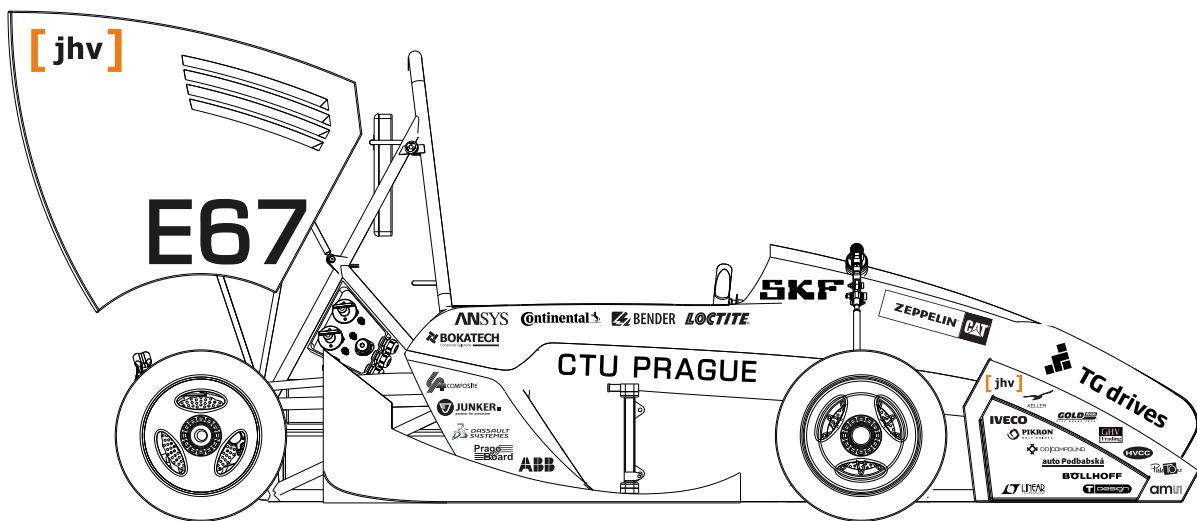




ELECTRICAL SAFETY FORM FSAE-E 2018



CZECH TECHNICAL UNIVERSITY IN PRAGUE

eForce FEE Prague Formula

E67

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List of Acronyms

ACP accupack.

ADC analog to digital converter.

AIR accumulator isolation relay.

AMS accupack management system.

BOTS break over travel switch.

BSPD break system plausability device.

CAN controller area network.

ECU-B electronic control unit - back.

ECU-P electronic control unit - pedals.

FAIL front Axels InterLock.

HV high voltage.

IMD isoaltung measuring device.

LV low voltage.

MC motor controller.

MCU microcontroller unit.

SDB shut down button.

SDC shut down circuit.

TS traction system.

TSMS traction system master switch.

VDCU vehicle dynamics control unit.

1 System Overview

Electrical systems of the car are divided into small blocks. The concept is to have all the systems distributed by 2 CAN buses (1st CAN_Powertrain for systems crucial data to proper function, 2nd CAN_Aux for all the other systems) and, if possible, all the signals transferred just by CAN bus. Baud rate is 500kbps and CAN is terminated in ECUP in front of car and in front motor controller by 120 Ohm resistor. There are in total 5 main control units of course all the units are fully self-made (HW and FW).

- ECUP (Electronic Control Unit Pedal) This device measures brake pedal and acceleration pedal positions, implements safety algorithms regarding to rules about torque encoder check and outputs these values to the CAN bus as drivers foot requests. It also monitors Shutdown Circuit point BOTS.
- VDCU (Vehicle Dynamics Control Unit) This device reads drivers foot requests, actual every wheel speed provided by ECUM and implements Traction Control Algorithms. The result is sent over private CAN bus to the MCF and MCR.
- MC (Dual Motor Controller) 2 units in total Front (MCF) and Rear (MCR). These units drives 4 motors in total, so every unit drives 2 motors. It provides speed of every wheel by actual RPM, temperatures and so on. Field Oriented Control is implemented with Resolvers as a position feedbacks.
- ECUF (Front + Dashboard) Interaction with driver in cooperation with ECUS (Steering Wheel LCD inside) by informing, warning and error LEDs, switches, rotary switches, push buttons. This is like a drivers CAN bus console.
- ECUB Providing low voltage power distribution to all the control units and periphery (Li-Ion LV battery with BMS inside). This unit implements all the safety and control algorithms regarding to Shutdown Circuit rules. The main function is to latch SDC and evaluation of SDC interruption point.
- ECUA DC-DC converter, BMS, Pre-charge and AIR controlling is implemented. This unit also communicate with Charging Station. There are other control and measuring systems not listed above, but systems listed are most important for safety and control.

There are other control and measuring systems not listed above, but systems listed are most important for safety and control.

Table 1: General parameters

Maximum Tractive-system voltage:	400 VDC
Nominal Tractive-system voltage:	345.6 VDC
Control-system voltage:	24 VDC
Accumulator configuration:	96s9p
Total Accumulator capacity:	7.78 kWh
Nominal HV Accumulator current:	270 A
Maximum HV Accumulator current:	315 A
HV accumulator cell type:	Lithium-Ion
LV Accumulator cell type:	Lithium-Ion
Motor type:	PMSM with resolvers
Number of motors:	4, one per wheel
Maximum combined motor power in kW	109

2 Electrical Systems

2.1 Shutdown Circuit

2.1.1 Description/concept

Shutdown circuit (SDC) starts in ECUP unit, then goes through all SDC elements in the car and ends in ECUA, which is placed inside the Accumulator Pack. In ECUP SDC starts from LV power +24V and ends in ACP by powering AIR coils switching circuit (See Figure 1: SDC scheme). The SDC consists of 2 master switches, 3 shut-down buttons(SDB), the brake-over-travel-switch(BOTS), the insulation monitoring device (IMD), the inertia switch, the brake system plausibility device(BSPD), interlocks in Motor Controllers and Accumulator Pack and the accumulator management system (AMS). All of these crucial parts do not act through any power stage, but carry directly the AIR current.

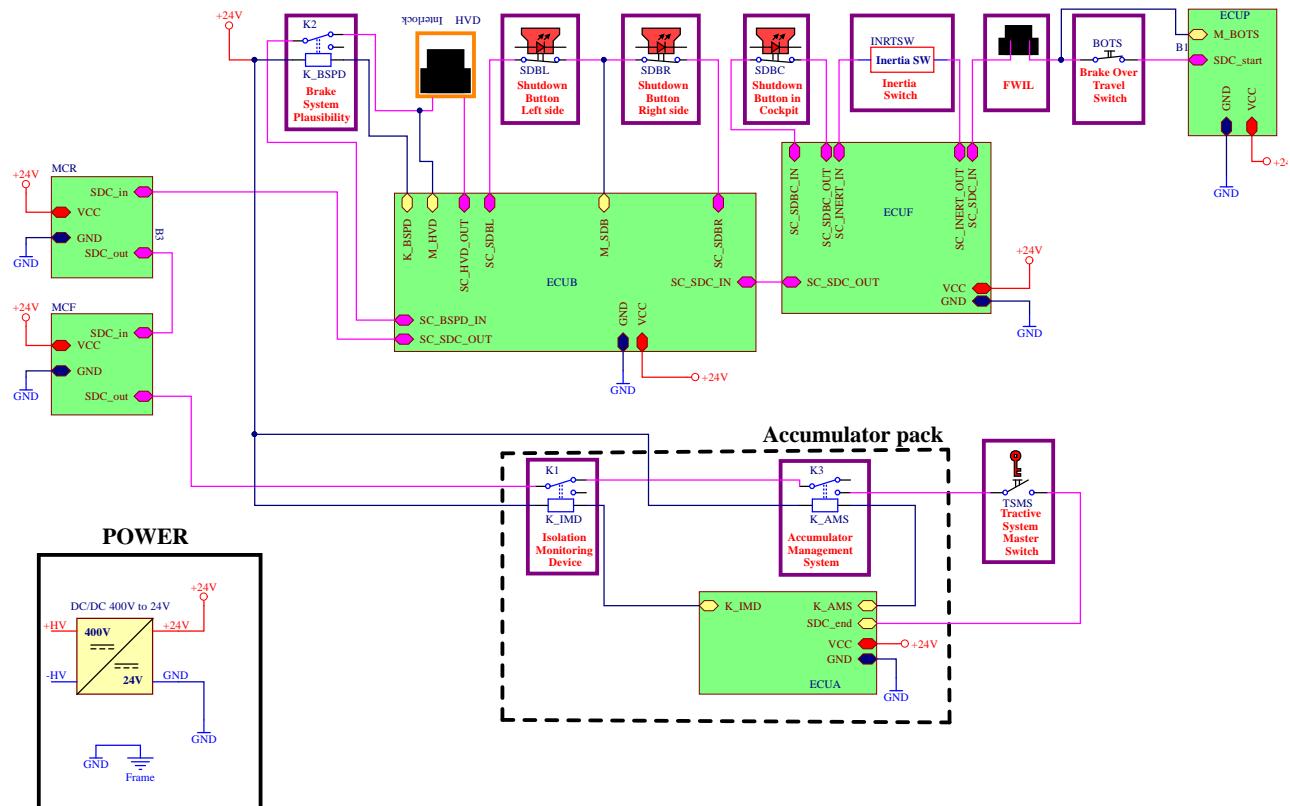


Figure 1: SDC scheme.

Table 2: List of switches in the 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 Open

Monitoring SDC

Every part of SDC is monitored by specific ECU (Electronic Control Unit) in order to identify disconnected element. BOTS is measured by ECUP, SDB-center and Inertia switch are measured by ECUF , interlocks in

Motor Controllers are measured by Motor Controllers, Interlock in Accumulator Pack is measured by ECUA and finally SDB-right, SDB-left and TSMS are measured by ECUB. Every piece of information regarding the state of closure SDC are running between ECUs by CAN.

We designed SDC to be single wire alike and distanced it from the system as much as it was possible. In order to remain SDC as a stand-alone wire we used optocouplers for main points of SDC. Optocouplers are connected in such a way, that they become active only in case of nonzero voltage occurrence at a certain point of SDC.

