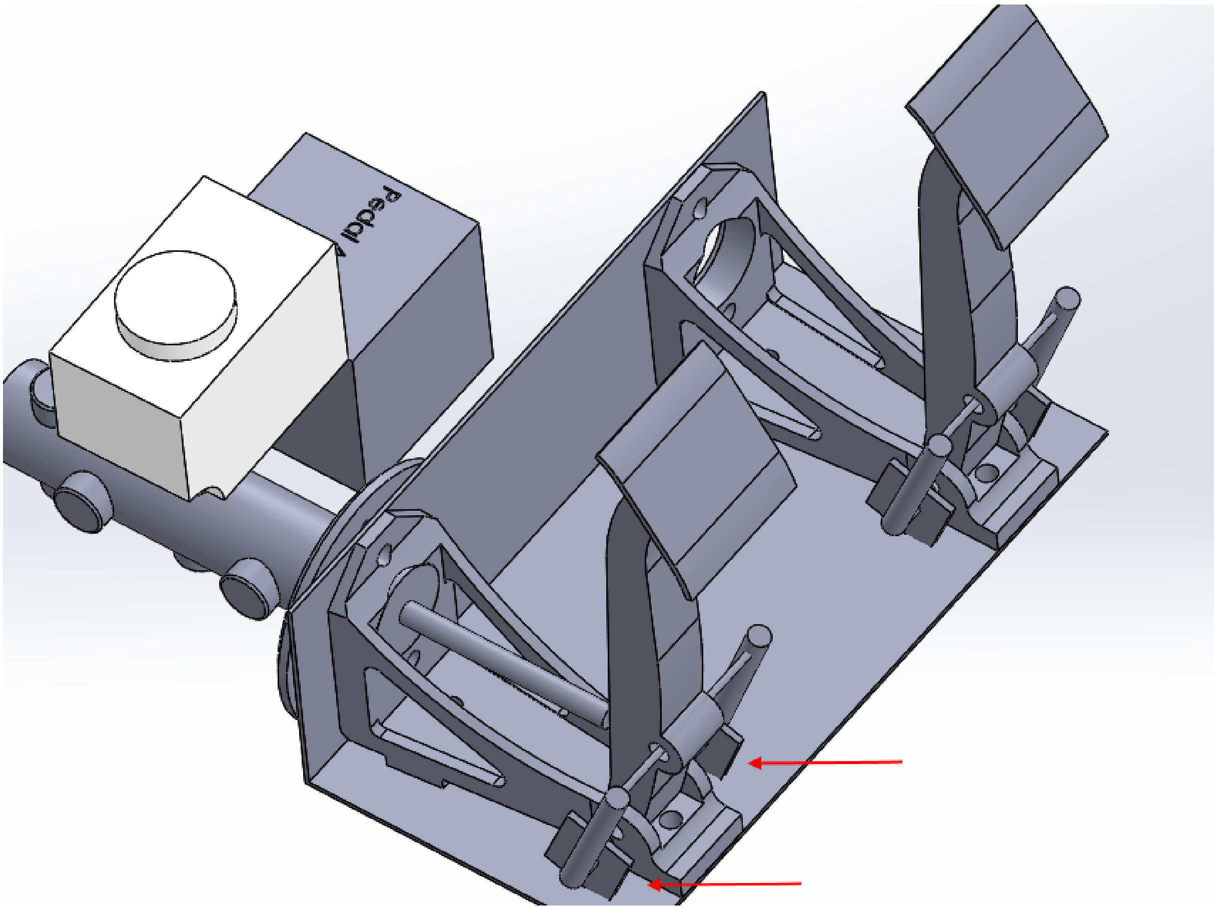


Figure 2.7 Brake pedal sensor position

2.4.4 Wiring/cables/connectors/

The wires connecting the LEM sensor to the rest of the circuit are silicone insulated 22AWG multicore wires rated for 150 Celsius. The connector used is a 3-pin servo plug.

The brake position signal is carried from the pedal box to the BSPD circuit through two coaxial cables with SMA connectors. See section 8.1 for description of the pedal box.

2.4.5 Position in car

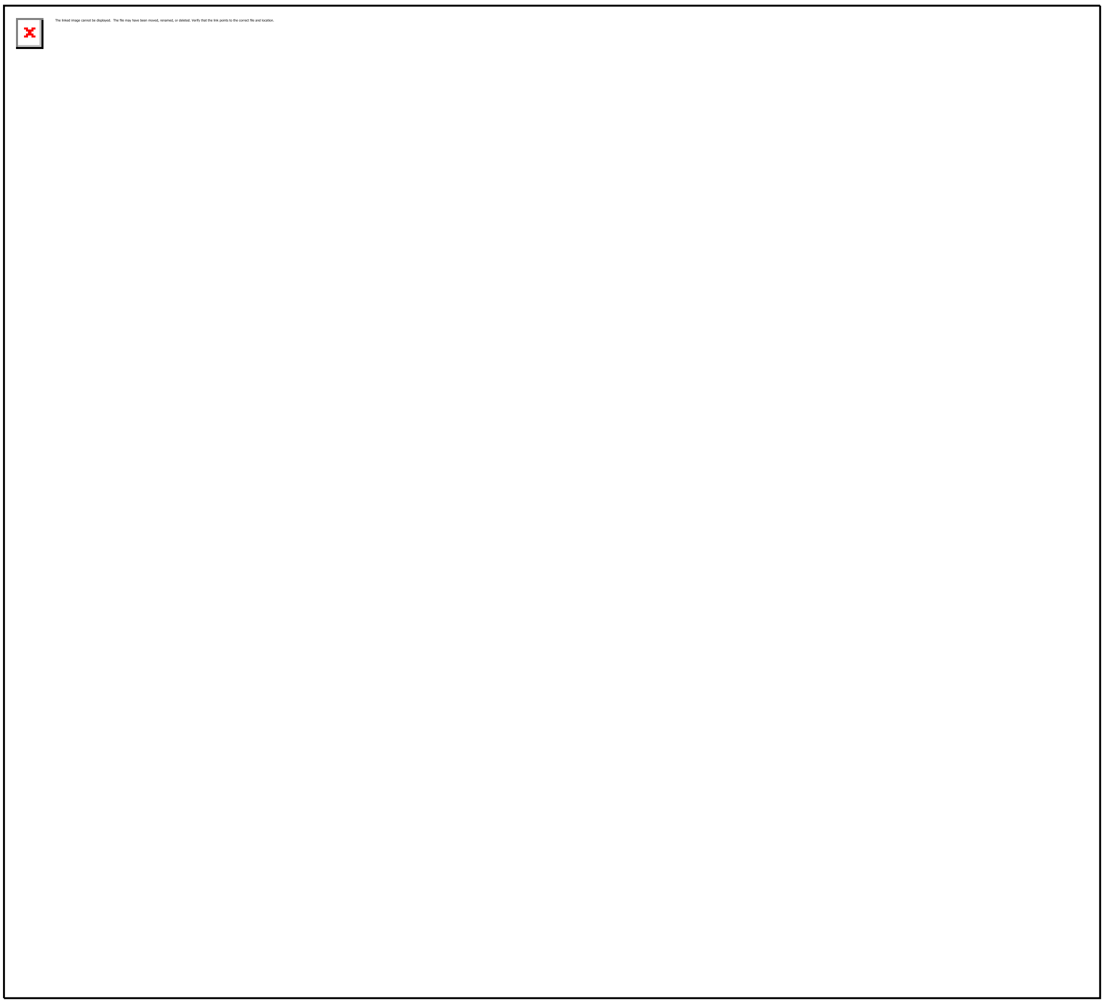


Figure 2.8 BSPD circuit box (green) and LEM sensor (blue) position

2.4.6 Testing Method

The testing of our implementation will be done by first disconnecting the wire from the motors and remove the wire from the current sensor.

Then a new wire with a steady current is placed through the current sensor to simulate a acceleration failure without actually driving. Now the driver should try to break and see if the electrical vehicle shuts down.

2.5 Reset / Latching for IMD and BMS

2.5.1 Description/circuitry

The relay used for the IMD and the BMS will be a latching relay from Panasonic part no: ADW1224HLW. This relay will make sure that when the IMD or BMS detected a fault the system will shut down and has to be manually reset before the car can continue.

2.5.2 Wiring/cables/connectors

2.5.3 Position in car

Will be part of the shutdown circuit. See Figure 2.5.

2.6 Shutdown System Interlocks

2.6.1 Description/circuitry

The interlocks make sure that all the safety systems and switches can activate the shutdown system and immediately disconnect the AIRs. Each interlock is placed in the path to power the AIR relays, and is therefore able to directly cut the power to the AIRs.

2.6.2 Wiring/cables/connectors

A diagram of the shutdown system and interlocks can be seen in section 2.1

2.6.3 Position in car

The shutdown system is placed inside the battery container. The emergency shutdown buttons are placed several places on the car.

See Figure 2.2 for the shutdown system and Figure 2.10Figure 2.10: Figure showing various indicators for the emergency buttons.

2.7 Tractive system active light

2.7.1 Description/circuitry

The TSAL is separated into three main parts. One parts check if any of the main relays are closed and another check if the outside system voltage exceed 50 V. The last part is a timer circuit which use a MOSFET to blink the red light. The three main parts are marked in red boxes as seen on Figure 2.9: TSAL circuitry. The circuitry marked in blue boxes are regulators for the circuit and light. The whole circuit is powered by the accumulator, and is therefore completely isolated and independent of the low voltage system.

The *'Relay state logic'* circuitry is measuring the resistor network R4-R7 to check if the relays are in a safe state. The two AIRs are between R4&R6 and R5&R7, respectively. Depending on the state of the relays, different voltages will be measured by the op-amps. Through calculations, a safe state is found when the measured voltage is 5%-7% of the accumulator voltage. This is checked with the two op-amps and the resistors R1-R3.

The 'System voltage threshold logic' measure the outside system voltage with the voltage divider R16&R17 and compare it with a reference from the 12V regulator and voltage divider R14&R15. If the measured voltage is less than the reference, the outside voltage is under 50V and a safe state is assumed. If the voltage is above 50V, the U3 relay will open, and the TSAL will blink red.

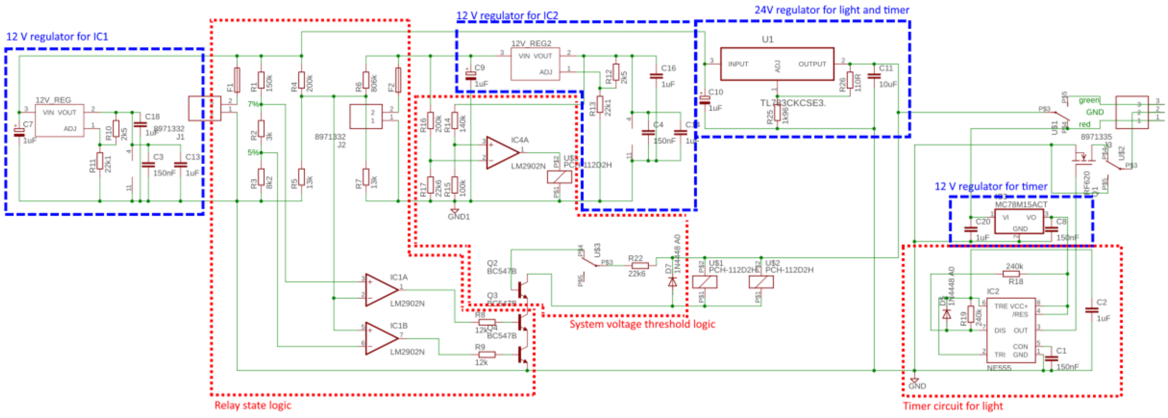


Figure 2.9: TSAL circuitry

The switch between the red and green light is controlled by two relays. The normal position is set to blink red to indicate an active accumulator. Only if all relays are open and the outside voltage is below 50V is the light switched to green. The light itself is a red/green signal tower and is visible from all angles around the light.

Supply voltage:	24 VDC
Max. operational current:	Green: 50 mA Red: 50 mA
Lamp type	LED
Power consumption:	Green: 1.2 W Red: 1.2 W
Brightness	Green: 8 x 16,5 candela Red: 12 x 16,5 candela
Frequency:	Green: constant Red: 3 Hz
Size (length x height x width):	70mm x 30mm x 70mm

Table 2.6 Parameters of the TSAL

2.7.2 Wiring/cables/connectors

The circuit require a 4-pin connector to power the circuit and to measure the accumulator and outside system voltage. The light is connected to a 3-pin connector.

As the circuits are only sensing TS voltages and powering a small light, wired with a thickness of 0.518 m^2 is more than sufficient.

To test the circuit and light safely when the accumulator is removed, a testing device should be made which can replicate all the relay states and system voltage. This can show if the op-amp are working and controlling the TSAL as expected.

2.7.3 Position in car

Figure 2.10 shows the TSAL (red), shutdown buttons (green), BMS and IMD indicators (yellow) and the Tractive System Indicator Light (blue).

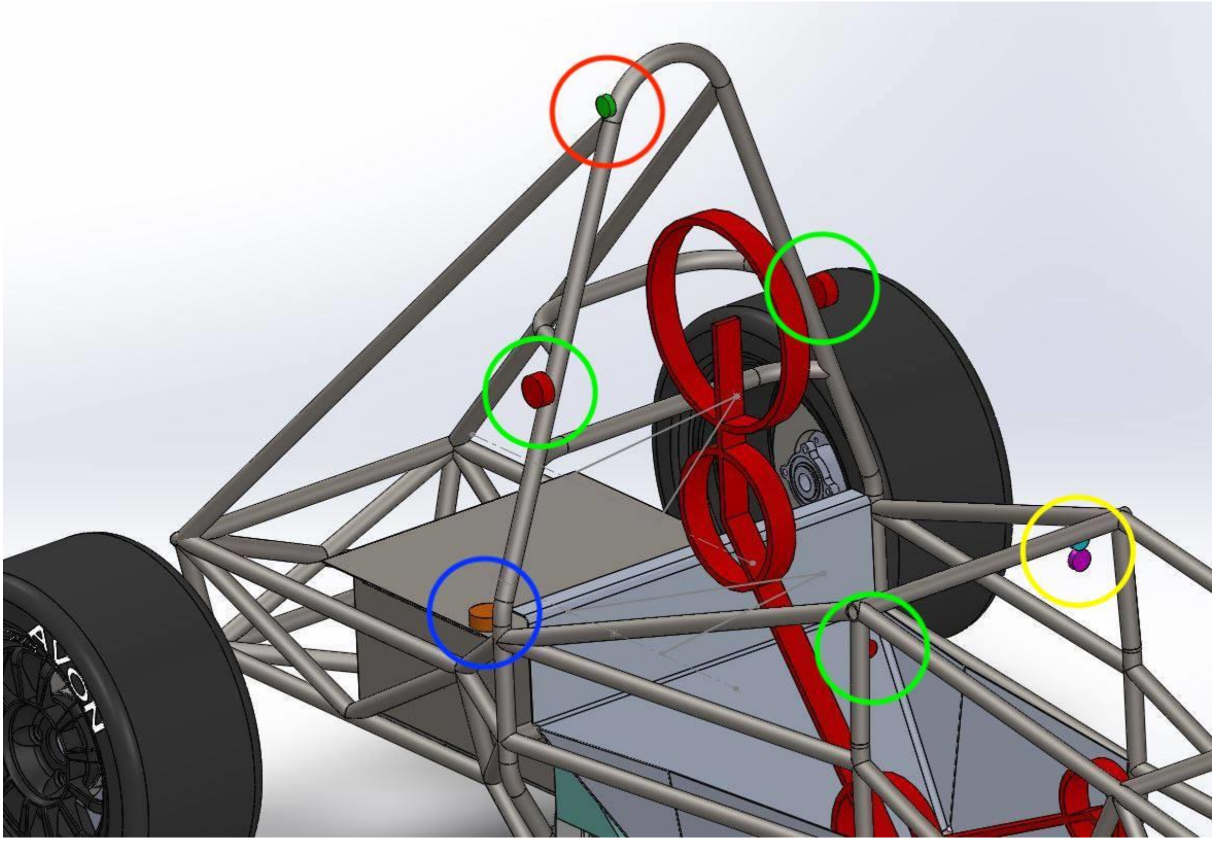


Figure 2.10: Figure showing various indicators

2.8 Measurement points

2.8.1 Description

The banana jacks are placed with a box. It consists of a plastic shield that can be flipped open exposing the banana jacks

2.8.2 Wiring, connectors, cables

This is a simple circuit. The wire from TS+ goes through a resistor to reduce the current and then into a red banana jack near the masterswitch. TS- goes directly to another red banana jack also near the master switch. For GLVS no resistor is needed because it's much lower voltage, so the wires are just directly connected to the black banana jacks near the GLVMS.