ECUB monitors the last point of SDC (behind TSMS). If a state of error on SDC is detected ECUB latches the off-state of SDC to stay off. If the occurred error is non-critical, it allows pilot to re-enter the TSON state. If monitored error is critical (such as IMD etc.), it notes the error to the memory-storage and does not allow SDC to become active until appropriate steps are taken. The logic flow-chart is shown in ??: ?. For more info about this look to next and Reset / Latching for IMD and BMS sections. SDC error states that require special handling

??: ? ECUB is last part of SDC before TSMS. It implements latching function using external memory so even in case of total shutdown of LV power it is possible to remember error states that occurred before the breakdown. The ECUB implements enough capacitor storage, that it is able to write the error to the memory even in case of immediate power-loss caused by the error. It is not possible to reactivate SDC and close AIRs until all the steps required by rules are done.

Master Switch

We use SCI A23-5 battery cut-out switches with continuous current rating 100A, shown on Figure 2: TSMS.



Figure 2: TSMS.

Shutdown Switch

We use OMRON A165E shutdown buttons, which have 3A current rating at 30VDC.

On the cockpit it is OMRON A165E-LS, shown on Figure 3: Cockpit SDB.

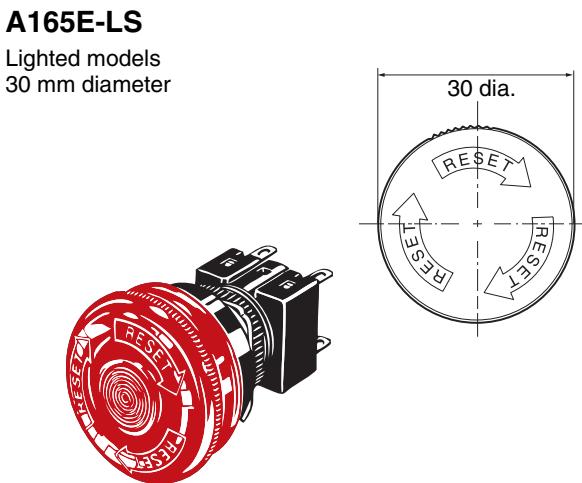


Figure 3: Cockpit SDB.

On the left and on the right sides there are OMRON A165E-LM buttons, shown on Figure 4: SDB left and right.

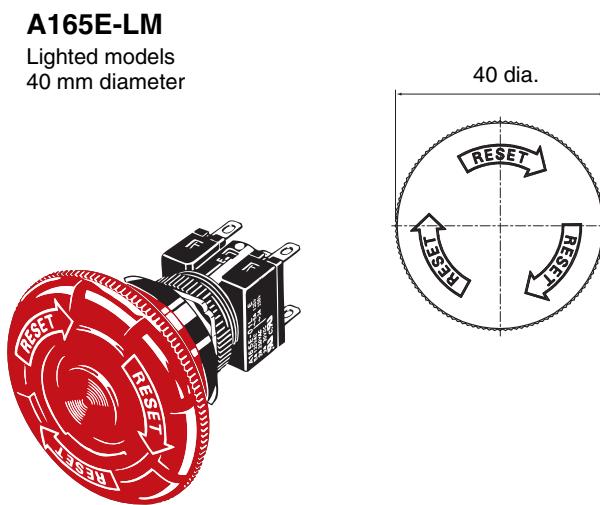


Figure 4: SDB left and right.

Brake Over Travel Switch

It is type A165E-M, current rating 3A, shown on Figure 5: Brake over travel switch

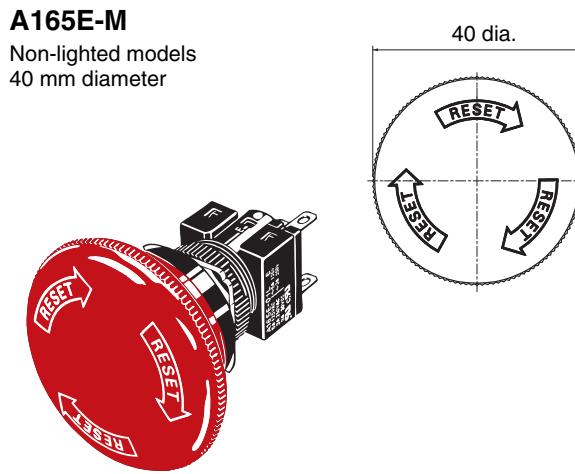


Figure 5: Brake over travel switch.

2.1.2 Wiring / additional circuitry

If connector is used to connect SDC between control units, disconnecting any of them results in opening SDC and therefore opening AIRs as well. In other words the SDC directly carries the current driving the accumulator isolation relays(AIRs). All circuits that are part of the shutdown circuit have been designed in a way, that, when in disconnected state, they remove the current controlling the AIRs.

The cross-section of Shutdown System wire is AWG22. Block wiring scheme shown on Figure 6: Example of used SDC monitoring method with optocouplers.

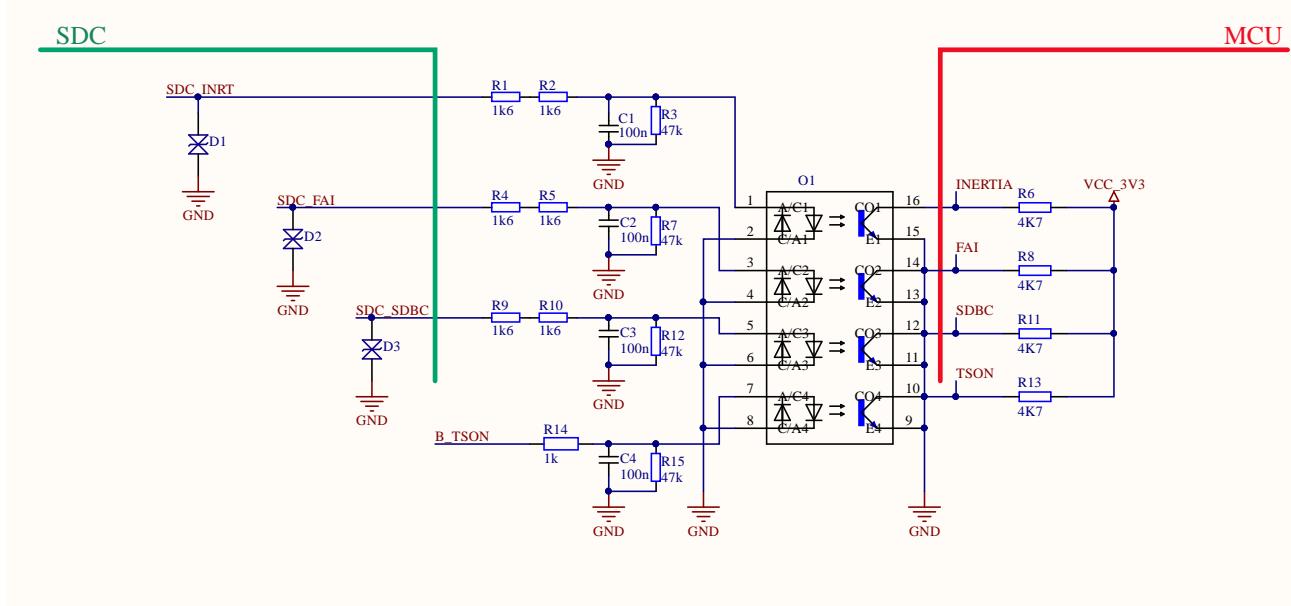


Figure 6: Example of used SDC monitoring method with optocouplers.

As shown, 4k7 resistors are used to limit current through optocoupler. With 24V supply that makes 15,2mA per optocoupler. We used 8 optocouplers = $\frac{1}{2} \cdot 12 \cdot 15 = 182,4$ mA.

Table 3: Wiring Shutdown circuit

Total Number of AIRs:	2
Current per AIR:	70mA
Additional parts consumption within the shutdown circuit:	182,4mA
Total current:	322,4mA
Cross sectional area of the wiring used:	0,322mm ² (AWG22)

2.1.3 Position in car

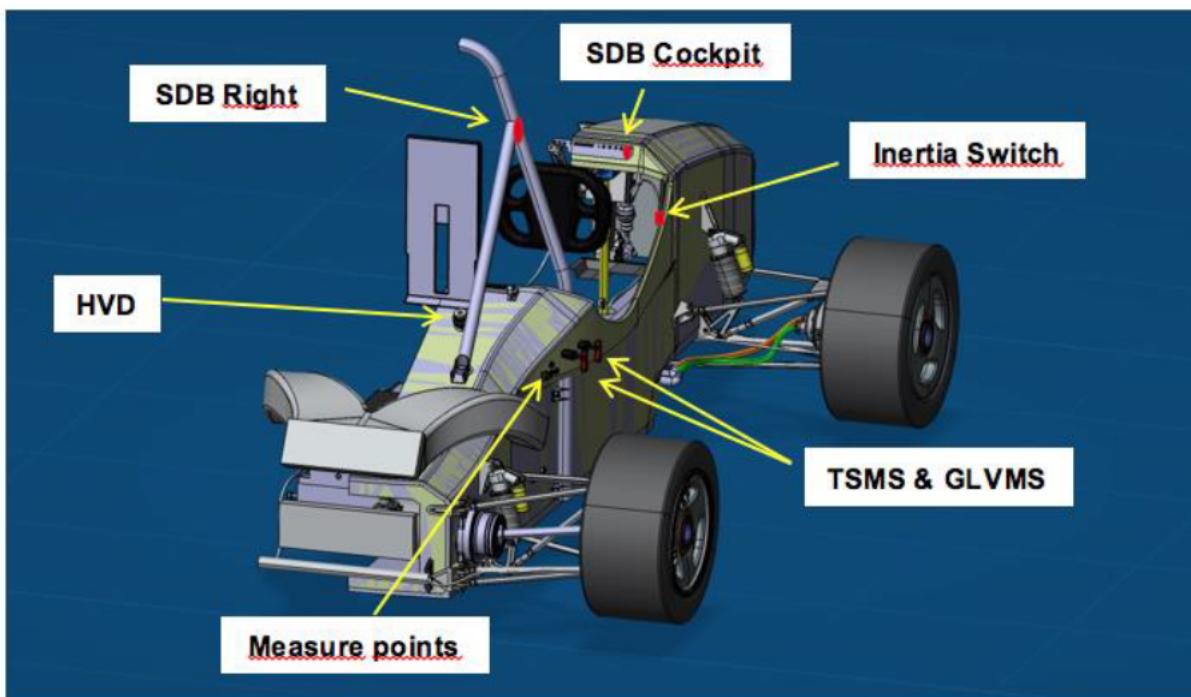


Figure 7: Inertia switch, SDB Left, Right and Cockpit, TSMS, GLVMS, HVD, Measure points.

2.2 IMD

2.2.1 Description (type, operation parameters)

We use A-ISOMETER IR155-3203 Insulation monitoring device (IMD) for unearthing DC drive systems. Our maximum tractive voltage is 403.2 VDC. The rules require minimal insulation value between TS and GLVS 500 Ohm/V. Minimal resistance value for our car is $403.2 \times 500 = 201\ 600$ Ohm. This was set as request for manufacturer, and device was programmed in factory.

Table 4: Parameters of the IMD

Supply voltage range:	10..36VDC
Supply voltage	24VDC
Environmental temperature range:	-40..105C
Selftest interval:	Always at startup, then every 5 minutes
High voltage range:	DC 0..1000V
Set response value:	201.6k (500/Volt)
Max. operation current:	150mA
Approximate time to shut down at 50% of the response value:	20s

2.2.2 Wiring/cables/connectors/

Describe wiring, show schematics, describe connectors and cables used and show useful data regarding the wiring including wire gauge/temp/voltage rating and fuses protecting the wiring.

Relay of Insulation Monitoring Device is electrically placed between MCF and relay for AMS measurement. Wiring is done using Raychem Spec44 wire, AWG 22, rated to 600V. Wiring is shown on Figure 1: SDC scheme. IMD opens relay in case of fault. IMD have output for relay, so there is not necessary adding zero diode on output. HV input to IMD is connected in according to datasheet.

2.2.3 Position in car

Provide CAD-renderings showing the relevant parts. Mark the parts in the rendering, if necessary

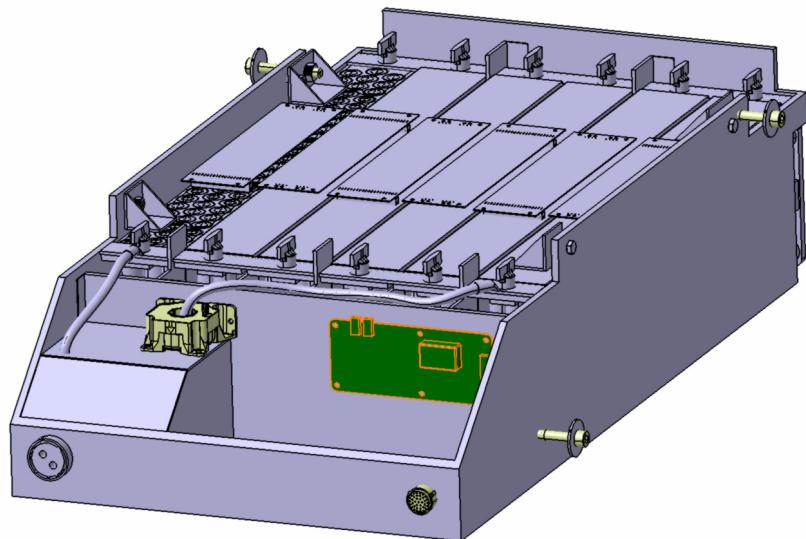


Figure 8: IMD position.

2.3 Inertia Switch

2.3.1 Description (type, operation parameters)

Inertia switch opens shutdown circuit in case of acceleration more than 6g. After acting the driver can reset this switch.

Table 5: Parameters of the Inertia Switch

Inertia Switch type:	Sensata 510FCS01-01
Supply voltage range:	No supply needed
Supply voltage:	No supply needed
Environmental temperature range:	-30..120C
Max. operation current:	10A
Trigger characteristics:	6g for 60ms / 11g for 15ms

2.3.2 Wiring/cables/connectors

Inertia switch is electrically placed between Shutdown button center on dashboard and the Shutdown input to ECUB, where is connected right Shutdown button on main hoop. Inertia switch will be connected by FQCT connectors. Wiring of inertia switch is shown on Figure 1: SDC scheme. Wiring of inertia switch is shown on ???: ??.

2.3.3 Position in car

Inertia switch is placed on the right side in the cockpit clearly shown in Figure 7: Inertia switch, SDB Left, Right and Cockpit, TSMS, GLVMS, HVD, Measure points.

2.4 Brake Plausability Device

2.4.1 Description/additional circuitry

BSPD is represented by a PCB with an on-board current transducer. Its function is to monitor power drawn from ACP and brake pedal pressure, and open SDC in case both signals are above allowed threshold for more than 0,5 seconds. Also, the event of disconnection of SDC is latched, thus it gets to reset only in case of the main power reset.

Table 6: BSPD data

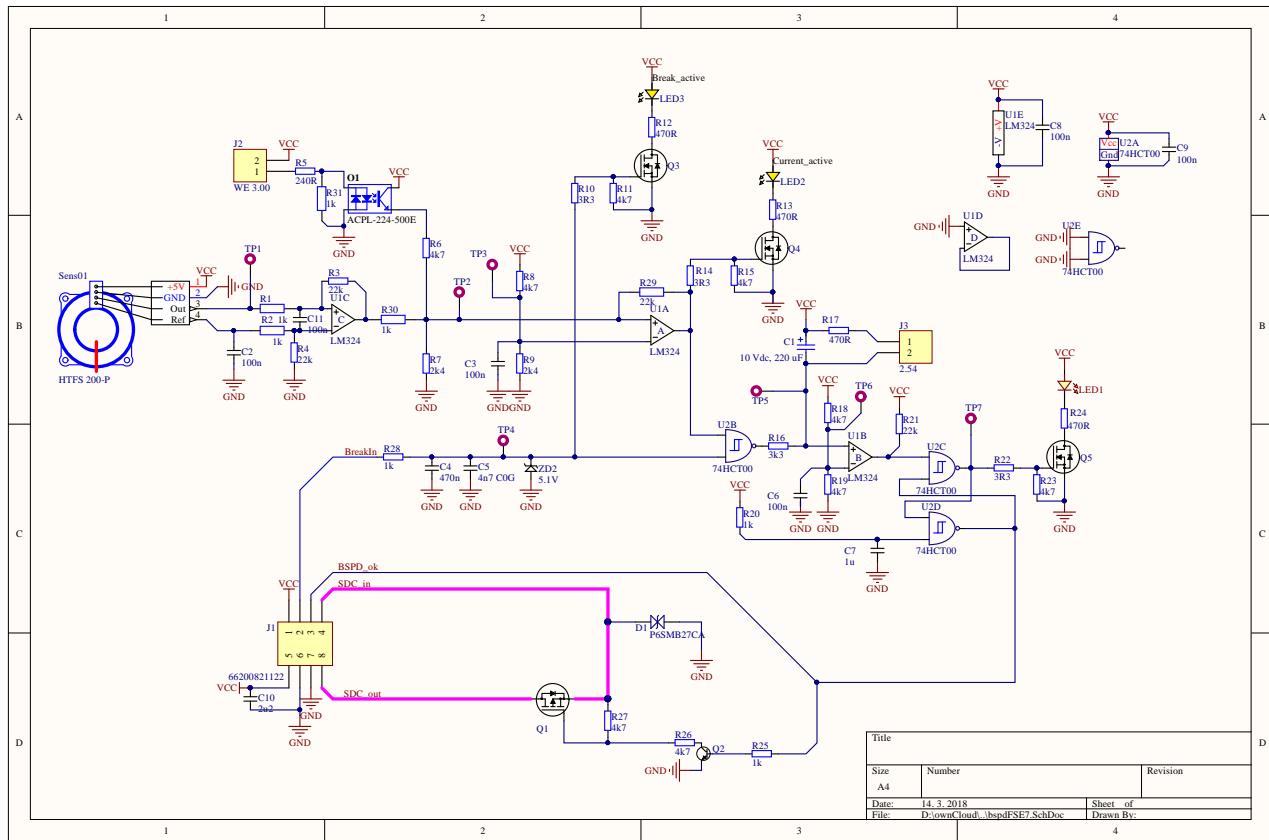
Brake sensor used:	Piezoresistive Pressure Transmitter PA-21Y / 100bar / 81691.1
Brake sensor physical response value:	Voltage, 4,5V
Tractive system power sensor type	Current Transducer LEM HTFS 200-P
Tractive system sensor physical response value:	Voltage of 85mV
Tractive System power sensor current threshold (5kW/Nominal TS voltage):	14A
Supply voltages:	5V
Maximum supply currents:	22mA
Operating temperature:	-40..105°C
Output used to control AIRs:	Open a MOSFET in SDC

2.4.2 Schematic

The BSPD PCB is mounted on a HV wire in such manner, that the HV wire goes through the current transducer. Current transducer provides analog voltage output of a value proportional to actual current (resp. power) drawn from ACP. This voltage is amplified and is converted to twostate logic levels voltage with the use of comparators. The value of High current signal logic level is set to be at 5kW of power drawn from ACP (14A).

Brake state is measured in ECUP, converted with help of a comparator to two-state logic levels voltage and is sent directly to BSPD via wiring.

Both logic signals are connected to NAND inputs. When both inputs are at High level, a capacitor C1 starts to charge through resistance R16. When voltage on C1 is higher than 2,5V, a comparator U1B sends signal to open SDC.