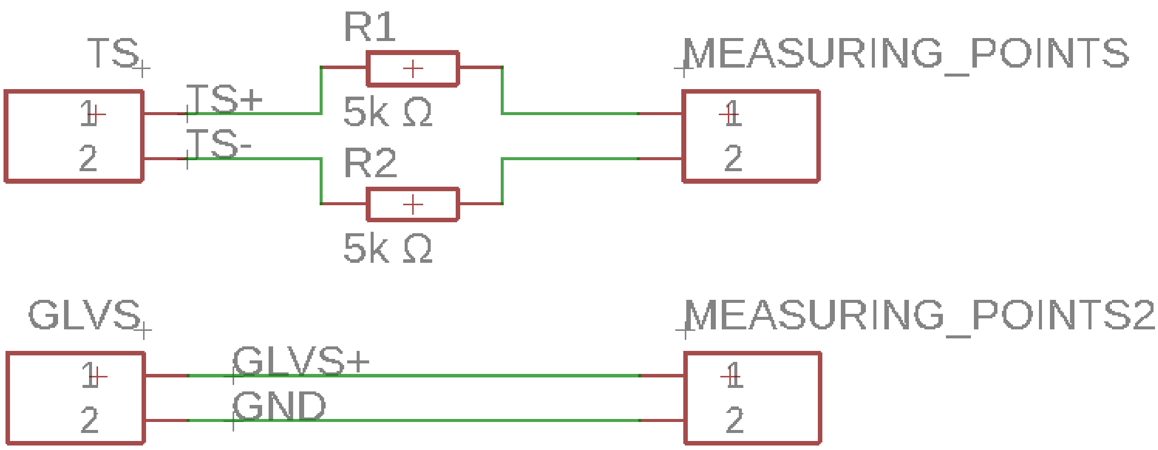


Figure 2.11 Measurement points schematic

2.8.3 Position in car

The Tractive System Measurement Points are depicted by the purple-blue box in Figure 2.5

2.9 Pre-Charge circuitry

2.9.1 Description

The Lithium Balance N-BMS have a build-in pre-charge controller. When it is requested to connect the accumulator, it will run a pre-charge phase where the outside system is charged to at least 90% of the accumulator voltage before connecting the main relay. The BMS will use an external relay and power resistor for the pre-charge operation, but the accumulator and system voltage will be continuously measured by the BMS itself to make sure the pre-charge operation is as expected. If an error occurs, the BMS will open all the relays and try again. If the pre-charge operation fails three times, the BMS will cancel the start-up sequence and communicate an error on the CAN bus.

2.9.2 Wiring, cables, current calculations, connectors

A pre-charge relay and power resistor will be connected in series such that the charging current will be limited by the resistor. The pre-charge system is parallel to the main positive AIR so that the system can be directly connected to the accumulator after the pre-charge operation is finished. The pre-charge relay and two AIRs will be controlled by the BMS pre-charge controller. It's important to note that it is done in such a way that the shutdown system is still able to disconnect all the relays if activated. In Figure 2.12: Pre-charge circuitry, a simple diagram of the relay configuration is seen.

The connectors and wires used to control the relays from the BMS is the ones specified in the BMS datasheet (Link: 12.3). The control wires come out from a larger BMS IO connector and have a cross sectional area of 0.5 mm².

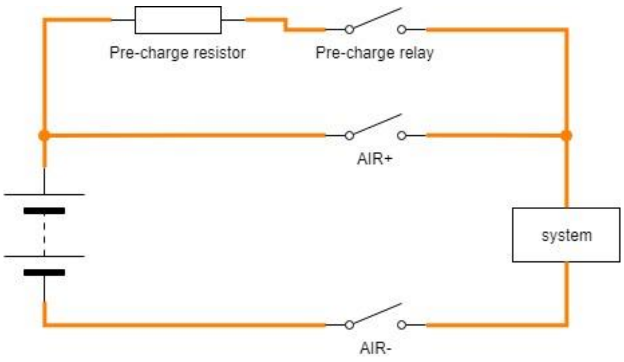


Figure 2.12: Pre-charge circuitry

The two motor controllers have a collective capacitance of 29 mF. A *N_(tau)=3_tau* charge time is chosen, which equals to 95% charge. Choosing a charge time of 10 second would require a resistor of:

*R = (t_charge) / (N_(tau) C) = 10 / (3*29*10^-3) = 115 Ohm*

A 100 ohm resistor would be a good resistance to choose. The voltage over the system and current through it can be calculated with the following formulas:

V_C = V_s (1 - e^(-t / RC))

I_c = (V_s - V_C) / R

Where V_s is the system voltage, which is set to 120V. In Figure 2.13: Plot of pre-charge levels, the system voltage and current is plotted as a function of time.

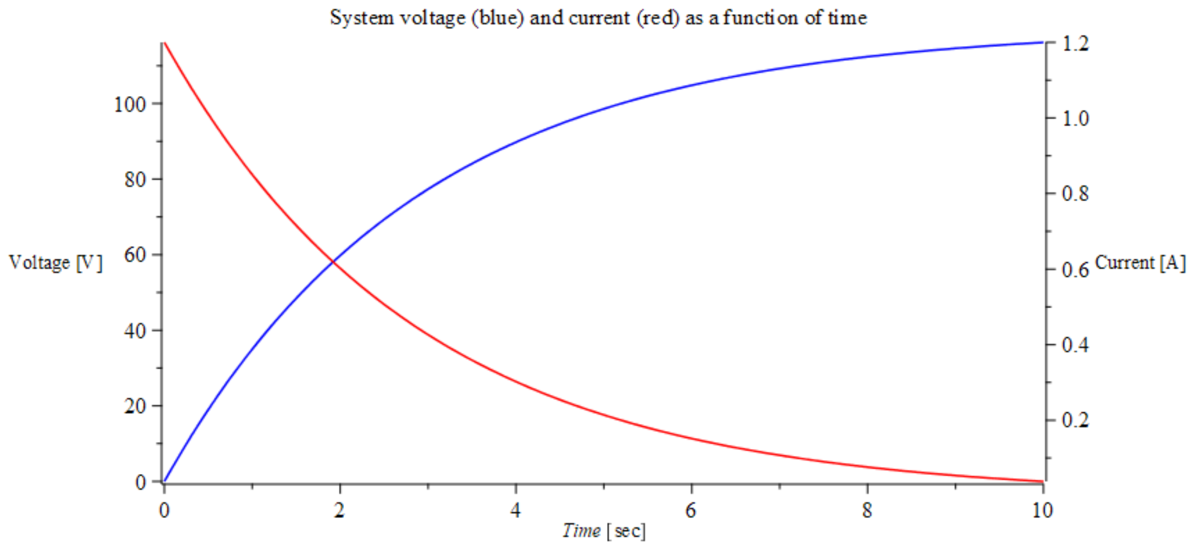


Figure 2.13: Plot of pre-charge levels

The maximum power through the resistor is calculated as:

P_R = V_s^2 / R

Assuming a maximum accumulator voltage of 120V:

P_R = 144 W

Which means that the pre-charge resistor must be able to handle 144W for at least 15 seconds.

Resistor Type:	RS Pro 131-1318 wirewound resistor
Resistance:	100Ω
Continuous power rating:	30W without heatsink. 100W with heatsink
Overload power rating:	200W for 15 seconds
Voltage rating:	1900V
Cross-sectional area of the wire used:	2.08 mm^2

Table 2.7 General data of the pre-charge resistor

Relay Type:	Omron G2R-1A-E 24DC
Contact arrangment:	SPST
Continuous DC current:	16A
Voltage rating	125VDC
Cross-sectional area of the wire used:	2.08 mm^2

Table 2.8 General data of the pre-charge relay

2.9.3 Position in car

The BMS is placed inside the accumulator box.

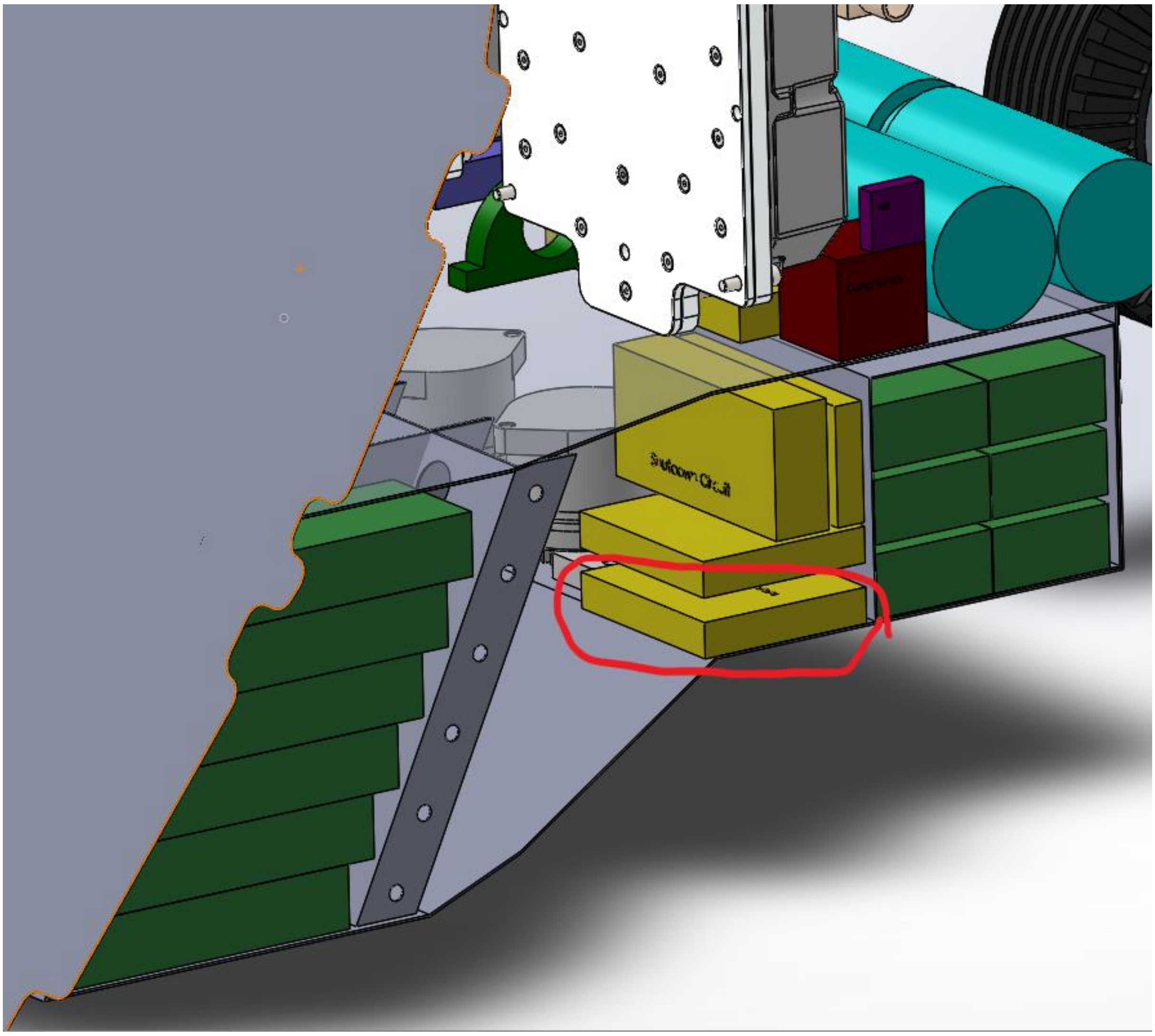


Figure 2.14: BMS position in accumulator box

2.10 Discharge circuitry

2.10.1 Description

A discharge circuit is required if the system voltage isn't discharging fast enough on its own after the accumulator has been disconnected. The discharge circuit consist of a relay and resistor in series connected to the system positive and negative poles. The relay is NC and connected to the shutdown system output. This way, when the shutdown system is disconnecting the AIRs, the discharge circuit resistor will close and start discharging the system.

The voltage can be calculated using the following expression:

$V_C = 120\, e^{(-t / RC)}$

And the current can be calculated with the expression:

$I_C = - V_C / R$

Three 100 ohm power resistors are put in parallel resulting in a resistance of 33.3 ohm. The system have a capacitance of 29 mF and a maximum system voltage of 120V. The voltage level and discharge current is plotted as a function of time. It can be seen in Figure 2.15: Plot of discharge levels.

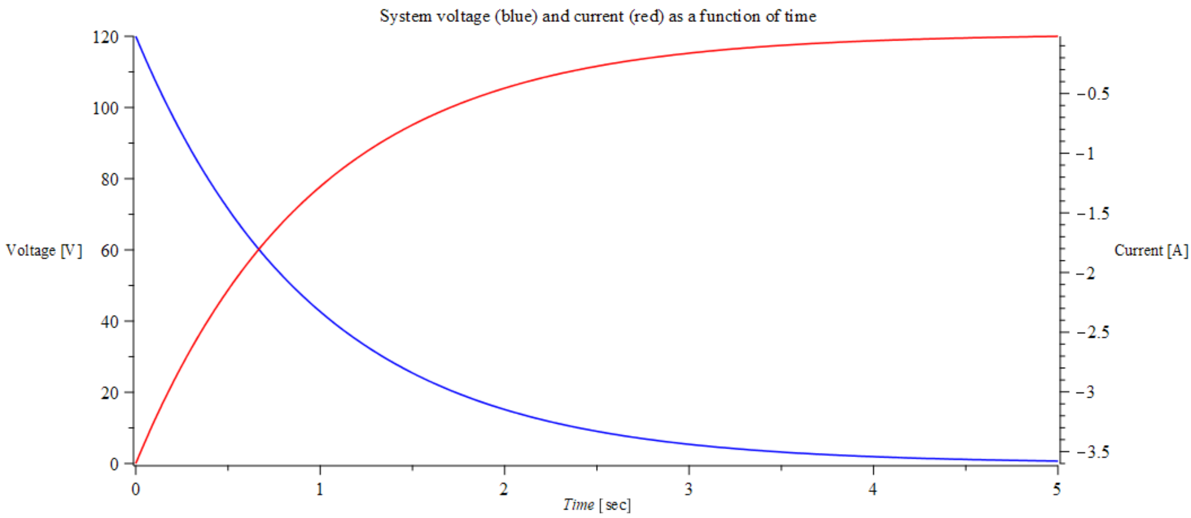


Figure 2.15: Plot of discharge levels

2.10.2 Wiring, cables, current calculations, connectors

Resistor Type:	RS Pro 131-1318 wirewound resistor
Resistance:	100Ω
Continuous power rating:	30W without heatsink. 100W with heatsink
Overload power rating:	200W for 15 seconds
Voltage rating:	1900V
Cross-sectional area of the wire used:	2.08 mm²
Resistor Type:	RS Pro 131-1318 wirewound resistor
Resistance:	100Ω

Table 2.9 General data of the discharge circuit

Three resistors are mounted in parallel for a combined resistance of 33.3 ohms. This gives the circuit a better ability to dissipate the power and results in a fast discharge time under 5 seconds.

2.10.3 Position in car

The Discharge Circuit is depicted by the yellow box on top of the accumulator container in Figure 2.5.

2.11 HV Disconnect (HVD)

2.11.1 Description

The HVD is directly connecting the system to the accumulator. By twisting the HVD and the pulling the male connector away from the female connector, the power to the system will be cut immediately. The HVD is interlocked with the shutdown system, such that the main relays will also open and ensure that the battery is fully isolated.

2.11.2 Wiring, cables, current calculations, connectors

The HVD is connected directly between the accumulator and the system. The wire and plugs are rated for a minimum of 800A and 120V. A HVD interlock is added to the plug, such that it cuts the power to the AIRs though the shutdown system.

Two connectors will be used, one for the negative pole and one for the positive pole. Each connector consists of a female part and a male part. The female part will be mounted to the accumulator box, while the male connector is mounted to the TS wires leading to the drives. Both connectors will be marked to ensure that the circuit is not connected in reverse.

Connector type:	Amphenol RIG-Lok, male and female
Current rating	800 A
Maximum voltage	2500 V
Mounted wire gauge	$50mm^2$
Environmental rating	300 Day Salt Spray Test Rating

Table 2.10 Amphenol connectors data

As the wires run in pairs it is important that everything is connected before running the vehicle.

2.11.3 Position in car

The HVD will be placed on the accumulator container in an easily accessible place so it can be disconnected quickly. The interlock is connected to the shutdown.

The HVDs are depicted by the cyan cylinders in Figure 2.5.

2.12 Ready-To-Drive-Sound (RTDS)

2.12.1 Description

The sound is produced by a 105dB siren. This sound is activated whenever the car is ready to drive. The siren sound is easily recognizable and not a sound that can be produced by the car.

2.12.2 Wiring, cables, current calculations, connectors

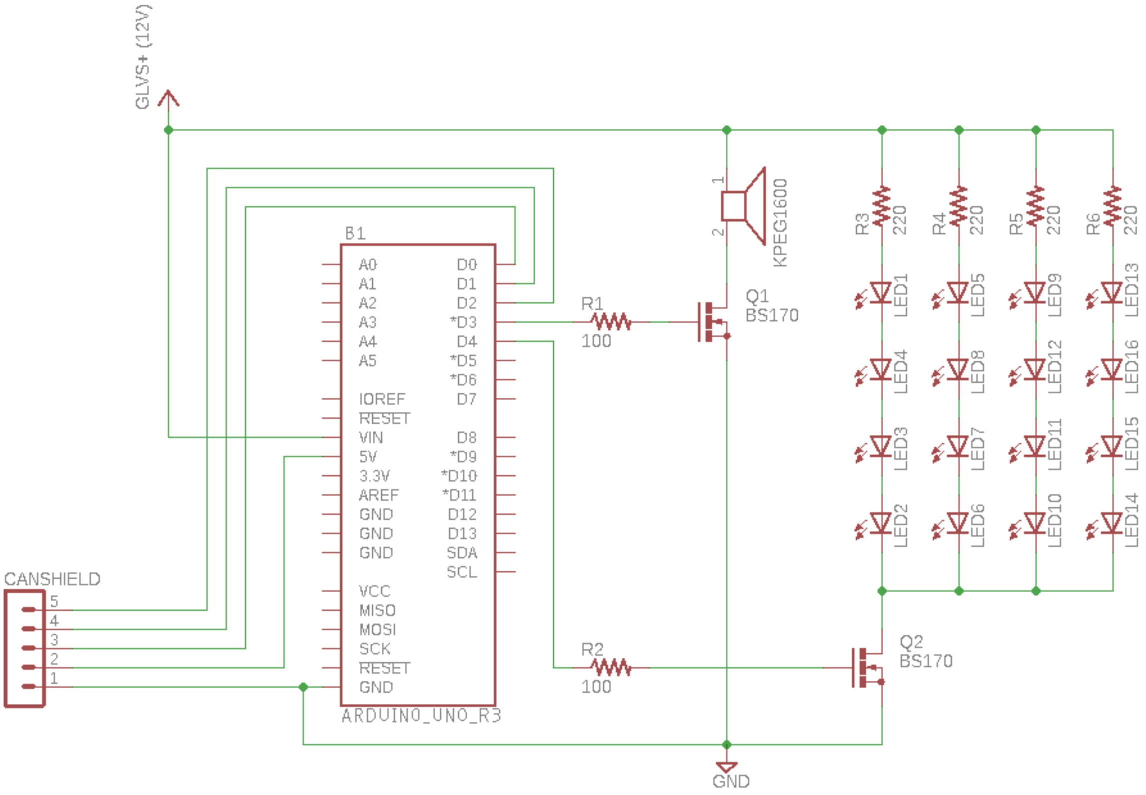


Figure 2.16 Ready to drive sound schematic

A CAN-bus shield is connected to an Arduino through SDI. When the Arduino receives a specific data string, a voltage on D3 will go high which will close Q1 and let current flow through the siren and thus produce sound for the desired time. A resistor to Q1 is place to limit the current to the transistor. The volume of the siren is controlled through pulse width modulation. The LED’s in the schematic have nothing to do with the siren, but the same Arduino is used to control the braking light.

2.12.3 Position in car

The siren will be placed at the very back of the vehicle.

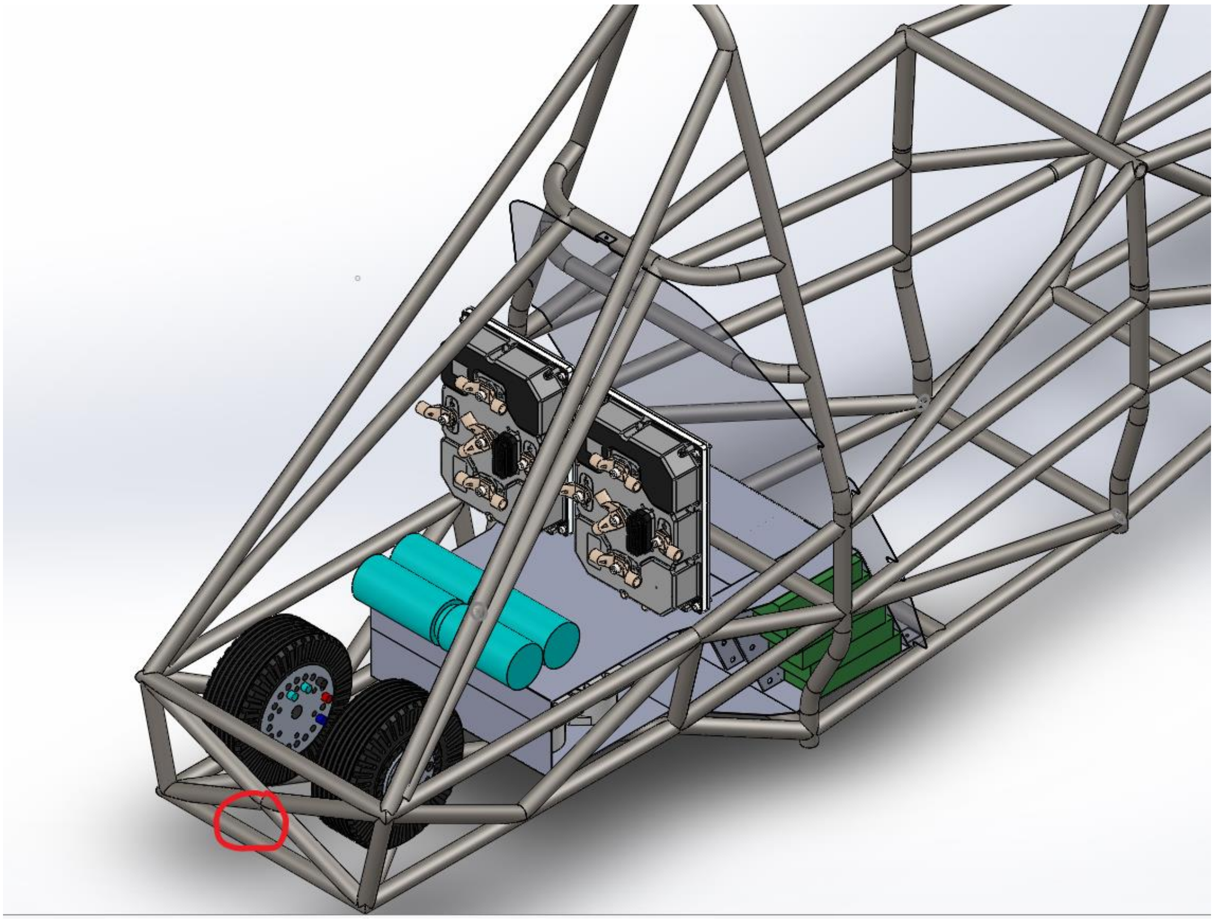


Figure 2.17: Ready To Drive Siren position

3 Accumulator

3.1 Accumulator pack 1

3.1.1 Overview/description/parameters

The accumulator pack consists of 7 segments in series. Each segment contains 6 packs of lithium polymer cells in parallel, and each pack consists of 4 cells in series. This results in a cell configuration of 28s6p. Each pack contains 10Ah, and are rated for 10C continuous discharge, and 20C peak discharge for 10s. In our use-case the battery should never exceed a discharge of much more than 14C at full acceleration, as per the regulations we are not allowed to surpass a power consumption of 80kW, which at the minimum voltage would require just under 845A, however the current draw will be limited to accommodate the HVD, such that no more than 800A will be drawn from the battery at any point.

The battery pack will be bolted to the vehicle.

Maximum Voltage:	117.6 VDC

Nominal Voltage:	103.6 VDC
Minimum Voltage:	95.2 VDC
Maximum output current:	1200A for 10s
Maximum nominal current:	600A
Maximum charging current:	120A
Total numbers of cells:	42 packs of 4 cells = 168 cells total
Cell configuration:	28s6p
Total Capacity:	22.38 MJ
Number of cell stacks < 120VDC	7

Table 3.1 Main accumulator parameters

3.1.2 Cell description

The cells are bought in packs containing 4 cells each.

Cell Manufacturer and Type	Multistar High Capacity
Cell nominal capacity:	2.5 Ah
Maximum Voltage:	4.2 V
Nominal Voltage:	3.7V
Minimum Voltage:	3.4V
Maximum output current:	20C for 10s
Maximum nominal output current:	10C
Maximum charging current:	2C
Maximum Cell Temperature (discharging)	60°C
Maximum Cell Temperature (charging)	60°C

Cell chemistry:	LiPo

Table 3.2 Main cell specification

3.1.3 Cell configuration

The cells will be used in a 28s6p configuration. More specifically 4 cells will be connected in series in packs. 6 packs will be connected in parallel, which will make up each segment. 7 segments will be connected in series, and make up the total accumulator.

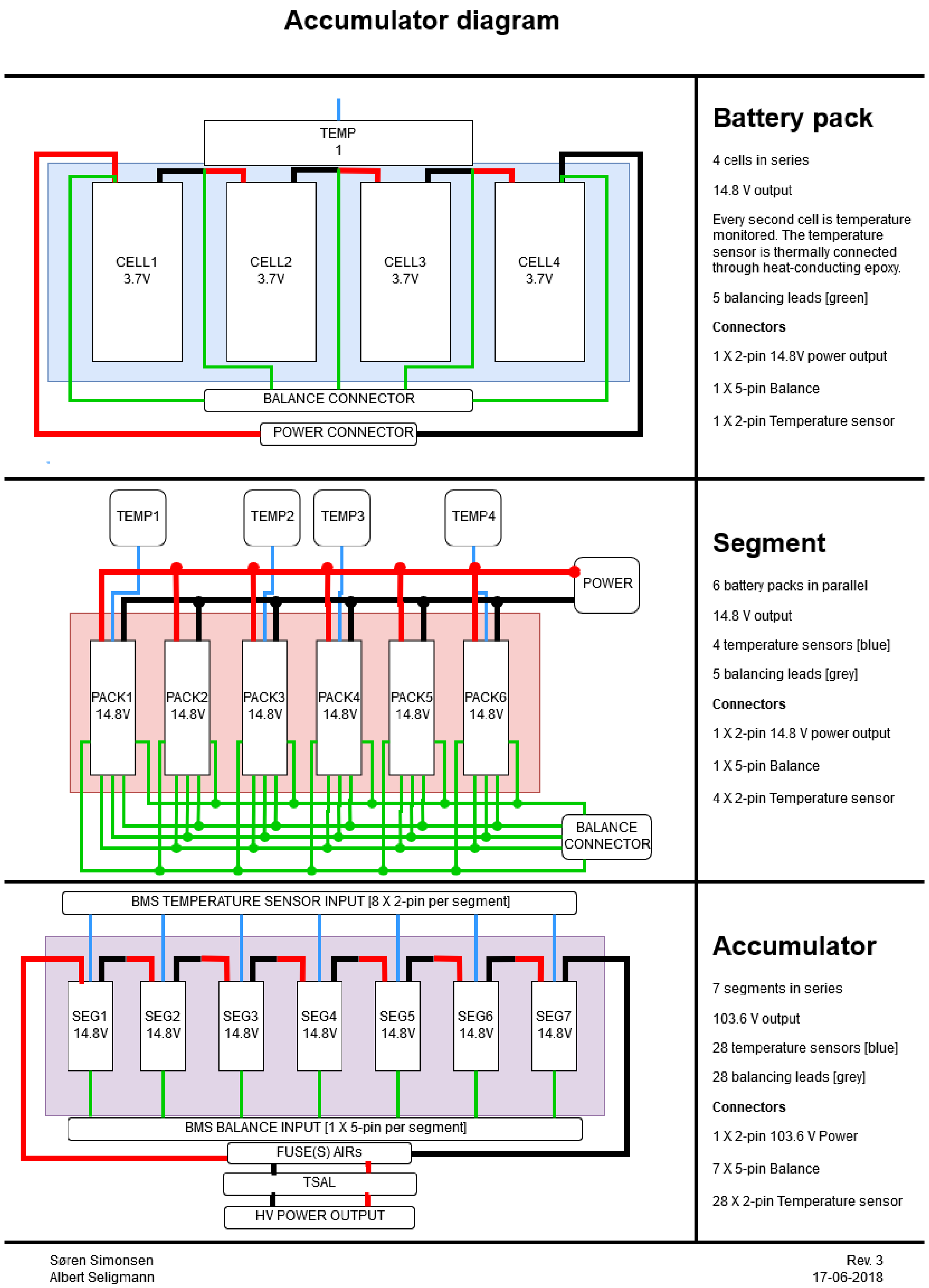


Figure 3.1: Accumulator configuration

3.1.4 Cell temperature monitoring

A temperature sensor will be installed in every second pack, which will monitor the temperature of cell 1 and 3's negative terminal and cell 2 and 4's positive terminal. The sensor will be placed less that 10mm from all of the above mentioned terminals, and be thermally connected to the terminals using thermally conducting epoxy.

The sensors used are 'Vishay thermistor NTCLE100E3103JB0' and will be connected directly to the BMS slaves with 0.35 mm^2 wiring. The BMS will be programmed to activate the shutdown system if the temperature exceeds the limit.

A diagram of the cell configuration and sensors can be seen in Figure 3.1: Accumulator configuration.

3.1.5 Accumulator insulation relays

One of the only available and usable relays will be used. The relays are relatively small for the capabilities and are hermetically sealed.

Relay Type:	TE Connectivity Kilovac K1K06X024EAFA
Contact arrangement:	SPST-NO (Form X)
Continuous DC current rating:	1000A
Overload DC current rating:	1200A for 180sec
Maximum operation voltage:	1000 VDC
Nominal coil voltage:	24 VDC
Normal Load switching:	Make and break up to 300A
Maximum Load switching	10 times at 1500A

Table 3.3 Basic AIR data

3.1.6 Fusing

The accumulator will have one main fuse, positioned as close to the terminals as possible.

Fuse type:	Bussmann/Eaton FWA-800A
Continous current rating:	800A
Maximum operating voltage	150 VDC

Type of fuse:	Fast blow
I2t rating:	280000 at 150 VDC
Interrupt Current (maximum current at which the fuse can interrupt the current)	200000A at 150 VDC

Table 3.4 Basic fuse data

Component	Continuous current rating
Cells	8 in parallel each rated for 100A, so 800A total
Internal wiring	800A
Relays	1000A
Connectors	800A

Table 3.5: Components protected by the fuse

3.1.7 Battery management system

The BMS used is a Lithium Balance n-BMS. One master controller and three slaves are required to balance all the cells. Each slave can monitor up to 12 cell voltages. The voltage sense and balancing wires are 0.5 mm^2 and are bundled in a large connector. The BMS is balancing with a 200 mA at 4.2 VDC max. Therefore, a 300 mA fuse should be sufficient to protect the system. The BMS support a cell voltage range of 0-5 V. The voltage limits will be programmed into the BMS according to the battery/LiPo safe limits.
It is required to measure and balance 28 cells in total. The slaves can be set up so two of the slaves balance 8 cells and the last one balance 12. The cell configuration can be seen in Figure 3.1: Accumulator configuration.
The slaves are connected to the master board via an isoSPI communication interface. A shielded cable is used to protect the communication against electrical noise.

The current is measured by the BMS using a hall effect current sensor. The BMS can be programmed to activate the shutdown system if the maximum TS current is exceeded. This can be very practical as the main fuse wont blow.

The temperature sensors are also connected to the slaves, which support up to 12 sensors per slave. To monitor all the required cell, three additional slaves might need to be added. The slaves have a measuring range of -40 to 85 °C, but the specific battery temperature limits will be programmed into the BMS. The wires used have a thickness of 0,35 mm^2 and are bundled together in a larger connector. The current running through the wires is very small, and a 100 mA fuse on each wire should be sufficient.

If the cell voltage or temperature limits are exceeded, the BMS will activate the shutdown system, which will open the AIRs. The BMS also have control over the two AIRs and the pre-charge relay, and can close them if the shutdown system have not been activated.

For all the specific battery parameters, see section 3.1.2.