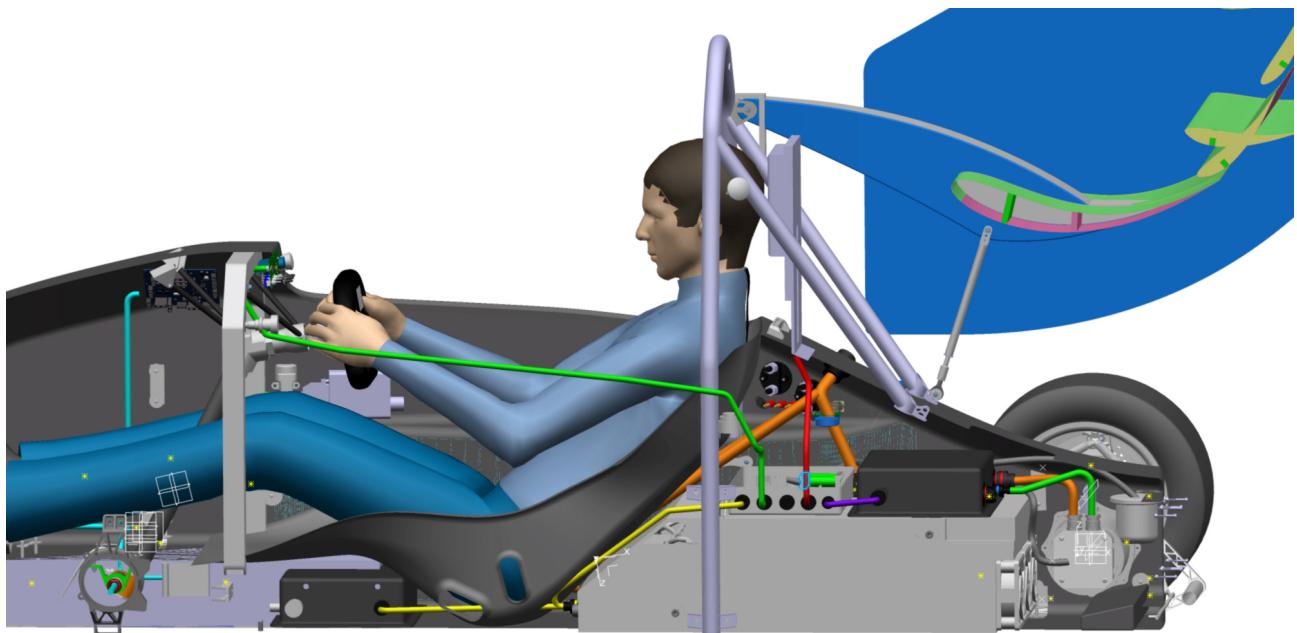


Figure 10: BSPD position

2.5 Reset / Latching for IMD and BMS

2.5.1 Description/circuitry

2.5.2 Wiring/cables/connectors

Measuring, what was original problem, is done by two optocouplers in ECUB. Figure 16 - Example of used SDC monitoring with optocouplers.

2.5.3 Position in car

Latch as well as reset of IMD and BMS error is placed in ECUB box on the back of car. See ??: ??.

2.6 Shutdown System Interlocks

2.6.1 Description/circuitry

We have interlocks in ACP HV connector (connector HV_A), Motor controller HV inputs and outputs, HV connector in Service box, HVD and in the LV connectors from ECUMs (ECUM Rear and ECUM Front) to motor (connectors M1, M2, M3 and M4). In the M1-4 connectors we have a loop, that protects motor from disconnecting from a vehicle (disconnection of any of them triggers the Shutdown circuit).

2.6.2 Wiring/cables/connectors

Scheme of entire Shutdown circuit can be found at Figure 6 - Block SDC wiring scheme

2.6.3 Position in car

HVD is clearly shown above in Figure 8 - Inertia switch, SDB Left, Right and Cockpit, TSMS, GLVMS, HVD, Measure points. For Service box position see Figure 17 - Motor controllers

Last interlock is in Accumulator Pack HV Connector shown in ACP HV Connector.

2.7 Tractive System Active Light

2.7.1 Description / circuitry

Our TSAL system consists of two parts, LEDs and generator of frequency with power-switch. Generator is in ECUB protected by fuse. The waveform is generated with a 555-based circuit. The TSAL uses pairs of anti-parallel LEDs and is connected with two wires. Color of the light is decided by the polarity of the driving voltage. The following table shows the operation mode depending on conditions C1, C2:

EV4.12.1 is achieved by U4 in Figure 21 - TSAL HV part schematic comparing the voltage on R59 with 3v3 reference. MHVout is connected to output connector of accumulator. O4 carries the information about HV presence to LV system and enables power to TSAL by opening Q5.

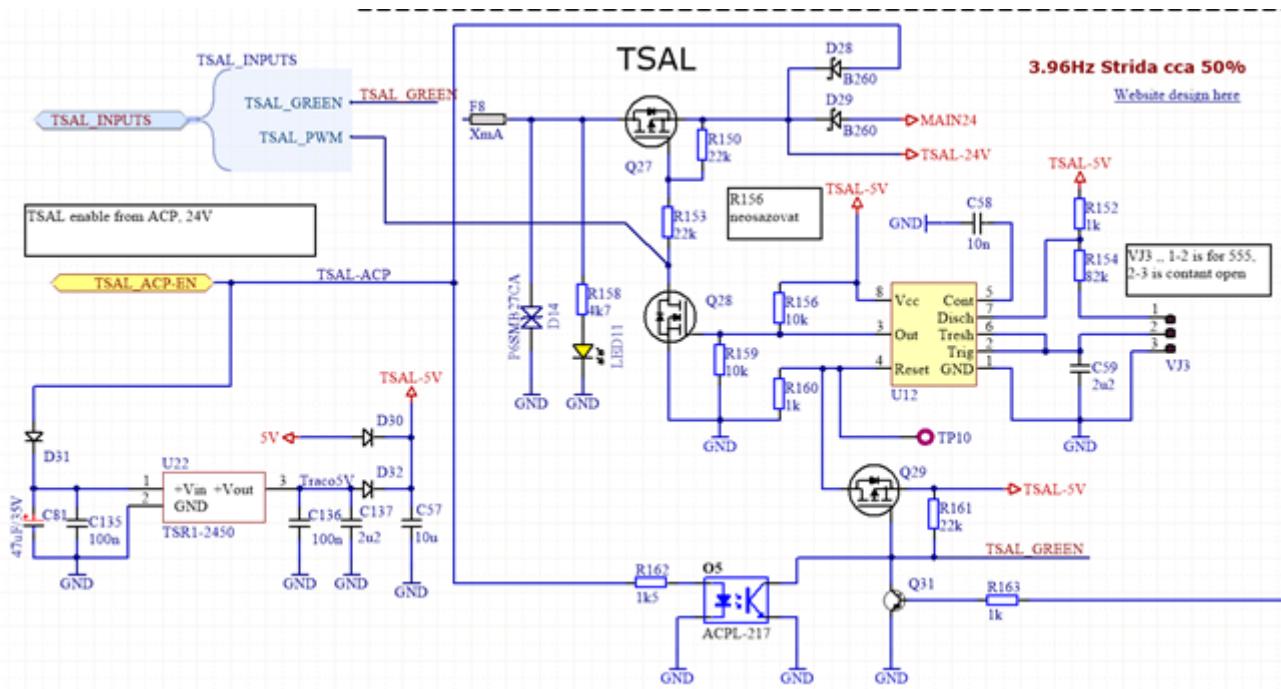


Figure 11: Schematic of generator for TSAL.

Table 7: Parameters of the TSAL

Supply voltage:	+/- 24VDC
Max. operational current:	300mA
Lamp type	Bi-color LED
Power consumption:	7.2 W
Brightness	124 Lumen (red), 29 Lumen (green)
Frequency:	3.96Hz
Size (length x height x width):	128mm x 20mm x 32mm

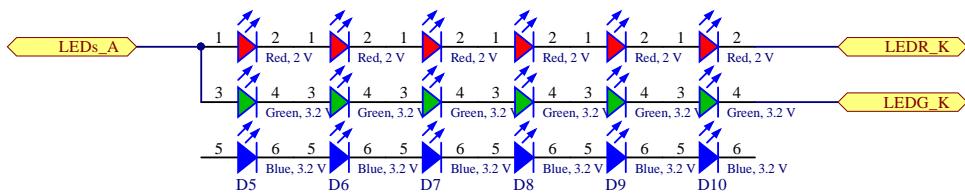


Figure 12: TSAL schematic.



Figure 13: TSAL HV part schematic.

Explanation of TSAL circuit

Left top corner of Figure 13: TSAL HV part schematic (input marked as HV-Viper) is directly connected to the output HV pins of ACP. The circuit is designed with STM chip VIPER16HN. It behaves as normal fly-back, with input voltage range from 50V up to 500V. Output of flyback is used to directly power the TSAL. ACP indication led is powered from primary side of transformer. To ensure correct behaviour we also measure and compare input voltage (using U12A OAMP as comparator with little hysteresis), to enable output (Q36 & Q33) only if input voltage is ≥ 60 VDC.



Figure 14: TSAL enable scheme

Function of circuit on Figure 14: TSAL enable scheme is that the TSAL is enabled even when the 60VDC limit is not reached but the AIR is closed nonetheless. In such state, the TSAL is enabled by signal AIR_EN. The circuit is powered by MAIN24 power (which is equal to the 24V enabled by GLVMS) or by the TSAL_ACP-EN power signal from the Viper-TSAL schematic (Figure 15: ACP indication LED wiring) below.



Figure 15: ACP indication LED wiring

2.7.2 Wiring/cables/connectors

LEDs are supplied from ECUB (by Harness_D by connector D1) by 2-wire low voltage cable (Figure 16: Wiring TSAL from ECUB).



Figure 16: Wiring TSAL from ECUB

2.7.3 Position in car

TSAL is placed under the main roll hoop, see Figure 17: TSAL position

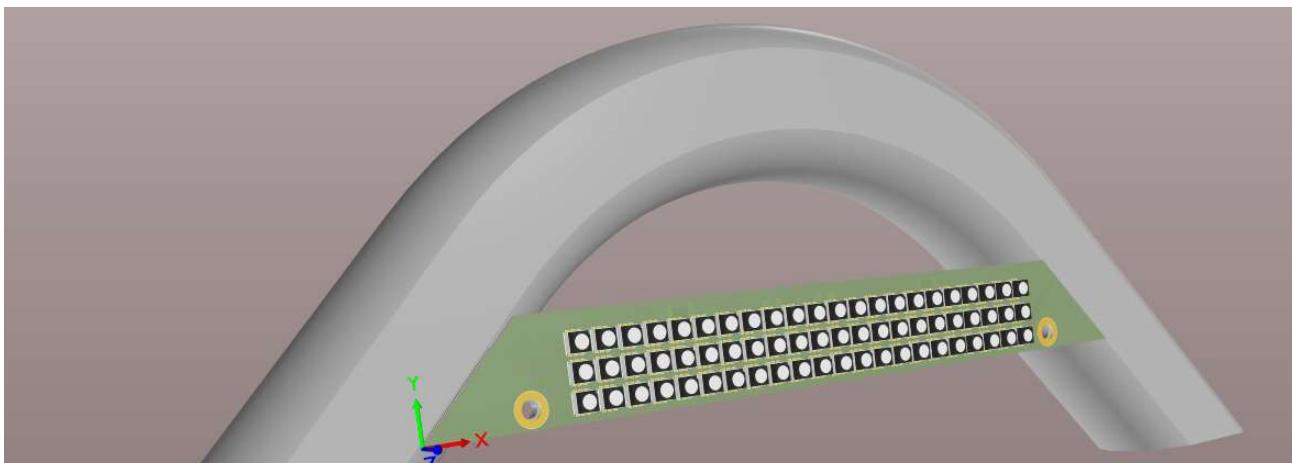


Figure 17: TSAL position.