3.1.8 Accumulator indicator

The accumulator indicator is a digital LED voltmeter placed on the accumulator container and will be measuring the voltage over the accumulator. The voltmeter works from 30V til 264V and will show the accumulator voltage on a LED display. A simple schematic in Figure 3.2: Voltmeter schematic show that the accumulator indicator is connected to the AIRs and thus showing the voltage present on the outside of the accumulator.

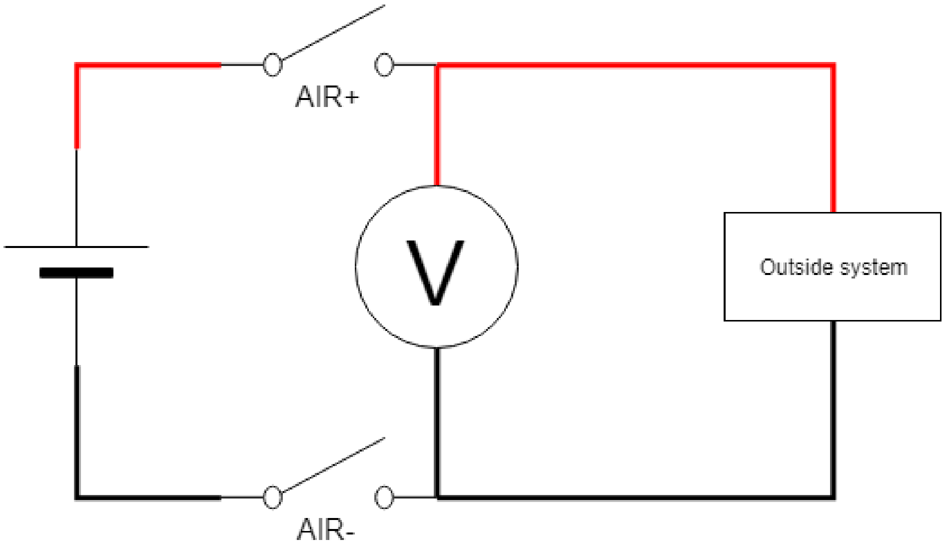


Figure 3.2: Voltmeter schematic

Simple schematic showing where the accumulator indicator (marked as V) is connected

3.1.9 Wiring, cables, current calculations, connectors

A schematic of the internal wiring is shown in section 3.1.3 as the accumulator diagram. As seen in the schematic, each battery pack will be connected in parallel.

The connections are made by crimping the conductors of the packs in parallel, for both positive and negative. The segments are then connected in series. The conductors consist of a very short (40mm) stud of 16mm2 multistrand wires (rated for 120A), which branches out to 2x 10mm2 multistrand wires (each 10mm2 wire is rated for 75A) terminated in a connector. The connectors are then connected to a wire-assembly made for connecting two segments. This wire-assembly consists of 2x 10mm2 wire for each pack in the segment, which would result in 12x 10mm2 wires.

The connection between wires and the packs uses XT90 male and female connectors which are also rated for 100A.

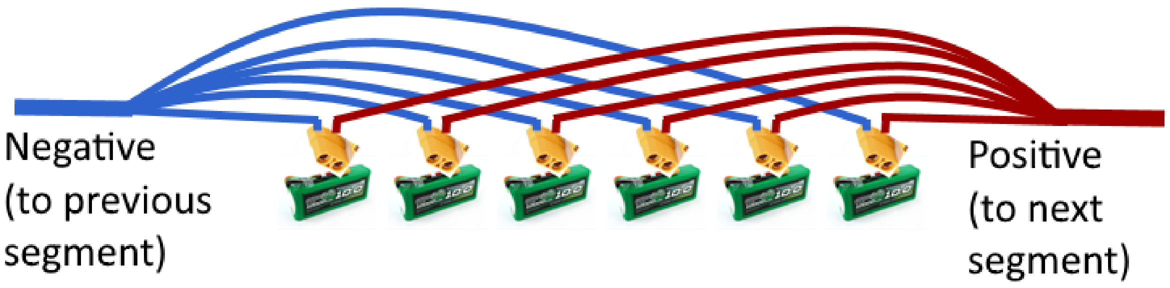


Figure 3.3: Internal wiring diagram

Determination of internal wiring gauge (from pack to segment crimp (wire-assembly))

The wires should be carrying a load of max 100A and will be very short (max 20 cm from battery pack to wire-assembly). The XT90 connectors can handle 10mm^2 as a max gauge.

Let's see how much power generated by the short wires:

R/km = 1.91 Ω
A = 10mm^2 (cross-sectional area)
L = 20 cm (length)
R = resistance
n ≈ 60 (number of these short wires)
P = total power from wires

$R = R/km \times L \times n = 2.292 \times 10^{-2} \Omega$

$P = I^2 \times R = (100A)^2 \times 2.069 \times 10^{-2} \Omega = \underline{229.2\ W}$

Since the wires used are rated for 75 A, the cross-section is doubled. For safety active air cooling will be deployed in the battery container.

Data for the chosen wire can be seen it Table 3.6 below. (Link to datasheet: 12.1.1)

Wire type	PRO POWER Tri-Rated Flexible PVC Equipment Wire
Continuous current rating:	75 A at 90 °C
Cross-sectional area	10 mm2
Maximum operating voltage:	600 VDC
Temperature rating:	105 °C
Wire connects the following components:	Battery pack and segment connector

Table 3.6 Wire data of 10 mm² wire

Wires from batterypack to power output (to controllers):

The wires to the drives will be directly mounted onto the busbars and will be the type described shown in Table 3.7 Wire data of 50 mm² TOXFREE-XZ1-K-(AS) 0.6/1kVTable 3.7. For maximal flexibility, we use multiple wires between out connections as parallel wires. This means they will have same wire gauge and length. Each pair of cables will be fused to protect against the short circuit current and the overload safety will be controlled by the controller.

As the datasheet values for this wire is very conservative, a test has been carried out to determine how much current can be passed through the wire at steady-state with no significant rise in temperature. The test was done with a power supply which can deliver up to 875A at 5V. With a current of 250A for 120s through a 50cm length of wire, the wire has reached a stable temperature, which is not far from room temperature. Therefore it is determined that the wire can easily carry 250A.

Calculating wire gauge (output wires)

There will be separated loading points for each pair of cables to the motor controller. To this will there be no need to calculate voltage drops, as wires will be short. Next to that do we know that the wires should be carrying about 420 A to one motor as max continuously.

Note that a 1x50mm^2 can carry 250A, so we chose to mount two wires in parallel for each motor. This means each wire will be carrying 210A.

I_L = P/U = 40kW/95.2V = 420A (Max peak current at lowest possible voltage).

I_c = 2 x 250 A = 500 A (Current value for 2x50mm^2)

$I_L < I_c$

The wires are then chosen as 50mm^2 mounted in parallel so that the same current will run through both wires (both positive and negative wires parallel mounted). More data is to find in Table 3.7.

Short circuit safety

A fuse will be installed for each output phase wire to disconnect the power source from the motor controller.

The current through each wire is calculated as:
U = 103.6 V
P = 40 kW
$Length_{max}$ = 8 m (maximum length from battery to motor)
$R_{W,\ total}$ = length x resistance per meter

I_L = P/U = 40kW/103.6V = 386A

The fuse value is chosen to 400A and will be mounted between the relay and the HVD. Even small changes in the voltage won't blow the fuse.

Then we must check that the fuse blows upon a short-circuit by calculating minimum current of a short-circuit.

$I_{sc} = U/R_{W,\ total} = 103.6\ V/8m \times 0.000368\ \Omega/m \approx 36kA$

This means that the fuse will burn almost immediately upon a short-circuit before the wires.

Link to datasheet for wire described in below table: 12.1.2

Wire type	TOXFREE-XZ1-K-(AS) 0.6/1kV
Continuous current rating:	Datasheet: 180 A at 45 °C (for a single wire) Tested at 250 A.
Cross-sectional area	2 x 50 mm², parallel, double isolated
Maximum operating voltage:	1000 VDC
Temperature rating:	-40° to 90 °C
Wire connects the following components:	Accumulator and motor controllers

Table 3.7 Wire data of 50 mm² TOXFREE-XZ1-K-(AS) 0.6/1kV

3.1.10 Charging / Chargers

The accumulator will be removed for charging. Once out of the vehicle, the charger will be connected to the accumulator and the BMS. The charger will be connected directly on the system side of the AIRs, as the shutdown then is able to disconnect the battery from the charger by closing the AIRs. The cells will be monitored by the BMS which is connected to the charger with a CAN bus. The BMS is able to control and shut down the charger via the CAN bus or directly disconnect it with the AIRs depending on the situation.
The charging leads are orange and both leads and connectors are isolated so it's impossible to get shocked by it.

The charger itself will have an external push type emergency shutdown button to cut off the power to the charger directly. Additionally, the charger has its own temperature monitoring system, which can adjust the charging power or shut it down all together. An external tractive system measuring point will also be added to measure the voltage directly.

Charger Type:	Powerfinn PAC 3200

Maximum charging power:	3.2kW
Maximum charging voltage:	160V
Maximum charging current:	20A
Interface with accumulator	CAN-Bus to the BMS
Input voltage:	70-236 VAC
Input current:	16A max

Table 3.8 General charger data

To facilitate removing the accumulator from the vehicle, we will use power connectors rated for minimum 400A each and could be connected to a $50mm^2$ wire.

We select four, two pole male and female connecters, with female mounted to the accumulator box and the male connectors to the wires. To ensure that a motor should not be able to run without all connecters plugged in, there is made two positive and two negative connectors. This secures that any combination with a missing connection keeps at least one motor unable to run. The positive and negative connectors will be marked so that no confusion will occur. At last wires are mounted so that negative male can't be plugged into a positive female and reverse.

The connectors used can be found in datasheets provided in the Appendix (link: 12.6) and Table 3.9.

Connector type:	Amphenol ePower connector 2 pole, male and female
Current rating	400 A
Maximum voltage	800 V
Mounted wire gauge	$50mm^2$
Environmental rating	IP67

Table 3.9 Amphenol connectors data

Before removing any connections is it very important that the vehicle is turned off, so that no current runs through the wires that are being disconnected. As the wires run in pairs it is important that everything is connected before running the vehicle.

3.1.11 Mechanical Configuration/materials

The accumulator container is made of carbon-steel sheets, outer walls thickness 1.4mm, inner wall thickness 0.9mm. Each pack is secured with a Velcro-strap within each segment.

3.1.12 Position in car

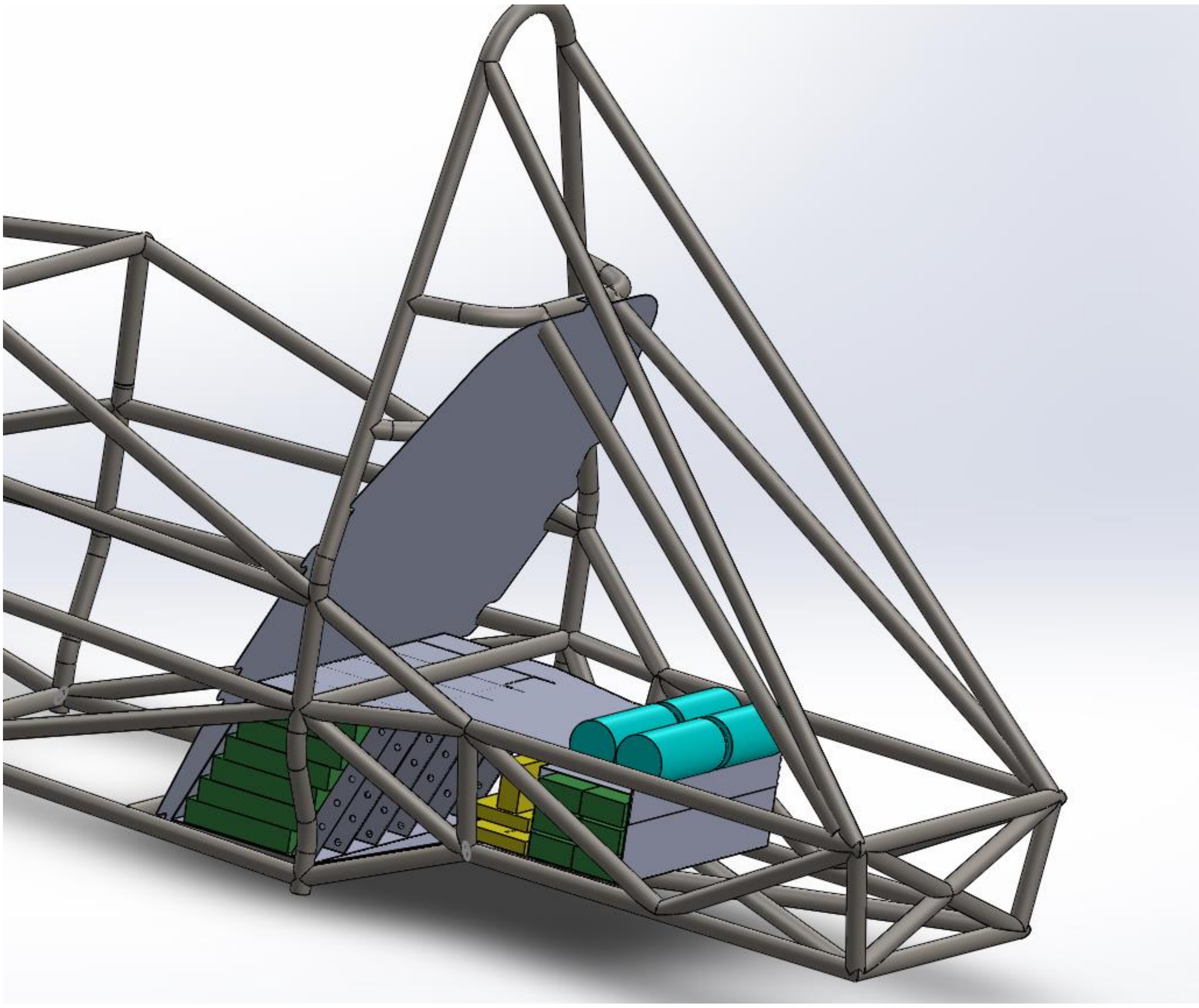
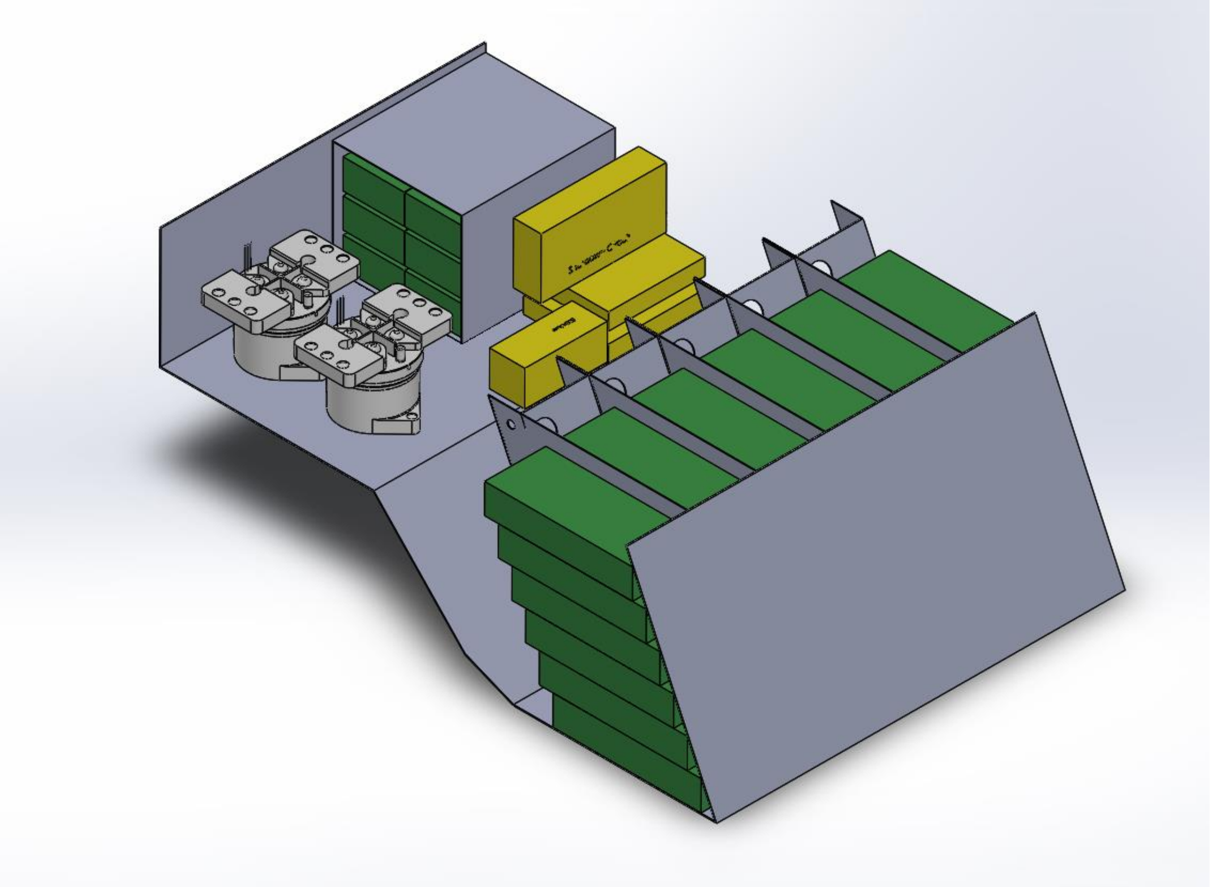


Figure 3.4: Position of accumulator in vehicle



Green boxes are the LiPo cells, yellow boxes are BMS, Shutdown Circuit and the main fuse and the grey structures are the AIRs. Not all segment walls, isolating walls or wires are depicted in the figure.