2.8 Measurement points

2.8.1 Description

High voltage measurement points (HVMP) are placed in the Service box. When not in use, they are covered with protective cups made from silicone rubber. From backside they are protected by sealed Service box all the time.

2.8.2 Wiring, connectors, cables

They are connected to ECUB (by Harness_G with connector G1). In ECUB is TSAL switch circuit and discharge circuit is in ECUM (ECUM is connected to ECUB by Harness_E connectors are E1 from ECUB and E2 into ECUM Rear). HVMP wires will be connected to the board in ECUB box, where is TSAL switch circuit, discharge circuit and 2 resistors 15k 1W (R1, R2) for HVMP. Value of this resistor can be measured from measuring points by multimeter with switched TSMS off.

2.8.3 Position in car

Measure points are placed on panel next to Master switches and HVD, see Figure 7: Inertia switch, SDB Left, Right and Cockpit, TSMS, GLVMS, HVD, Measure points.

2.9 Pre-Charge circuitry

2.9.1 Description

Pre-charge circuit is controlled by ECUA. (Isolation on PCB is referred from 8.3 Electronic control unit acp (ECUA)) Our pre-charge is assembled from 3 resistors. 2 of them have the same value 470R, the third is mainly part of safety precaution and has value 2k2. There is always a chance that the resistor fails, in that case the remaining resistors may be used as fully functional pre-charge, only slower.

TS ON button sets whole car in state pre-charging. ECUA starts pre-charge process. It takes safety precautions and then relay and AIR are switched to close pre-charging current. Fully closed SDC and ECUA decision are needed to start pre-charging. If every point is fulfilled and pre-charge is successfully finished, second AIR closes. Pre-charge relay opens and car leaves pre-charge state. (Pre-charge relay is normally open type.)

Pre-charge safety on ECUA

Except from what rules require we implemented several safety precautions. In case, that SDC error doesn't occur and driver pushed TS ON button following safety precautions are taken to prevent switching AIR in case of problem that has not yet been detected.

First one is completely non-programmable protection against switching voltage difference by AIR. It uses voltage measurement and then comparators and logic to disable microcontroller decision in case of SW error. Second one is measuring all states and voltages by microcontroller on ECUA which can determinate error before non-programmable protection would have to act.

Third (time-out) protection is used when everything seems to be OK, but the charging is too slow caused by too high pre-charge resistance (any of pre-charge resistors fails), or some leakage of charge in capacitor or any other possible error occurs. If voltage difference is not equaled in time less than 2 seconds, the ECUA stops pre-charge and waits 5 seconds before trying again. (In order to not overpower resistors.) If number of attempts to pre-charge is in this state higher than 8, something is clearly wrong and ECUA opens SDC and indicates error. Sending message about error and sets car into not-ready state.

2.9.2 Wiring, cables, current calculations, connectors

Describe wiring, show schematics, describe connectors and cables used and show useful data regarding the wiring.

- Give a plot Percentage of Maximum Voltage vs. time
- Give a plot Current vs. time
- For each plot, give the basic formula describing the plots

Additionally, fill out the tables:

Table 8: General data of the pre-charge resistor

Resistor Type:	
Resistance:	
Continuous power rating:	
Overload power rating (1 sec):	
Overload power rating (5 sec):	
Overload power rating (15 sec):	
Voltage rating:	
Cross-sectional area of the wire used:	

Table 9: General data of the pre-charge relay

Relay Type:	
Contact arrangement:	
Continuous DC current:	
Voltage rating	
Nominal Coil Voltage:	
FET type:	
Maximum Drain-Source Current:	
Drain-Source Breakdown Voltage:	
On Characteristics Gate Threshold Voltage:	
Cross-sectional area of the wire used:	

2.9.3 Position in car

Provide CAD-renderings showing all relevant parts. Mark the parts in the rendering, if necessary.

2.10 Discharge circuitry

2.10.1 Description

Discharge circuit's purpose is to discharge capacities connected to TS voltage and ensure TS safety in shutdown state. Such capacities are only in two MCs. Discharge is activated whenever shut down circuit (SDC) is open. (That means, accupack (ACP) is disconnected from TS by AIRs) This behavior is controlled by electronic control unit - back (ECU-B), which monitors latching of SDC. It's state is distributed through CAN to other units. When SDC opens, ECU-B sends message to MCs, which then closes relays and connects discharge resistors to capacitor bank charged on TS voltage. When AIRs are closed, ECU-B sends message to MC to open discharge circuit.

2.10.2 Wiring, cables, current calculations, connectors

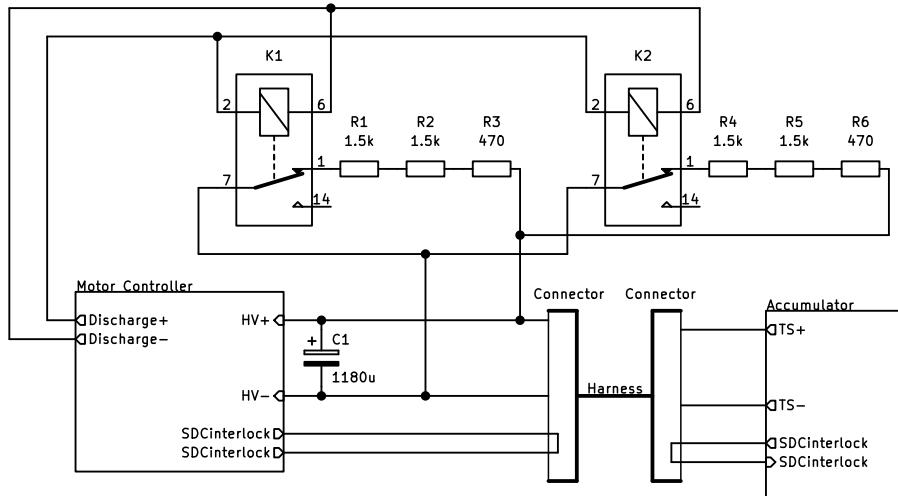


Figure 18: Discharge circuit of one MC.

Figure 18: Discharge circuit of one MC shows a simplified discharge circuitry. Discharge resistors are placed in MCs right next to the only capacity that provides a storage for potentially dangerous charge/energy in TS. If high voltage (HV) cable is disconnected on either side, the SDC opens due to the interlocks and both AIRs open. Because there is no output capacitance in ACP there is no way the power could be on ACP output HV connector.

Capacity sum of all capacitors in MCs is 2360 μF . For discharging this capacity in less than 5 seconds to voltage (below 60V), maximum resistor value is calculated by solving R from Equation 1: Wiring, cables, current calculations, connectors.

$$V_c = V_s * e^{(\frac{-t}{R*C})} \quad (1)$$

Values

- $V_c = 60\text{V}$ (safe voltage limit)
- $V_s = 403.2\text{V}$ (TS voltage)
- $t = 5\text{s}$ (maximum discharge time)
- $C = 2360\mu\text{F}$ (total capacity in TS)

Maximum resistance from Equation 1: Wiring, cables, current calculations, connectors, $R = 1112\Omega$ is for discharging all capacitors in TS. In our case, capacity is split between two MCs. Two parallel resistor combinations of three $1\text{k}\Omega$ resistors in series (3s2p) in each MC is used (3s4p in total). $1\text{k}\Omega$ resistors are PWR221T-30-1001F. Total value of Discharge resistor bank is $R = 750\Omega$, which is less than maximal calculated

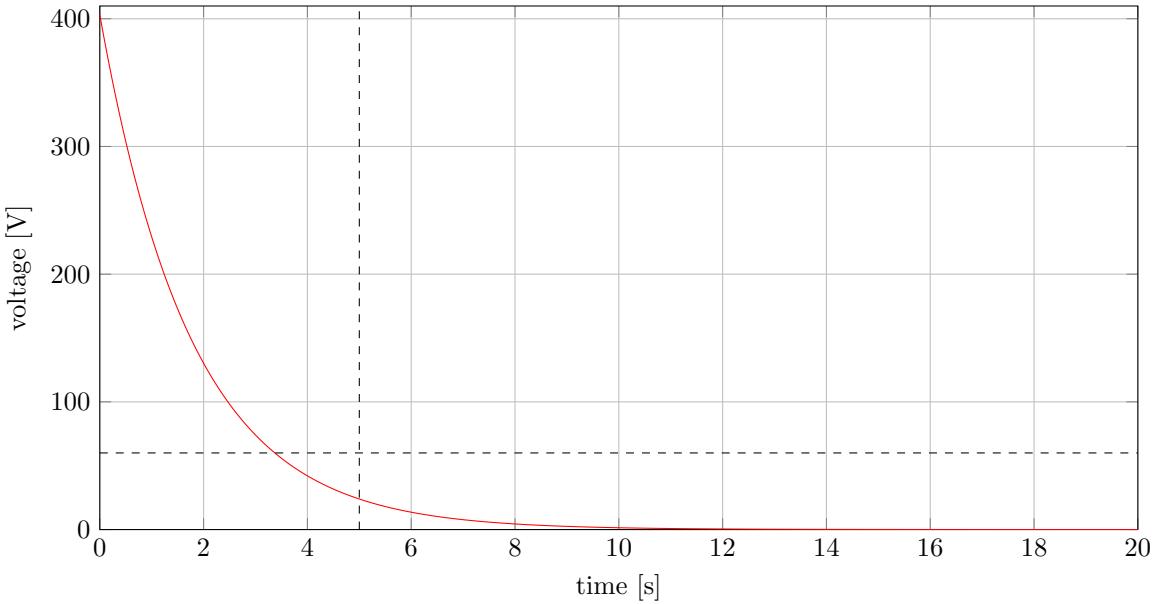


Figure 19: TS voltage during discharge. (AIRs open)

$R = 1112\Omega$. The 60V threshold with such configuration is reached in 3.37s. Figure 19: TS voltage during discharge. (AIRs open) shows TS voltage in time during discharging.

The formula describing Figure 20: Discharge current through resistor bank vs. time is:

$$I_d = \frac{V_c}{R_d} \quad (2)$$

$$I_d = \frac{V_s * e^{(\frac{-t}{R*C})}}{R_d} \quad (3)$$

Where V_s is voltage on TS, R_d is total value of discharge resistor bank and I_d is discharge current. Current through individual 3s resistor combinations can be calculated as $I_d/4$.