Figure 3.5: Internal structure of accumulator

3.2 Accumulator pack 2

A low voltage pack will be used for powering control system components. Similar cells as described in section 3.1.2 will be used but with a nominal capacity of 2Ah, and in an 6s1p configuration.

This GLVS pack will be temperature monitored through 2 sensors, voltage sensed, and have its own fusing. An auxiliary BMS will be used for this.

3.2.1 Charging / Chargers

This pack will be removed from the vehicle and charged by a standard LiPo charger, whenever the main battery is charged.

4 Energy meter mounting

4.1 Description

We assume that the energy meter will be identical to the 2017 energy meter, i.e. that it will consist of three separate components.

4.2 Wiring, cables, current calculations, connectors

The data logger will be supplied from the GLVS 12 V net of the car using a 3-way Binder connector.

The high current sensor and the high voltage sensor will be connected to the data logger using the supplied cables.

The high voltage sensor will be connected directly to the accumulator HV+ and HV- lines using the supplied cables.

Relevant cable data and power calculations can be found in section 3.9

4.3 Position in car

The two parts comprising the data logger are depicted by purple box (voltage sensor) and the green structure (current sensor) in Figure 2.5.

5 Motor controller

5.1 Motor controller 1

5.1.1 Description, type, operation parameters

The motor controller is made for controlling the motor via CAN bus. It takes the DC power from the battery and convert it to AC. A number of safety features is provided in the controller for safe use of the drivetrain. An example of that is the mandatory self-diagnosis tool, which check MOSFET connections etc.

Motor controller type:	Permanent magnet synchronous motor Contr oller
Maximum continous power:	60kW
Maximum peak power:	100kW for 10s
Maximum Input voltage:	125VDC
Output voltage:	125VAC
Maximum continuous output current:	500A
Maximum peak current:	800A for 60s
Control method:	PWM
Cooling method:	Water
Auxiliary supply voltage:	24 V

Table 5.1 General motor controller data

5.1.2 Wiring, cables, current calculations, connectors

There is a high power part and a low power part of the motor controller.

For the low power net, it is an AmpSeal 35 pin waterproof plug there is in use.

For the high power net we use cable shoes by RS components (Link: 12.2.1) bolted to the motor controller .

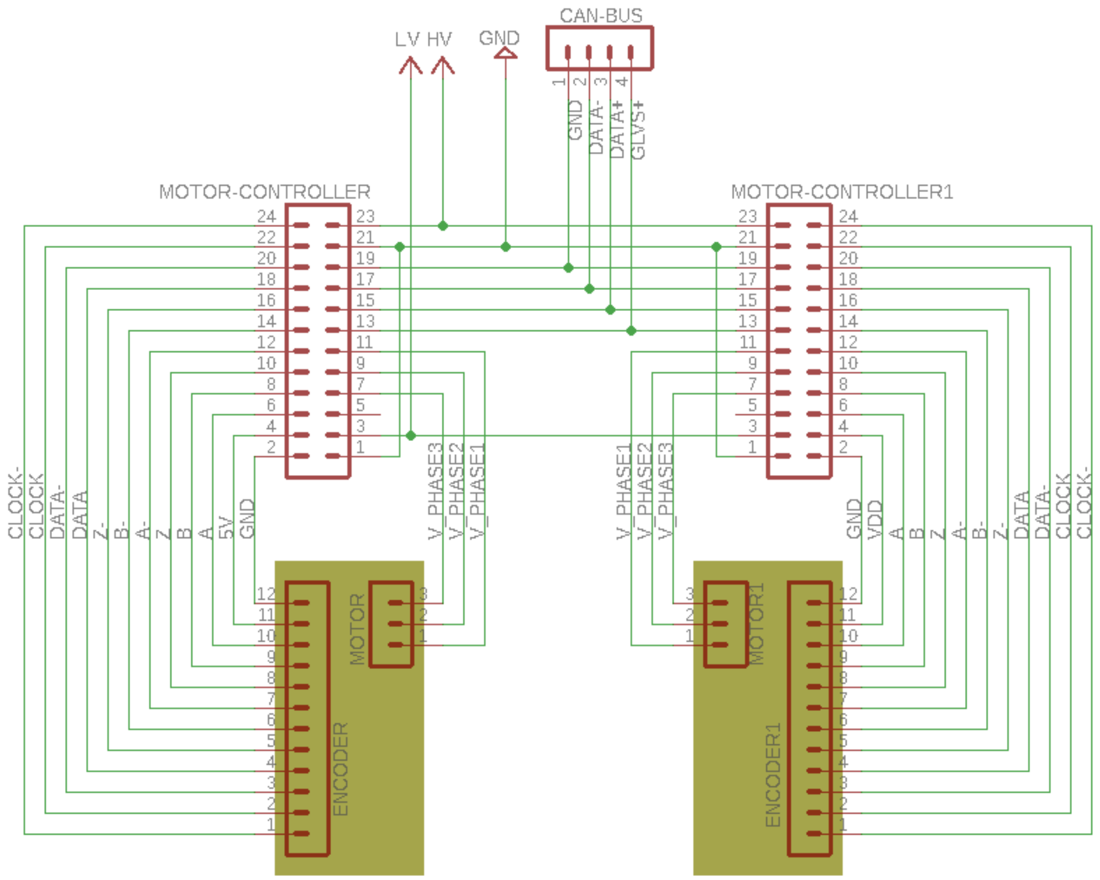


Figure 5.1: Motor controller and motor schematic

Wire from battery to controller

We use 50mm^2 wires as it's the recommended size to use by EmDrive (manufacturers of the motor controller).

The wires selected are fire-resistant and double isolated.

In the datasheets from the supplier (Link: 12.1) is provided graphs describing current values at different temperature levels.

The wires are already chosen in 3.1.9.

Cables will be run from the HVD and be shorter than 5 meters.

Data for the wire used:

Wire type:	Silicone cable, cobber, 50mm^2, FHL2G
Current rating:	350A
Maximum operating voltage:	1000 VDC

Temperature rating:	180 °C

Further information about the wires can be found in the Appendix

5.1.3 Position in car

The motor controllers position in the car. See the red ring.

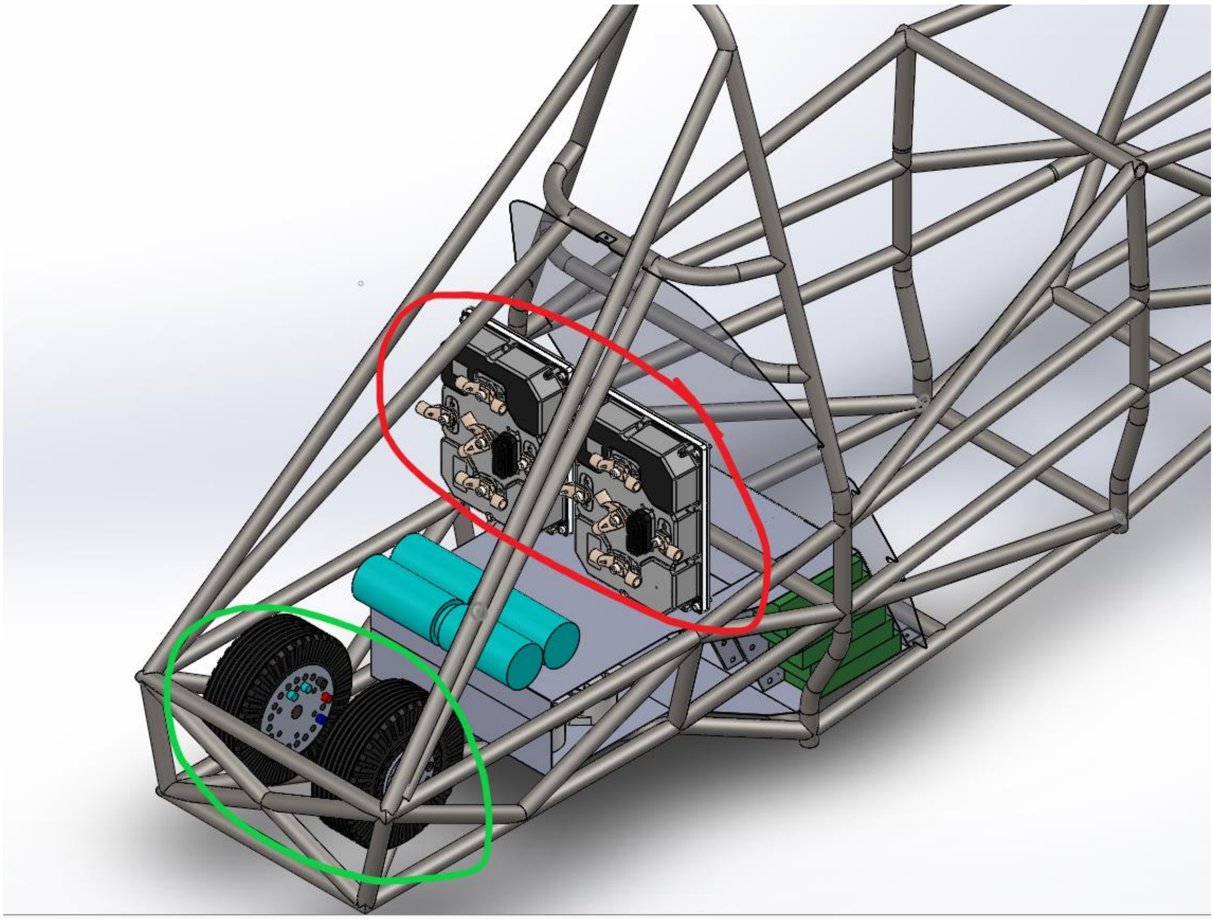


Figure 5.2: Motor controller position

5.2 Motor controller 2

Same as controller 1, see section 5.1. The position of the second controller is mirrored along the longitudinal axis.

6 Motors

6.1 Motor 1

6.1.1 Description, type, operating parameters

EMRAX motor is pancake axial
flux synchronouspermanent magnetelectric motor, which can also work as a generator with the same performance characteristics.
EMRAX motor features axial flux, ermanent magnet synchronous motor and a sinusoidal three phase input. It is E marked (complies with essential protection requirements of 89/336/EEC). Two same sizedmotors connected on the same shaft allows stacking capability.

Motor Manufacturer and Type:	EMRAX 228 low voltage
Motor principle	Permanent magnet synchronous motor
Maximum continuous power:	42kW
Peak power:	100kW for a few seconds.
Input voltage:	130 VDC
Nominal current:	450A
Peak current:	900A
Maximum torque:	125Nm
Nominal torque:	240Nm
Cooling method:	Liquid cooled

Table 6.1 General motor data

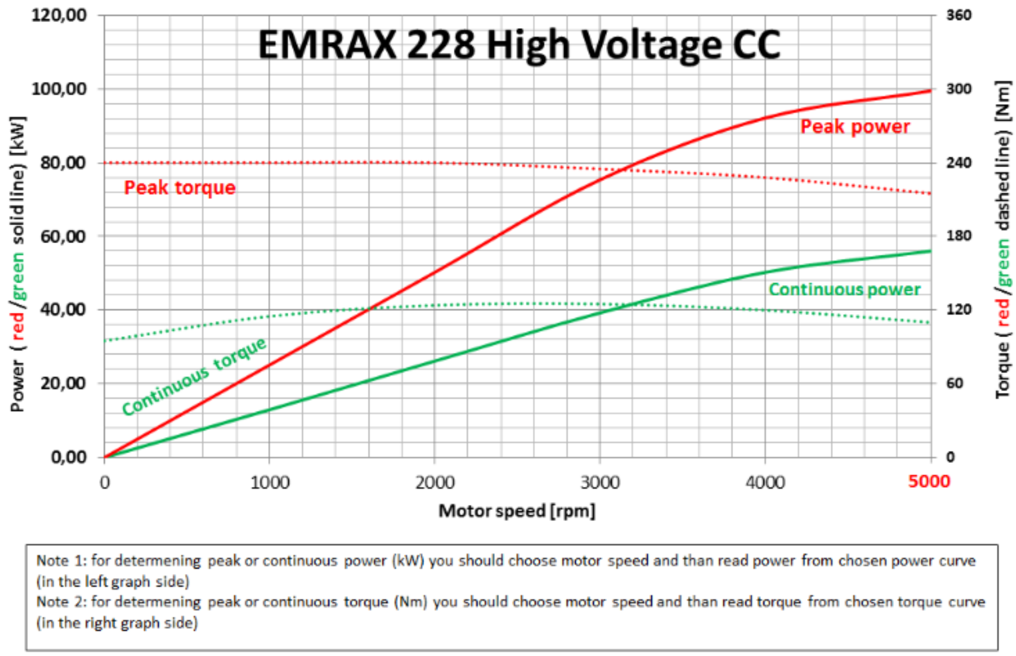


Figure 6.1: Plot of power vs. Rpm including a line for nominal and maximum power.[1]

[1] The plot shown is for the High Voltage CC (combined cooled) version of the motor. As no other versions are shown in the datasheet of the motor, it is assumed that the plot is similar for the Low Voltage Liquid Cooled Version.

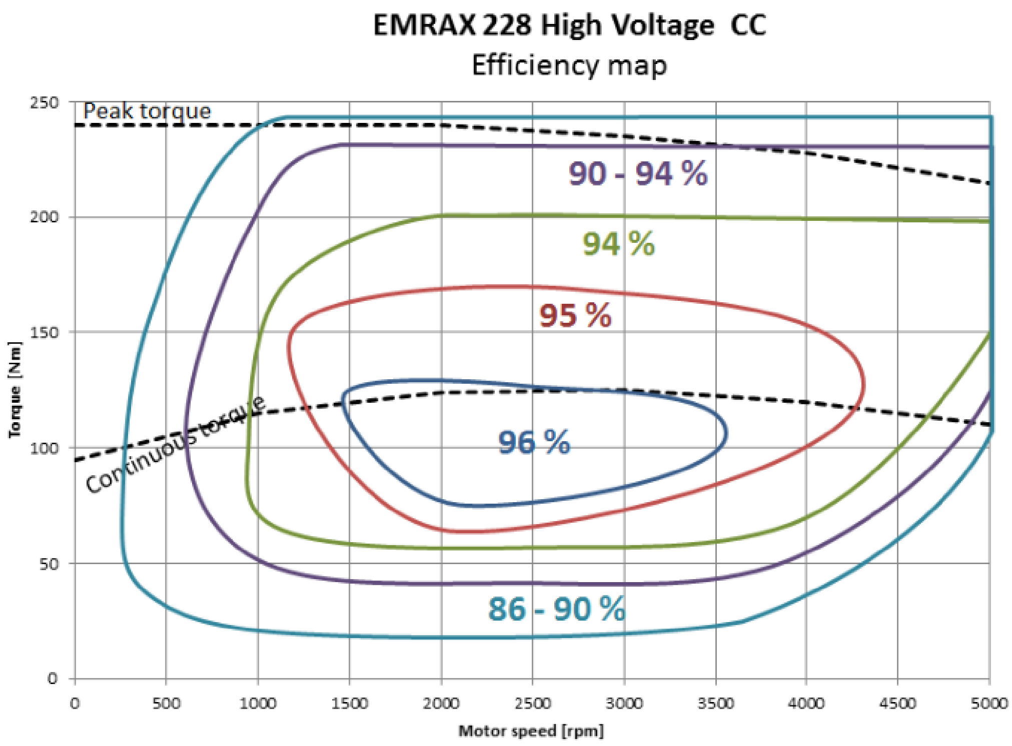


Figure 6.2: Plot of torque vs rpm including a line for nominal and maximum torque.[2]

6.1.2 Wiring, cables, current calculations, connectors

The wiring is described as in Figure 5.1: Motor controller and motor schematic.