Peak power on individual resistors is 18W and resistor can handle up to 30W, see subsection A.6: Discharge resistors datasheet.

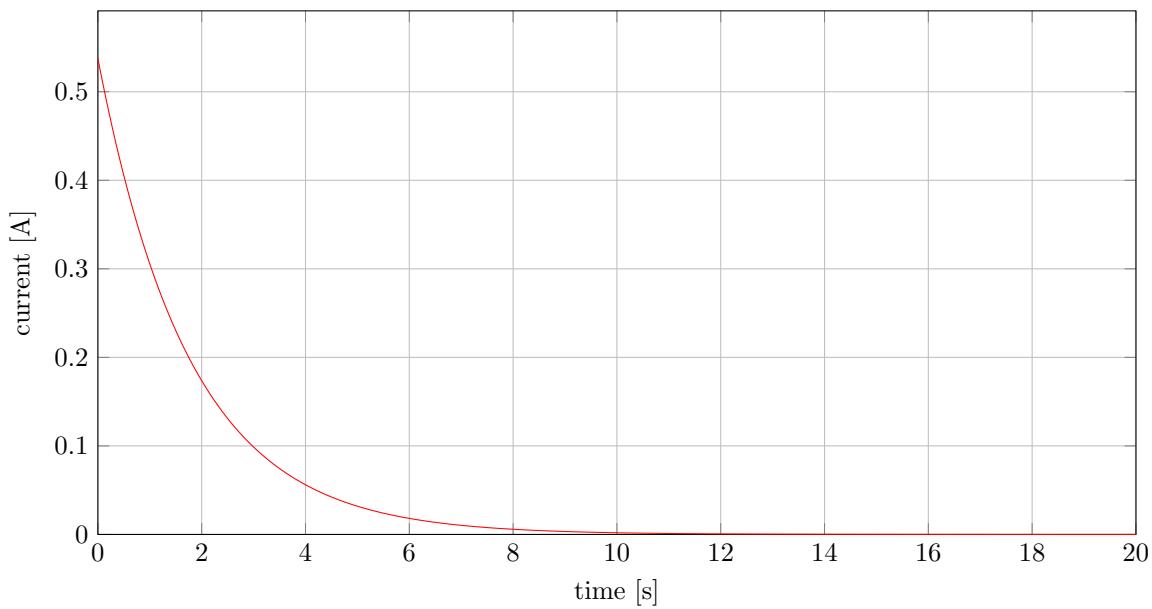


Figure 20: Discharge current through resistor bank vs. time

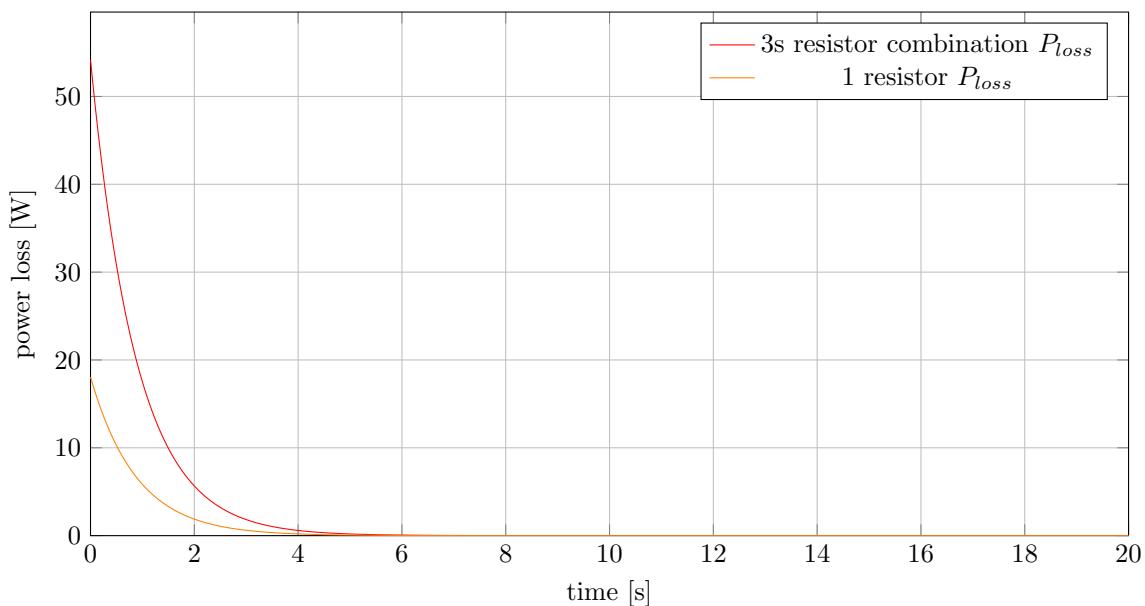


Figure 21: Discharge power loss on 3s resistor combination and individual resistors vs. time

Table 10: General data of the discharge circuit

Resistor Type:	PWR221T-30-1001F in 3s4p configuration
Resistance:	$1k\Omega$
Continuous power rating:	30W
Overload power rating (1 sec):	not specified
Overload power rating (5 sec):	not specified
Overload power rating (15 sec):	not specified
Voltage rating:	250V (3 in series: 750V)
Maximum expected current:	0.1A per resistor, (3s4p configuration with total 0.4A current)
Average current:	0.04A on resistor(taking account 4 seconds of discharging)
Cross-sectional area of the wire used:	$0.129mm^2$

Table 11: General data of the dis-charge relay

Relay Type:	TE PE014012
Contact arrangement:	1 pole, normally closed
Continuous DC current:	5A
Voltage rating	$250V_{ac}/30V_{dc}$ ¹
Nominal Coil Voltage: 12V	
Cross-sectional area of the wire used:	$0.129mm^2$

2.10.3 Position in car

Discharge resistors are mounted on aluminum cooler also with IGBT modules in MC boxes.

2.11 HV Disconnect (HVD)

2.11.1 Description

A circular connector ASHD 0 24-44420 S N + ASHD 6 24-44420 P N is used as HVD. By disconnecting HVD positive and negative pole of Tractive System is quickly disconnected. Disconnection is done by turning the plug left, this motion is clearly hinted by a label. By turning left the lever system in connector disconnect pins and release plug. There are sockets used in the receptacle rather than pins, therefore no harm can be done to crew by touching the receptacle.

Interlock is achieved by using ASHD 0 24-44420 S N - 016 as a receptacle and ASHD 6 24-44420 P N - 016 as plug. This connector has several other low current pins size AWG 22. Two of them are used as interlock, there is only shunt loop at the plug.

Datasheet is to be seen in Figure 48: HVD interlock datasheet.

2.11.2 Wiring, cables, current calculations, connectors

HVD is placed between Accumulator Pack and Motor Controllers, Energy Meter is also placed after Motor Controller in the circuit. Positive pole of Tractive system is interrupted. There are four pins connected to each other in the plug and the back of the plug is sealed. OLFLEX HEAT 180 SiF are used as HV wires, four pins are used. One HV pin is rated to 200A.

2.11.3 Position in car

HVD is placed on panel next to Maser switches and Measure points, see Figure 22: HVD position.

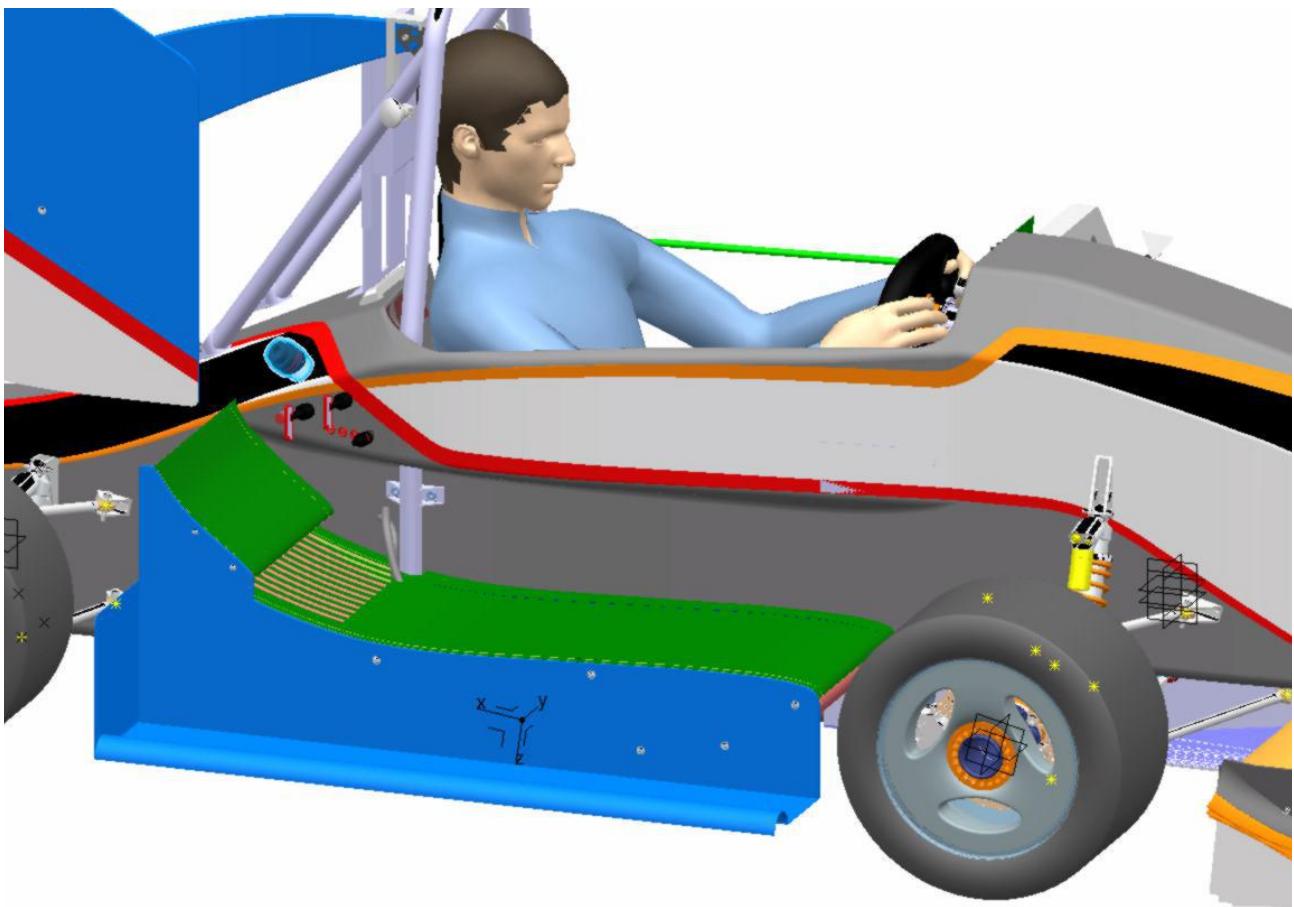


Figure 22: HVD position.