The wires minimum cross-sectional area should be 38mm^2 (required by the motors power use), so we need to use 50mm^2 because of lower wire dimensions than 38mm^2 does not exist. The wires selected are fire-resistant and double isolated.

Wires from battery to controllers are the same type and dimensions as the wires from the controllers to the motors.

Cables will be mounted with cable shoes by RS components and will be shorter than 2m in length.

See 3.1.9 for wire specifications.

6.1.3 Position in car

The motor position in the car. See the green ring.

[2] The plot shown is for the High Voltage CC (combined cooled) version of the motor. As no other versions are shown in the datasheet of the motor, it is assumed that the plot is similar for the Low Voltage Liquid Cooled Version.

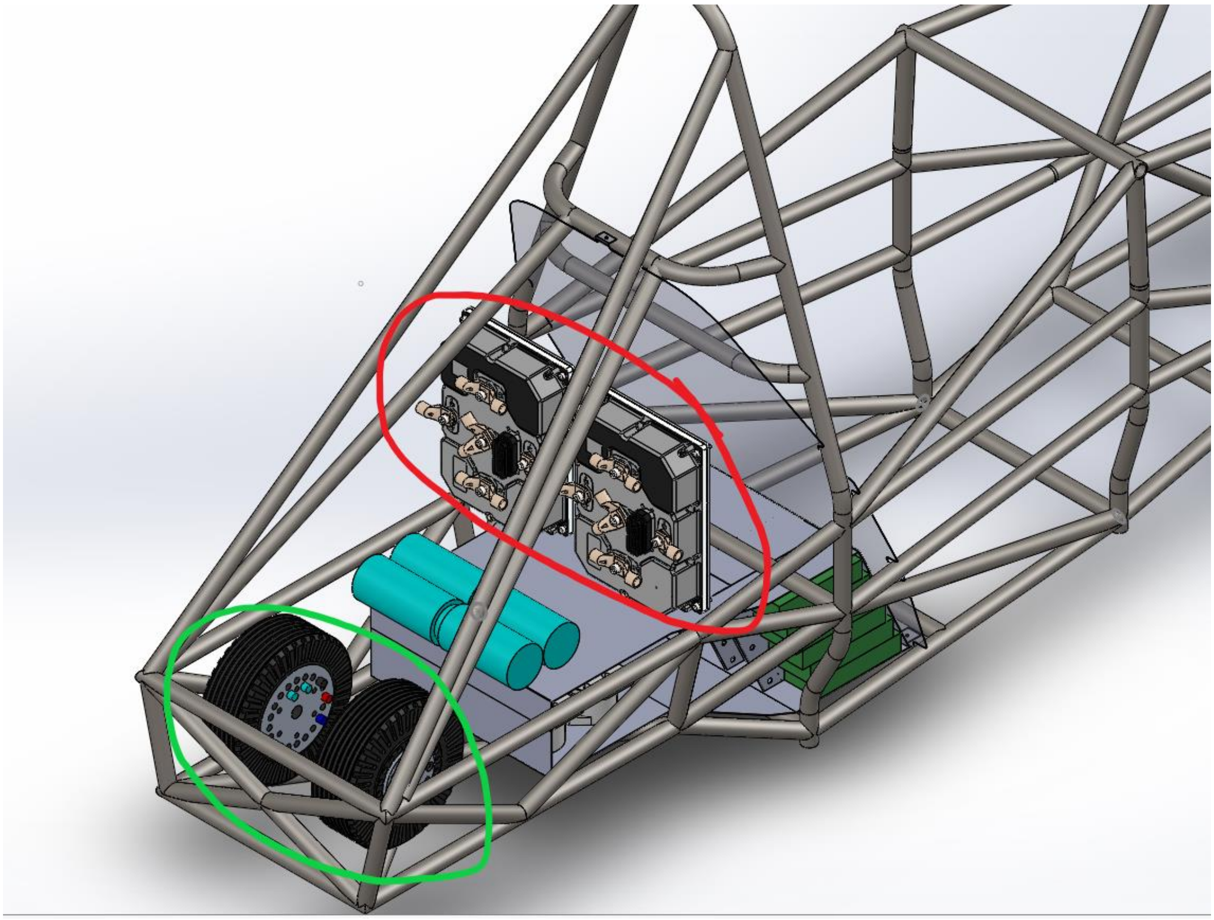


Figure 6.3: Motor position

6.2 Motor 2

Same as motor 1, see section 6.1. The position of the second motor is mirrored along the longitudinal axis.

7 Torque encoder

7.1 Description/additional circuitry

The encoder used is an RLS RM44SC magnetic encoder base unit. It is designed for integration onto electric motors or other devices for shaft position and rotational speed measurement. A solid metal housing helps achieve the highest IP ratings, high EMC immunity, extended operating temperature range and the best possible shock and vibration resistance.

The functionality of the encoder is based on the principle of increasing position for clockwise rotation of a magnetic actuator. The output of the RM44SC encoder is For more information about cables and connectors see section 5.1.2. If the encoder detects a failure, e.g. a short circuit or open circuit, the master control system will ensure complete shutdown of the traction system and eventually a complete shutdown of the entire electrical system, if required.

Torque encoder manufacturer and type:	RLS RM44SC magnetic encoder base unit
Torque encoder principle:	Magnetic encoder
Supply voltage:	5V
Maximum supply current:	35 mA
Operating temperature:	-40°C to +125 °C (IP64) -40°C to +85 °C (IP68)
Used output:	Natural binary, Serial data (RS422)

Table 7.1 Torque encoder data

7.2 Wiring

The wiring is accomplished using an integrated cable in the encoder. For schematic see Figure 5.1

7.3 Position in car/mechanical fastening/mechanical connection

The torque encoder is embedded in the motor.

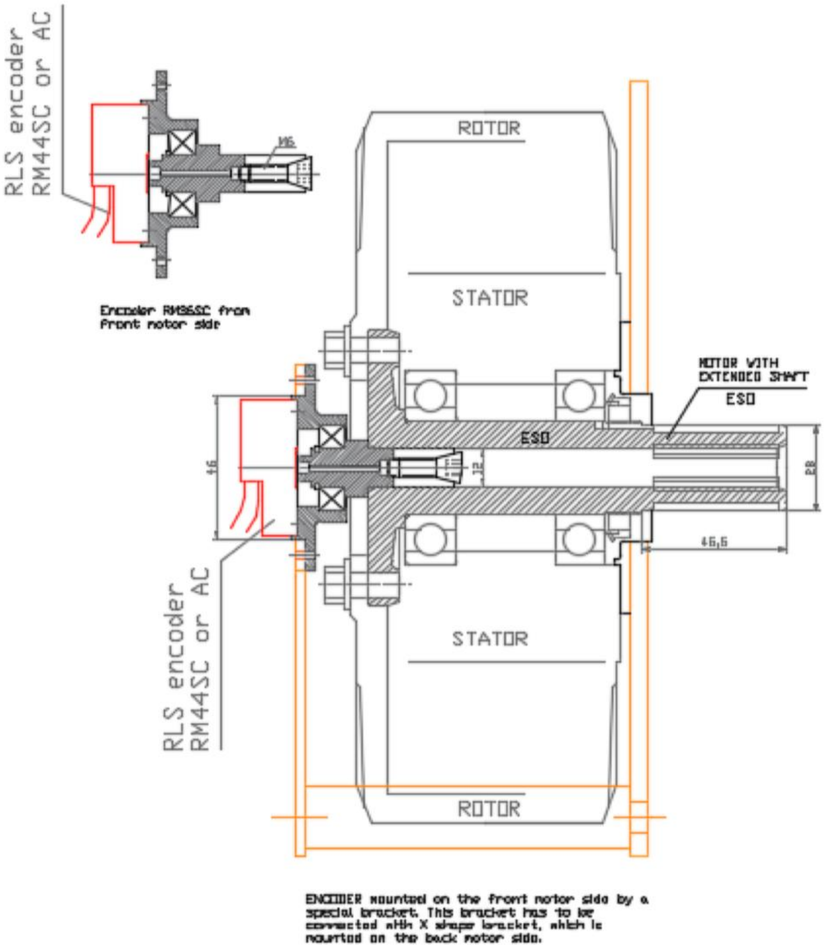


Figure 7.1: Torque encoder position

8 Additional LV-parts interfering with the tractive system

8.1 Driver input circuit

8.1.1 Description

This circuit collects data from the pedals and steering wheel and transmits it from an Arduino to the ECU via CAN. The data is used to calculate a target torque for each motor and detect implausibility of brake pedal and speed pedal. Furthermore, the measured brake pedal position is amplified and transmitted to the BSPD via two coaxial cables (non-digitally).

The steering wheel position is measured by a Formula Seven Pro Steering Rack, which produces a 0.5 - 4.5-volt signal depending on the angle. The braking pedal and torque pedal have identical circuit design except for the BSPD amplifier on the brake pedal, which does not have an impact on this system. Each sensor is constructed using two Bourns 53RAA-R25-A15L potentiometers.

Interface to ECU	CAN-bus
Supply voltage	12V
Steering position sensor used	Formula Seven Pro Steering Rack
Steering position sensor operating range	0.5 – 4.5V
Pedal sensors used	Bourns 53RAA-R25-A15L potentiometers
Pedal sensors maximum operating range	0.275 – 4.725V

Table 8.1: Driver input data

8.1.2 Pedal implausibility detection

On the pedal sensor both potentiometers go from low to high. All ADC's are 0-5 volts. If a voltage of OV/5V is measured it is detected as a short-circuit/open-circuit. Each potentiometer is connected in series with different resistors as to create different slopes for their transfer functions. The resistors values are at least 620ohm on both sides. This ensures that the readings should never reach 0% or 100% allowing us to detect short and open circuit if they do. Furthermore, the pedals should only be to within 5% - 95% of the operating range of the sensors. This will allow us to detect mechanical error if the operating range is exceeded.

If the values of the pedal sensors differ more than 10% for more than 100ms it is detected as an error. If more than 5% accelerator pedal travel is detected while braking or more than 5% brake pedal travel is detected while accelerating it is detected as an error.

Any error detected will result in the power to the motors immediately being shut down.

8.1.3 Schematic

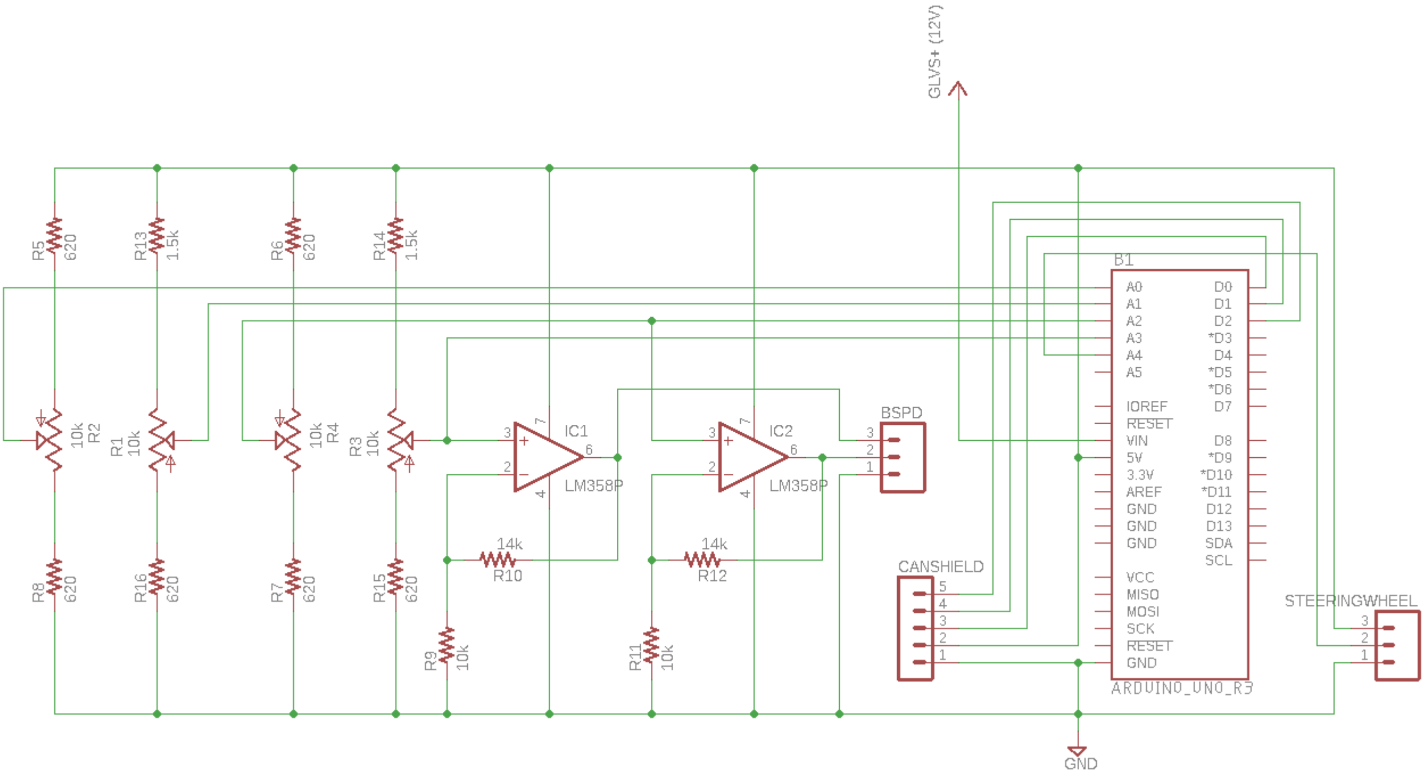


Figure 8.1: Driver input system

Each potentiometer is connected in series with a resistor on both sides of at least 620ohm. This creates a voltage division that removes the top and bottom 5.5% voltage range from the potentiometer signal.

$$\frac{620\ ohm}{2 \cdot 620\ ohm + 10k\ ohm} \cdot 100\% = 5.5\%$$

One potentiometer is connected in series with two 620ohm resistors and the other in series with a 620ohm and a 1.5k ohm resistor. This is done to create different slopes for their transfer functions.

The op-amps make up two non-inverting amplifier circuits that converts the 0 – 5 volt signals of the brake sensors into 0 – 12 signals.

$$\frac{V_{out}}{V_{in}} = 1 + \frac{14k\ ohm}{10k\ ohm} = \frac{12}{5}$$

The steering wheel sensor is supplied with 12 volts as specified by its datasheet (Link: 12.4).

The wires connecting the potentiometers to the rest of the circuit are silicone insulated 22AWG multicore wires rated for 150 Celsius. The connector used is a 3-pin servoplug.

The brake position signal is carried from the pedal box to the BSPD circuit through two coaxial cables with SMA connectors.

8.1.4 Position in car

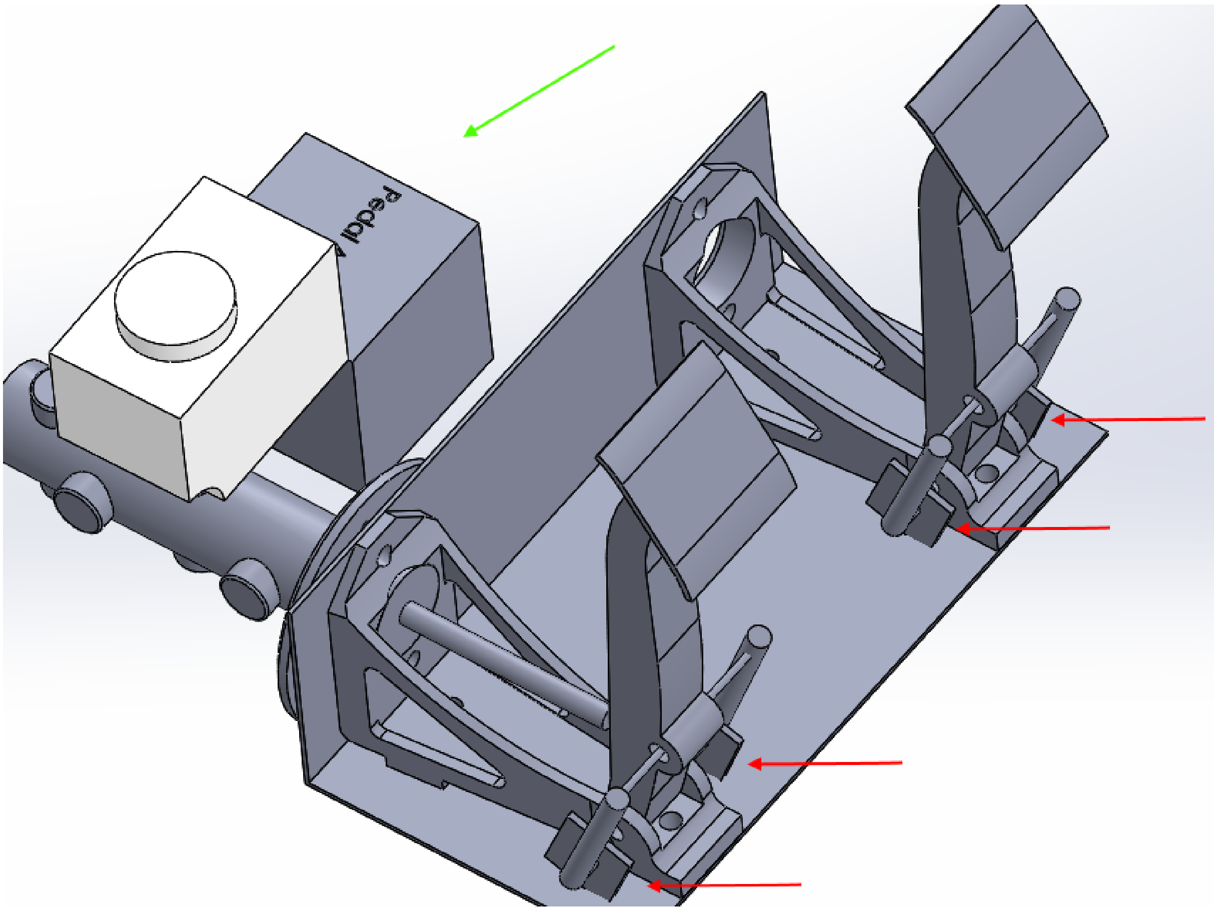


Figure 8.2: Driver input system mechanical design. Green arrow: Circuit enclosure. Red arrows: Sensor mounting

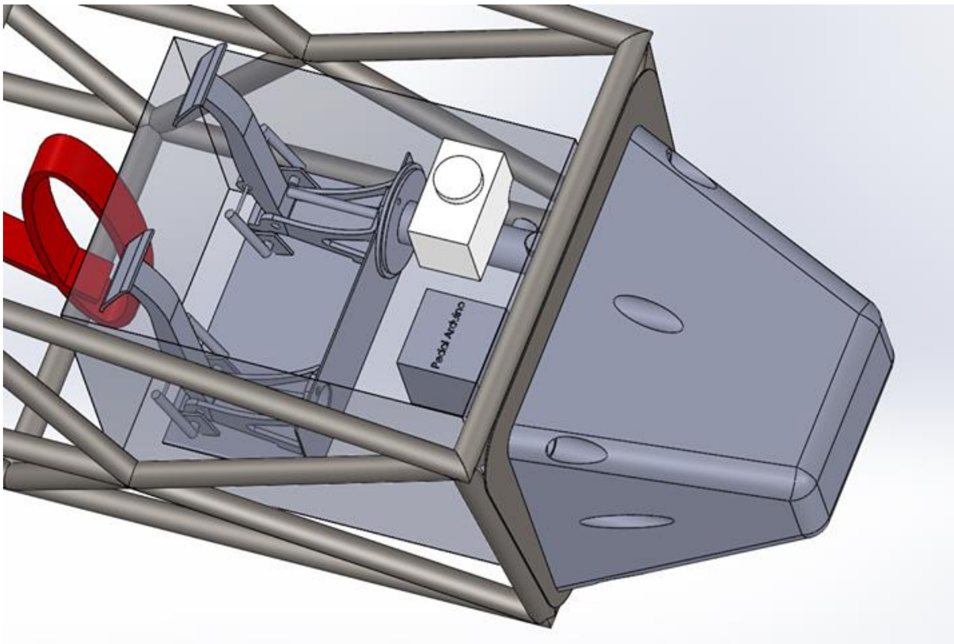


Figure 8.3: Driver input system placement

9 Overall Grounding Concept

9.1 Description of the Grounding Concept

The vehicle will have a steel frame entirely made of conductive steel tubing. The steel frame will ensure that any TS or GLVS part within 100mm of the frame will have a resistance of 300mOhm measured at 1A.

9.2 Grounding Measurements

All relevant connections or risks will be measured using a precision resistance measuring tool, to make sure the grounding is proper.

The resistance between every grounded system and the GLVS measurement point will be measured, to ensure a resistance of maximum 300mOhm. Parts of the vehicle within 100mm of either a TS or GLVS component which may become conductive will be ensured to have a resistance to ground of maximum 5Ohm.

10 Firewall(s)

10.1 Firewall 1

10.1.1 Description/materials

The firewall is constructed by a 1 mm aluminium sheet covering the entire side facing the TS and 1 mm of ABS plastic sheet, fulfilling the UL94-V0 requirements facing the drive. No parts are visible to the driver.

Grounding of aluminium sheet in the firewall is provide by an aluminium bolt welded on to the sheet, to which a grounding cable can be attached and run to a welded on steel bolt on the Control system ground connection.

The steel bolt will be welded on the tubing of the chassis frame close to the connection point of the firewall, and cobber wire will be run between the two bolts.

10.1.2 Position in car

The grounding point is marked by the red circle.

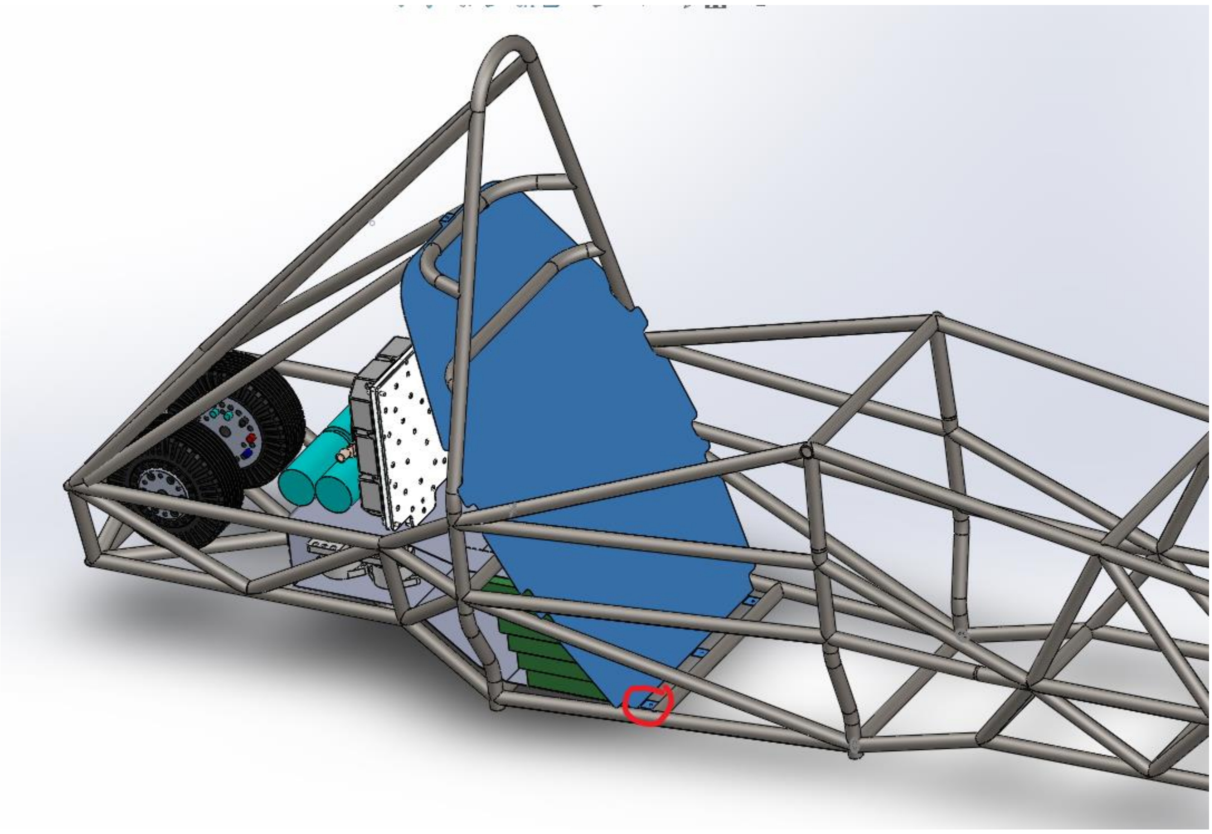


Figure 10.1: Firewall overview

11 Alternative Fuel Systems and Hybrids

This section is not relevant to our car, as we are not using any alternative fuel systems.

11.1 Drive By Wire Throttles

11.1.1 Description

11.1.2 Position in car

11.2 Gaseous Fuel

11.2.1 System Description

11.2.2 Position in car

11.3 Hybrids

11.3.1 System Description

11.3.2 Position in car

11.4 Alternative Liquid Fuels

11.4.1 System Description

11.4.2 Position in car

11.5 Other Systems

11.5.1 System Description

11.5.2 Position in car

12 Appendix

12.1 Wiring

3.1.9 Wiring, cables, current calculations, connectors

12.1.1 Pack to segment crimp

3.1.9 Wiring, cables, current calculations, connectors

http://www.farnell.com/datasheets/2573984.pdf

Nominal Cross Sectional Area mm²	Current Rating (Peak) Amps	Voltage Drop mV/A/m
1.5	21	15
2.5	30	9.1
4	41	5.7
6	53	3.8
10	75	2.2
16	100	1.4
25	136	0.89

Current ratings are based on a conductor operating temperature of 90°C and an ambient air temperature of 45°C and assumes single wire isolated in free air.

Conductors

Class 5 Flexible Copper Conductors for Single Core Wire

Nominal Cross Sectional Area mm²	No. of Strands x Strand Size (mm)	Max. Resistance of Conductor at 20°C Plain Wires Ω/km
0.5	16 × 0.2	39
0.75	24 × 0.2	26
1	30 × 0.2	19.5
1.5	30 × 0.25	13.3
2.5	50 × 0.25	7.98
4	56 × 0.3	4.95
6	84 × 0.3	3.3
10	136 × 0.3	1.91
16	126 × 0.4	1.21
25	196 × 0.4	0.78

The above table is in accordance with BS EN 60228 (previously BS 6360)

12.1.2 Busbar to power output

3.1.9 Wiring, cables, current calculations, connectors

http://scankab.com/cables//marine-and-offshore-cables/ship-cables-halogen-free/installation-cables/toxfree-xz1-k-(as)-0-6-1-kv

Installation cables

SCANKAB CABLES

TOXFREE® XZ1-K (AS) - 0.6/1 kV

SKU	EAN	Dimension (mm²)	Current Value (A)	Packaging	Diameter (mm)*	Weight (kg/km)*
64001002	5704403042340	1x2,5	25	D./Cut	5,4	45
64001004	5704403042357	1x4	35	D./Cut	5,9	61
64001006	5704403042364	1x6	46	D./Cut	6,5	81
64001010	5704403042371	1x10	64	D./Cut	7,4	122
64001016	5704403042388	1x16	88	D./Cut	8,6	181
64001025	5704403042395	1x25	117	D./Cut	10,4	271
64001035	5704403042401	1x35	147	D./Cut	11,7	370
64001050	5704403042418	1x50	180	D./Cut	13,4	510
64001070	5704403041428	1x70	233	D./Cut	15,3	704
64001095	5704403041435	1x95	285	D./Cut	17,4	923
64001120	5704403041442	1x120	333	D./Cut	19,0	1157
64001150	5704403041114	1x150	386	D./Cut	21,3	1438
64001185	5704403041459	1x185	444	D./Cut	23,9	1750
64001240	5704403045679	1x240	528	D./Cut	26,9	2283
64001240G	5704403063956	1G240	528	D./Cut	26,9	2283
64001300	5704403062454	1x300	612	D./Cut	29,6	2864
64001400	5704403057443	1x400	823	D./Cut	34,0	3784
64002001	5704403041367	2x1,5	23	D./Cut	8,0	97
64002002	5704403042425	2x2,5	31	D./Cut	9,1	131
64002004	5704403042432	2x4	43	D./Cut	10,2	176
64002006	5704403042449	2x6	55	D./Cut	11,4	234
64002010	-	2x10	75	D./Cut	13,3	348
64002016	5704403062379	2x16	100	D./Cut	15,1	493
64003001	5704403041060	3x1,5	23	D./Cut	8,9	118
64003001G	5704403041541	3G1,5	23	D./Cut	8,9	118
64003002	5704403041107	3x2,5	31	D./Cut	9,8	156
64003002G	5704403044917	3G2,5	31	D./Cut	9,8	156
64003004	5704403044696	3x4	43	D./Cut	10,9	211
64003006	5704403041190	3x6	55	D./Cut	12,2	285
64003010	5704403041404	3x10	75	D./Cut	14,6	442
64003016	5704403041640	3x16	87	D./Cut	16,8	642
64003025	5704403042456	3x25	110	D./Cut	21,0	1008
64003035	5704403041411	3x35	137	D./Cut	24,0	1363
64003050	5704403042463	3x50	167	D./Cut	27,9	1894
64003070	5704403042470	3x70	214	D./Cut	30,5	2532
64003095	5704403042487	3x95	259	D./Cut	36,6	3397
64003120	5704403042494	3x120	301	D./Cut	40,2	4252
64003150	5704403047673	3x150	347	D./Cut	45,1	5299
64003185	5704403061013	3x185	397	D./Cut	50,7	6495
64003240	-	3x240	468	D./Cut	57,3	8461
64004001	5704403041077	4x1,5	20	D./Cut	9,7	140
64004001G	5704403042920	4G1,5	20	D./Cut	9,7	140
64004002	5704403041374	4x2,5	28	D./Cut	10,6	185
64004002G	5704403041534	4G2,5	28	D./Cut	10,6	185
64004004	5704403041381	4x4	37	D./Cut	12,1	262
64004006	5704403041398	4x6	47	D./Cut	13,5	351
64004010	5704403041589	4x10	65	D./Cut	16,0	544
64004016	5704403041596	4x16	87	D./Cut	18,7	802

30-04-2018 3

12.1.3 Accumulator to drives

5.1.2 Wiring, cables, current calculations, connectors

https://www.coroplast.de/fileadmin//user_upload/Coroplast_Wires_and_Cables_EN.pdf

Silicone-insulated single-core high-voltage automotive cables, unscreened – copper and aluminium

Application: HV aggregates, charging devices and internal battery cabling

Cable construction in accordance with LV 216-1 and ISO 6722

Construction of HV wiring systems for hybrid and electric vehicles

Operating temperature range in accordance with ISO 6722

–40 °C to +200 °C/3,000 h
–40 °C to +225 °C/240 h

The unscreened high-voltage cables complement the Coroplast high-voltage cables product family. Wherever high-voltage cables are housed in metallically enclosed spaces, such as in the internal high-voltage batteries, the high-voltage cables do not need to be screened, subject to proof of EMC suitability.

As in the case of the screened Coroplast high-voltage cables, the electric conductor materials of copper and aluminium can be chosen between, in accordance with our modular system. The cable geometries remain cross-section-dependent. The tried-and-tested, electrically safe, mechanically highly stable and flexibility-promoting silicone insulation material continues to be a guarantee of the functionality of the Coroplast high-voltage cables across the entire vehicle lifespan.

You can find detailed information on the design of these cables on the following pages of this brochure.
A first impression of the current load ratings of the unscreened high-voltage cables can be gained from the threshold value curves in the technical section.