2.12 Ready-To-Drive-Sound (RTDS)

2.12.1 Description

We use piezo siren AE20M. The siren makes sound when ECUB recognize ready-to-drive state of car, it receives message from ECUF about TS ON button and SDC is in non-error state, if message would be lost ECUB doesn't send confirmation status and ECUF does not allow to activate ready to drive status. Sound pressure level of this siren is more than 90 dB(A) at 1 m, Output frequency is from 2,9 kHz. Controlling of RTDS is done by ECUB by transistor. RTDS beeps 2 seconds.



Figure 23: RTDS.

2.12.2 Wiring, cables, current calculations, connectors

There are only two wires from ECUB to RTDS piezo siren, one switched by transistor and the second is ground (block connections is on Figure 24: RTDS wiring).



Figure 24: RTDS wiring.

2.12.3 Position in car

Ready to drive sound is placed on the top of Accumulator Pack next to the Motor Controller, see Figure 25: RTDS position.

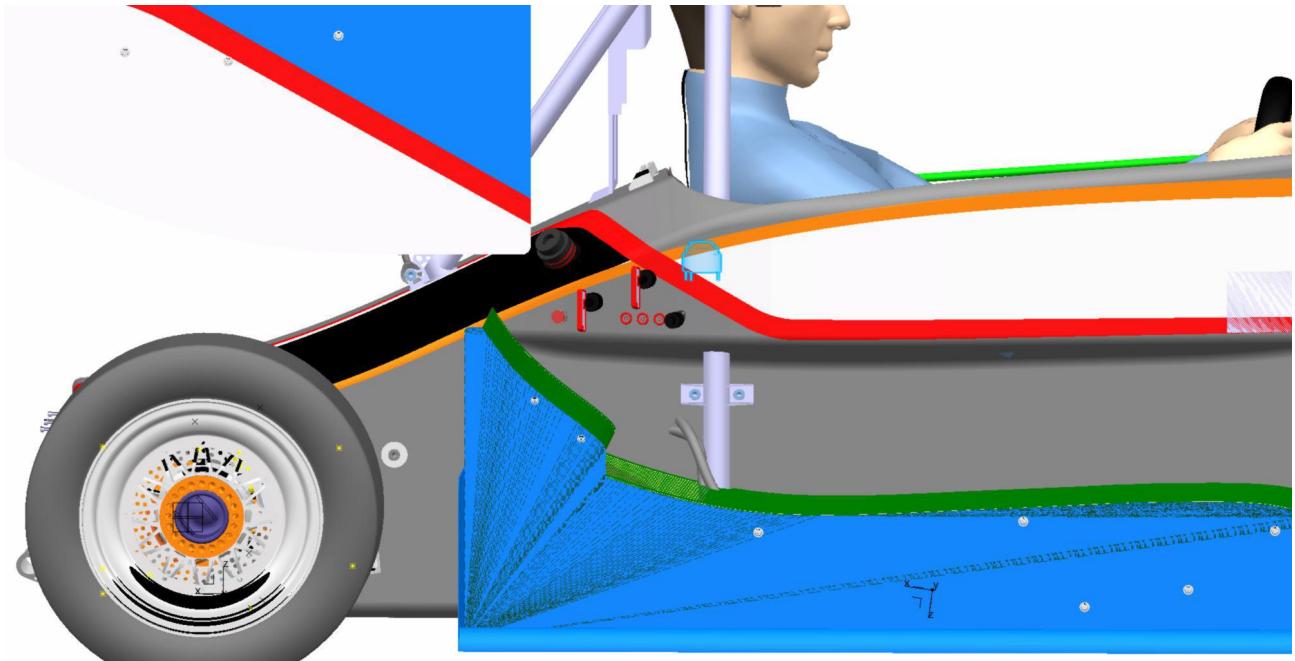


Figure 25: RTDS position.

3 Accumulator

3.1 HV Accumulator pack

3.1.1 Overview / description/parameters

Describe concept of accumulator pack, provide table with main parameters like number of cells, cell stacks separated by maintenance plugs, cell configuration, resulting voltages-; minimum, maximum, nominal, currents, capacity etc. Fill out the following table:

Table 12: Main accumulator parameters

Maximum Voltage:	400 VDC
Nominal Voltage:	345.6 VDC
Minimum Voltage:	182 VDC
Maximum output current:	315 A (until any cell reaches 80 °C)
Maximum nominal current:	270 A
Maximum charging current:	54 A
Total numbers of cells:	864
Cell configuration:	96s9p
Total Capacity:	27.99 MJ
Number of cell stacks ; 120VDC	6

3.1.2 Cell description

Describe the cell type used and the chemistry, provide table with main parameters. Fill out the following table:

Table 13: Main cell specification

Cell Manufacturer and Type	SONY VTC5A
Cell nominal capacity:	2.5 Ah
Maximum Voltage:	4.25 V
Nominal Voltage:	3.6 V
Minimum Voltage:	2 V
Maximum output current:	35 A (until cell reaches 80 °C) (14C)
Maximum nominal output current:	30A(12C)
Maximum charging current:	6A(2.4C)
Maximum Cell Temperature (discharging)	80 °C
Maximum Cell Temperature (charging)	60 °C
Cell chemistry:	Lithium-Ion

3.1.3 Cell configuration

Cell configuration is 96s9p. Cells are divided into 6 stacks, configuration of each stack is 16s9p. Cells are connected by welding. Main cells interconnection is done by nickel sheet. This sheet is welded to each cell. There is additional copper sheet welded over the nickel sheet (for lowering resistance of the main current path).

3.1.4 Cell temperature monitoring

The cells temperature is monitored by NTC temperature sensors. The manufacturer is TDK, type is: B57330V2103F260. Insulation of the sensors is done by 3M PTFE Film Electrical Tape. Breakdown voltage of this tape 9.5 kV, operating temperature is 180 °C. Thickness of this tape is 0.1 mm. Sensors are soldered in PCBs that are covered with insulating tape and then mounted to each stack.

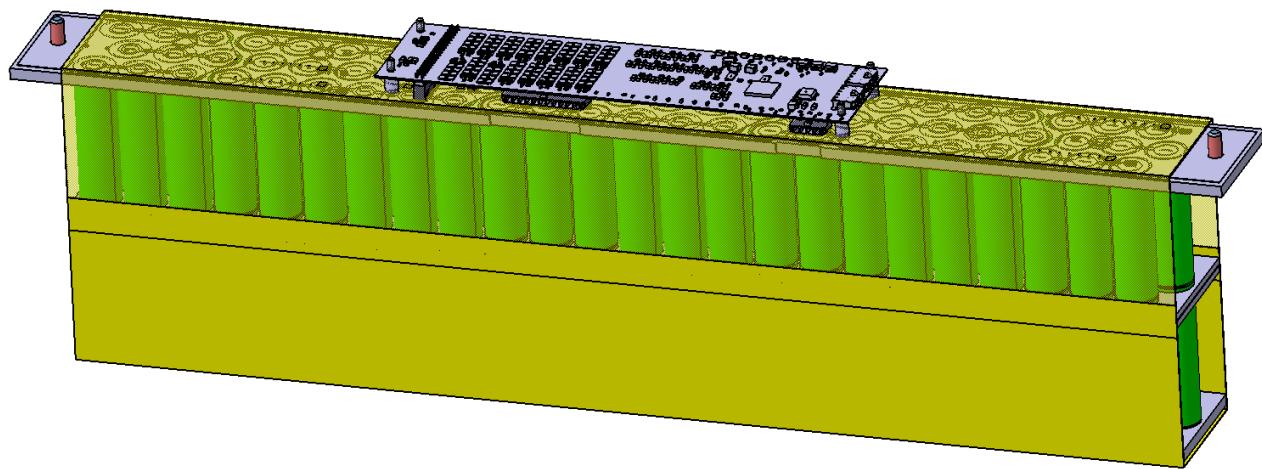


Figure 26: Stack configuration.

Position of temperature sensors on the top of each stack (highlighted objects)



Figure 27: Top position of sensors.

Position of temperature sensors on the bottom of each stack (highlighted objects)



Figure 28: Bottom position of sensors.

Top and bottom view of one stack

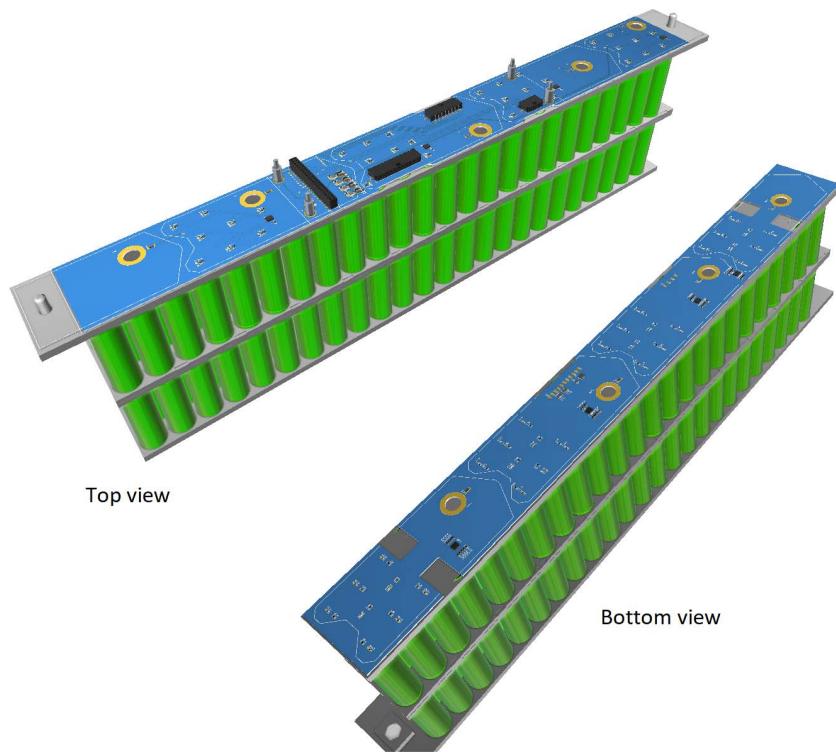


Figure 29: Rear and bottom view.