High-voltage automotive cables 600 V AC / 1,000 V DC – single-core, unscreened

Conductor material: Copper

Layout tables in accordance with LV 216-1

Silicone – high-voltage cables FHL2G 0.35 mm² to 120 mm² (Standard cross-sections)

Conductor					Core
cross-section [mm²]	finely stranded (nom.) (max.) [mm]	extra finely stranded (nom.) (max.) [mm]	diameter (max.) [mm]	resistance at 20 °C (max.) [mΩ/m]	diameter [mm]
0.35	12 x 0.21	45 x 0.11	0.9	52.0	2.1 (– 0.3)
0.5	16 x 0.21	64 x 0.11	1.1	37.1	2.3 (– 0.3)
0.75	24 x 0.21	96 x 0.11	1.3	24.7	2.5 (– 0.3)
1.0	32 x 0.21	126 x 0.11	1.5	18.5	2.7 (– 0.3)
1.5	30 x 0.26	192 x 0.11	1.8	12.7	3.0 (– 0.3)
2.5	50 x 0.26	320 x 0.11	2.2	7.6	3.6 (– 0.3)
4.0	56 x 0.31	120 x 0.21	2.8	4.7	4.4 (– 0.4)
6.0	84 x 0.31	183 x 0.21	3.4	3.1	5.0 (– 0.4)
10	80 x 0.41	320 x 0.21	4.5	1.82	6.5 (– 0.6)
16	126 x 0.41	512 x 0.21	5.8	1.16	8.3 (– 0.6)
25	196 x 0.41	790 x 0.21	7.2	0.743	10.0 (– 0.6)
35	276 x 0.41	1,070 x 0.21	8.5	0.527	11.0 (– 0.7)
50	396 x 0.41	1,600 x 0.21	10.5	0.368	13.2 (– 0.8)
70	360 x 0.51	2,175 x 0.21	12.5	0.259	15.1 (– 0.8)
95	475 x 0.51	3,000 x 0.21	14.8	0.196	17.4 (– 1.0)
120	608 x 0.51	3,700 x 0.21	16.5	0.153	19.5 (– 1.0)

32 Coroplast

12.2 Cableshoes

12.2.1 Cableshoes for motor controller connection

5.1.2 Wiring, cables, current calculations, connectors

https://docs-emea.rs-online.com/webdocs/1505/0900766b81505595.pdf

RS PRO

ENGLISH

Datasheet

Stock No: 531-891

RS Pro CT Series Uninsulated Tin Plated Tubular Ring Terminal, M10 Stud Size, 50 mm²

Product Details

RS Pro Ring Tube Crimp Terminals

From RS Pro, a range of heavy duty copper tube ring terminals manufactured from a pure grade copper base to BS2871 and electro-tin plated to BS1872,1984. These HD copper tube ring crimp terminals are for use on multi-stranded cables and are available with a flared or a chamfered entry (see stock numbers 841-7598 and 841-7608) and in a variety of sizes.

RS Tube Terminals - Uninsulated Terminals & Kits

Tube Terminals

Heavy duty tube terminals and butt splices for terminating cables in the 6mm² to 150mm² size range. The terminals are available with different bolt hole diameters. Both ring terminals and butt splices are manufactured from tinned copper tube with a flared cable entry to ease termination (Excepting 6mm² size). Rated to 150°C.

Specifications:

Wire Size	50 mm²
Stud Size	M10
Inner Ring Diameter	10.4mm
Insulation	Uninsulated
Contact Material	Copper
Shrouded	Unshrouded
Contact Plating	Tin
Series	CT
Overall Length	43.2mm

12.3 BMS

2.9.2 Wiring, cables, current calculations, connectors

Datasheet obtained directly from LithiumBalance. Not available online.

See data for GPIO ports J4A IO and J4B IO.

- Part number and revision version of the board
- Serial number including the production date

To read the QR-labels, Lithium Balance can recommend to use dedicated QR readers. If smart phones are used the "QR Reader from TapMedia Ltd" have been tested successfully.

2.2 Connections and cables

To simplify installation, Lithium Balance provides cables which can be ordered together with the BMS boards.

Connector	**Cable assembly Order code**	**Cable dimensions**
MCU J4a IO cable	000807	100 cm, 20AWG = 0,5 mm²
MCU J4b IO cable	000808	100 cm, 20AWG = 0,5 mm²
MCU J5 Shunt & HV	000847	50 cm, 20 AWG = 0.5 mm²
ISOSPI Connection MCU J3 CMU J1, J2	000802, 803, 804, 805	Shielded cable: 12, 30, 100, 500 cm
CMU J4 Cell Voltage	000809	150 cm, 20AWG = 0,5 mm²
CMU J3 Cell Temp	000801	100 cm, 22AWG = 0,35 mm²

Table 2.1 Overview of n-BMS connectors and matching cables

2.2.1 MCU J4a Connector IO Connector1 – 35 pin

The J4a connector provides interfaces for:

- Board Power and Ground
- Digital Input/Output signals
- Ignition (Wake-up)
- Hall sensor signals
- HVIL signal
- General/Aux temperature sensors

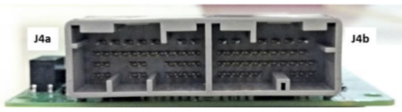


Figure 2-2 MCU J4a and J4b IO Connectors

Please note that the MCU J4a and J4b connectors are keyed differently, thereby assuring that only the correct cables fit into J4a (000807) and J4b(000808)

The J4a connector PIN numbers and associated 000807 cable wire numbers are summarised in Table 2.2

J4a Pin No.:	**PIN Name**	**000807 wire number**	**IN/OUT**	**Description**
1	GPIO10	1	In/Out	Configurable IO signal
2	GPIO9	2	In/Out	Configurable IO signal
3	HVIL OUT	3	Out	HV INTERLOCK OUT – For future SW-releases
4	HVIL IN	4	In	HV INTERLOCK IN – For future SW-releases
5	GND Power/In	5	In	Ground for board
6	GND Power/in	6	In	Ground for board

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Created: 08/12/2017 14:32
LITHIUM BALANCE BATTERY MANAGEMENT SYSTEMS

12.4 Formula Pro Steering Rack

8.1.3 Schematic

http://www.formula-seven.com/wp-content/uploads/2017/03/F7-Steering-Rack_with-Rotary-Sensor.pdf

Steering Rack, Hall Effect rotary Encoder

- Steering rack rotary Sensor
- Contact less magnetic encoder
- High accuracy

Electrical Data	
Working angle	0 … 360 [°]
Indep. linearitiy (without misalignment)	±0.3 ±0.3, % of meas. Range
Indep. linearitiy (with allowed misalignment @ 360°)	±0.5, % of meas. Range
Max. hysteresis	0.1 [°]
Resolution	12 [Bit]
Max repeatability	0.1 [°]
Sample rate fast mode	(5) [kHz]
Sample rate slow mode	1.66 [kHz]
System Propagation delay fast mode	(800) [ms]
System Propagation delay slow mode	4600 [ms]
Max. temperature coefficient of the output signal	100 [ppm/°K]
MTTFd / MTBF	240/240 [years]
Power supply voltage	8 … 35 [VDC]
Current consumption without load (typ.) fast mode	(19) [mA]
Current consumption without load (typ.) slow mode	14[mA]
Min. ohmic load at output	10 [kOhm]
Max. capacitive load at output	100 [nF]
Reverse polarity protection of power supply	Yes
Electrical connection	Cable 3 pole
Cross section of single wires	0.56 (AWG20) [mm2]
Length of cable	1 [m]
Redundancy feasible	Yes
Electrical connection redundant	Cable 6pole
Cross section of single wires redundant	0.25 (AWG24) [mm2]
Output characteristics	Positive gradient CW
Output Signal	0.5 … 4.5 [VDC]

Mechanical Data	
Mechanical range	360 (continuos) [°]
Protection class	IP68
Min. life	No movements limitation
Operating & storage temperature	-40 … +85 [°C]
IEC 68-2-6 Vibration (Amax = 0.75mm, f = 5 … 2000 Hz)	50 [g]
IEC 68-2-27 Shock	200 [g]
Mounting hole	2 through-holes 4.4 mm

12.5 Drives technical data

2.9.2 Wiring, cables, current calculations, connectors

Datasheet obtained directly from EmDrive Mobility. Not available online.

4.3 emDrive500

Table 4: emDrive500 technical specifications

emDrive500	min.	typ.	max.	unit
Electrical data				
Input DC link voltage range	30		125	V
Input DC link current range	0		800	A
Output phase to phase voltage range	0		84	V_{RMS}
Output current range	0		800	A_{RMS}
Output continuous current			500	A_{RMS}
Output maximum one minute peak current			800	A_{RMS}
Output continuous power			62	kVA
Output maximum one minute peak power			110	kVA
Input DC link capacitance		14500		µF
Number of output phases		3		
Switching frequency		16		kHz
Output frequency range	0		1,2	kHz
EMI Y capacitor, DC + and DC – to heat sink		3		µF
Discharge resistor: DC + to DC -		none		
Pre-charge resistor requirements: charge time to 3τ	0,5		1	
Control unit electrical data				
Supply voltage range	9		30	V
Supply current range at typ. supply voltage (idle state, PWM disabled)		?		A
Supply current range at typ. supply voltage (operating, PWM enabled)		?		A
Protection functions				
DC link voltage measurement range			135	V
DC link over voltage protection			125	V
DC link under voltage protection	0			V
DC link voltage measurement resolution		0,1		V
Over current protection: primary protection (adjustable)			800	A_{RMS}
Over current protection: secondary protection (adjustable)			900	A_{RMS}
Output current measurement range	0		1000	A_{RMS}
Output current measurement resolution		0,25		A_{RMS}
DC link capacitors temperature protection - power derating point		75		°C
MOS-FET temperature protection - power derating point		100		°C
Motor over temperature protection (only if sensor connected)			140	°C
Motor temperature sensor input type KTY 84-130		0,6		kΩ
KTY 84-210		2		kΩ
NTC		10		kΩ
Insulation				
DC + to heat sink, DC – to heat sink		250		V
DC + to logic level, DC – to logic level		250		V
Logic level to heat sink		250		V
Isolation resistance: DC + to heat sink, DC – to heat sink	100			MΩ
Protective class		I		
Mechanical data				
Weight		4,9		kg
Height		65		mm
Width		280		mm
Length		205		mm
Power contacts tightening torque (M8)	18	20	22	Nm
Chassis mounting screws tightening torque (M6 x 40 or longer)	8		12	Nm

12.6 Amphenol ePower connectors

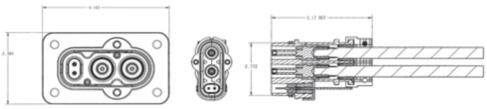
3.1.10 Charging / Chargers

www.amphenol-industrial.com **Amphenol**

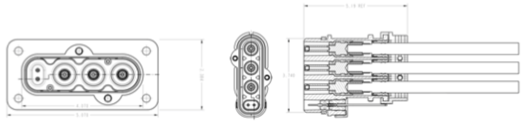
ePower Features

- Two or three circuit power
- Crimp, lug or bus bar termination
- IP2X on pin and socket
- Environmental IP67 rating
- Two HVIL circuits
- 1,000VDC rating
- Integrated EMI shielding
- 8.0mm, 11.1mm, & 18mm RADSOK® technology for 200, 400, & 700A continuous current capability
- Strain relief for jacketed cable incorporated into shell
- Excellent vibration resistance
- All aluminum shell
- RoHS Compliant

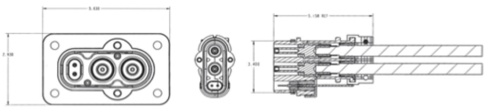
200 A 2 Way Receptacle and Plug



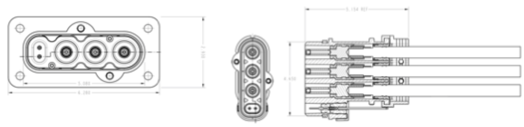
200 A 3 Way Receptacle and Plug



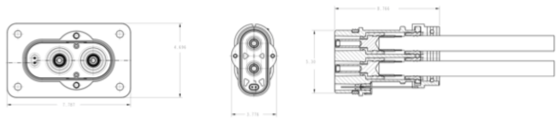
400 A 2 Way Receptacle and Plug



400 A 3 Way Receptacle and Plug



700 A 2 Way Receptacle and Plug



HOW TO ORDER

1		2		3		4		5		6		7		8	
e		P		2		2		25		1		1		UL	
Product Line		Connector		Amp Level		Number of Poles		Wire Size		Key Position		Plating		Approval	
e	ePower	P	Plug	2	200A	2	2 Pole	BB	Busbar (Receptacle Only)	1	Available in 2 & 3 Pole	1	Electroless Nickel	UL	Sizes 1A and 40 Only
		R	Receptacle	4	400A	3	3 Pole	25	25mm^2 (200A Only)	2	Available in 2 & 3 Pole	FL	Gray Zinc Nickel (500 hours)		
				7	700A			35	35mm^2 (200A Only)	3	Available in 2 & 3 Pole				
								50	50mm^2 (200A or 400A)	4	Available in 2 & 3 Pole				
								1A	1 AWG (200A or 400A)	5	Available in 3 Pole Only				
								70	70mm^2 (400A Only)	6	Available in 3 Pole Only				
								95	95mm^2 (400A Only)	7	Available in 3 Pole Only				
								40	4/0 (400A Only)	8	Available in 3 Pole Only				
								24	240mm^2 (700A Only)						
								30	300mm^2 (700A Only)						

12.7 Inertia Switch

2.3 Inertia Switch

https://www.jsae.or.jp/formula/jp/SFJ/docu/STJ_resettable-crash-sensor.pdf

Sensata Technologies

Sensata Technologies' 360° Resettable Crash Sensors directly shut down the fuel pump or main contactor upon vehicle impact, reducing the risk of fire and electrical shock in post-crash situations. These devices are a low cost solution to vehicle safety requirements and approved for vehicle installation by major automotive manufacturers worldwide.

Sensata is an ISO and TS registered company. We provide world-class quality products error-free and on time.

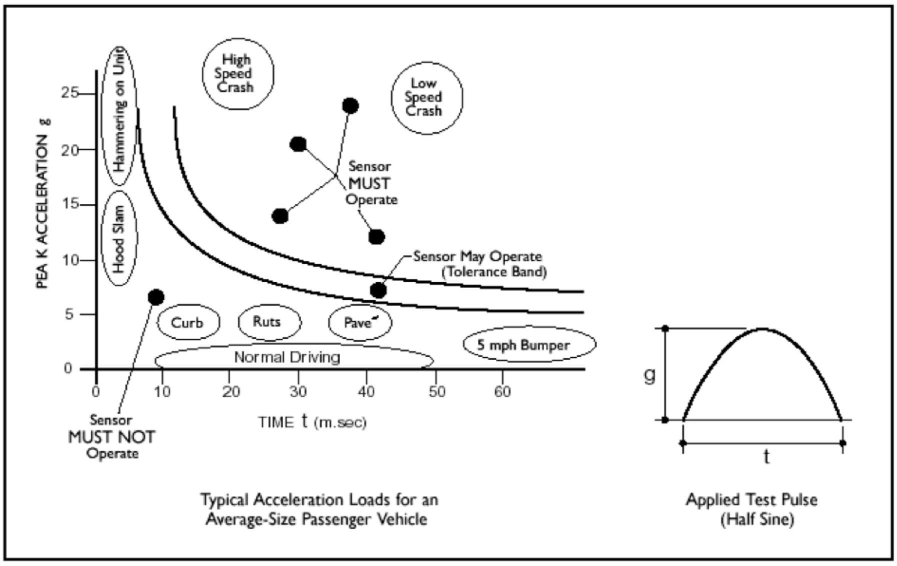
Features:

- Unique magnet restrained mass inertia mechanism
- Rated at 10 Amps electrical load
- Manually resettable
- Shock calibration ranges available between 8g and 30g
- Stops fuel pump or electrical system operation
- Secondary circuit provides additional function

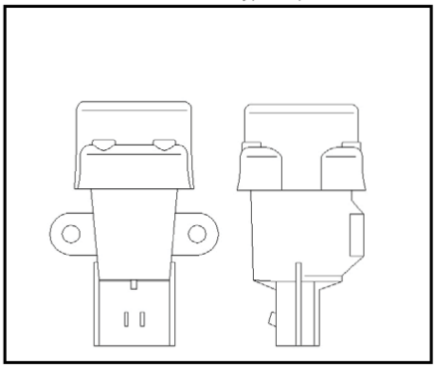
Benefits:

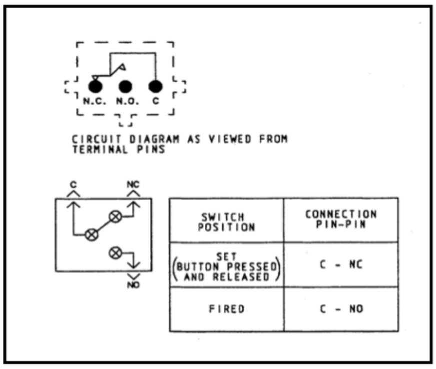
- Reduces the risk of fire following a crash
- Responsive to 360° impact
- Ability to trigger GPS distress signal
- Capable of carrying fuel-pump load
- Sensory feedback
- Customized for various installations

www.sensata.com Printed in U.S.A., December 2010



Above are the typical performance characteristics of resettable crash sensors





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