Table 14: General cell temperature parameters.

Temperature sensor accuracy:	1%
Total number of cells:	864
Total number of sensors:	384
Max. distance from monitored negative cell terminal:	2 mm
AMS opens AIRs during dis-charging if cell temperature is above:	60°C
AMS opens AIRs during charging if cell temperature is above:	60°C

3.1.5 Accumulator Management System

Describe the AMS used including at least the following:

Table 15: Cell voltage limits.

Minimum cell voltage (shutdown limit):	2.2 V
Maximum cell voltage (shutdown limit):	4.2 V
Measurement precision (mV):	± 0.75

Each sense connection is protected with fuse. There are two types of fuses used:

Littelfuse 0251001.MXL (Those are used, where the cells are contacted via PCB)

Eaton TR/3216LV1-R (Those are used, where measure wires are connected directly to cells)

Cell highest allowed voltage is 4.25 V so AMS reacts when the voltage is above 4.2 V. Cell lowest allowed voltage is 2 V so AMS reacts when the voltage is below 2.2 V. Reaching any of limits causes AIRs disconnection.

Highest allowed temperature (by datasheet) for discharging is 80 °C and for charging 60 °C. Due to FSE rules our battery pack is limited to 60 °C. AMS reacts when the temperature is higher than 60 °C reaching limit causes AIRs disconnection.

Recommended Operating Conditions

TA = 25C and TOP = 57.6 V; Min/Max values stated where TA = 40C to 105C and TOP = 12 V to 79.2 V (unless otherwise noted)

			MIN	NOM	MAX	UNIT
V _{TOP}	Supply voltage	TOP – GND (VSENSE16 = TOP)	12		79.2	V
V _{IO}	Digital interface voltage		2.7		5.5	V
V _{TOP_DELTA}	Max delta, TOP to highest cell ^{[1][2]}	VSENSE16 – TOP		0	300	mV
I _{IO}	Output current, any one pin	GPIO0, GPIO1, GPIO2, GPIO3, GPIO4, GPIO5, TX, FAULT_N			5	mA
I _{IO_T}	Output current, sum of	GPIO0 + GPIO1 + GPIO2 + GPIO3 + GPIO4 + GPIO5 + TX + FAULT_N			20	mA

Figure 30: Recommended operating parameters.

Each AMS board senses whole stack, that means it senses 144 cells, connected in 16s9p configuration. Comms wirings are protected by two 1kV 1nF capacitors CC1206KKX7RCBB102 by Yageo. There is placed one on each side (there is one on every AMS). The AMS is connected to Accumulator ECU that has capability of direct AIRs shutdown. The galvanic isolation between TS and GLV is done by two 1kV 1nF capacitors CC1206KKX7RCBB102 by Yageo. It is located on separated board connected between first AMS and Accumulator ECU.

3.1.6 Accumulator indicator

Describe the indicator, show wiring, provide tables with operation, PCB design, etc

3.1.7 Wiring, cables, current calculations, connectors

Describe the internal wiring, show schematics, provide calculations for currents and voltages and show data regarding the cables and connectors used.

- Discuss maximum expected current, DC and AC how long will this be provided?
- Compare the maximum values to nominal currents

- Give a table for each kind of wire in your tractive-system:
- Describe your maintenance plugs, provide pictures
- Use tables like the one shown below:

Table 16: Wire data of company A, 0.205 mm².

Wire type	
Continuous current rating:	
Cross-sectional area	
Maximum operating voltage:	
Temperature rating:	
Wire connects the following components:	

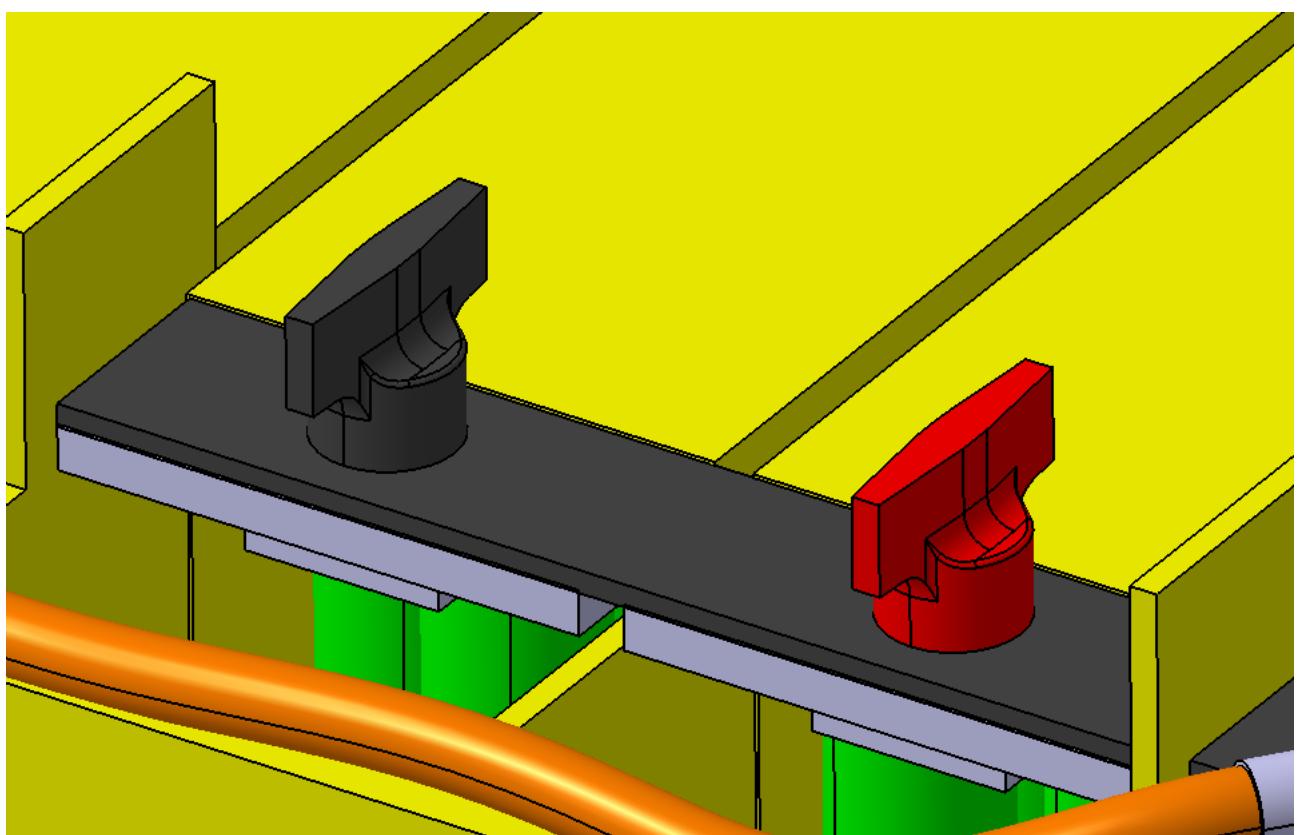


Figure 31: Maintenance plugs I.



Figure 32: Maintenance plugs II.

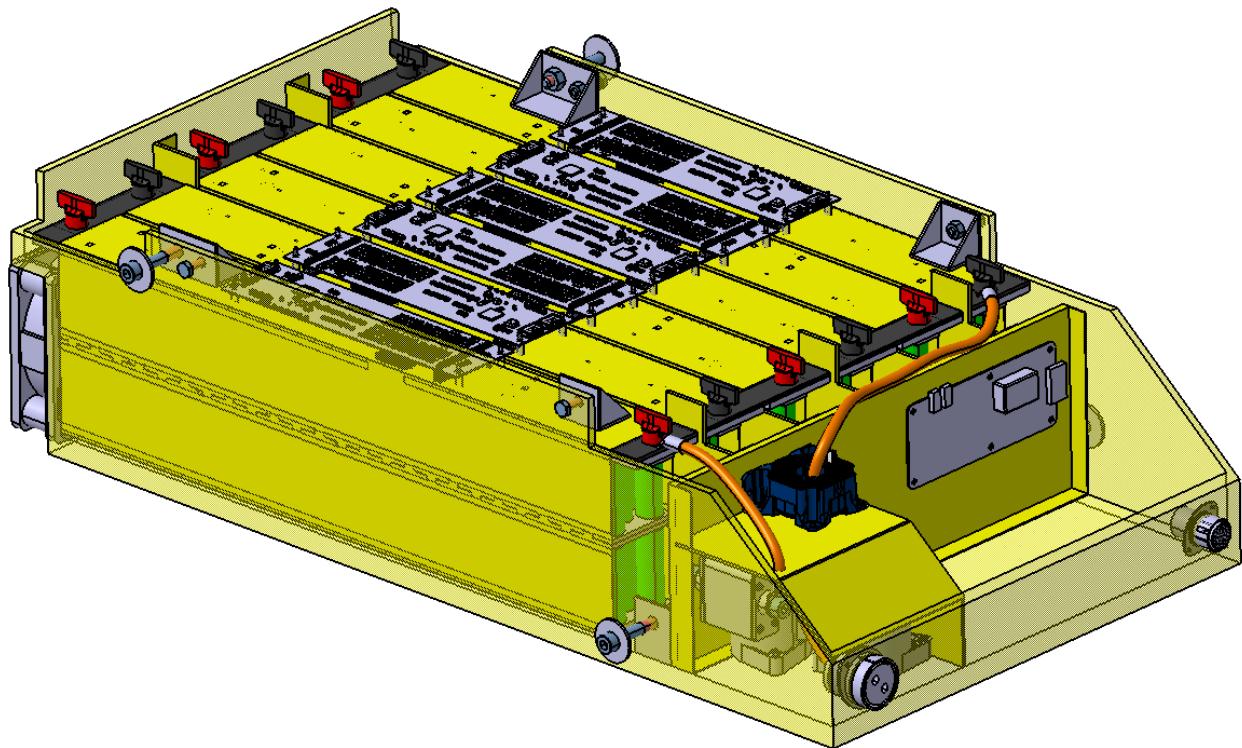


Figure 33: Accumulator pack HV wiring I.

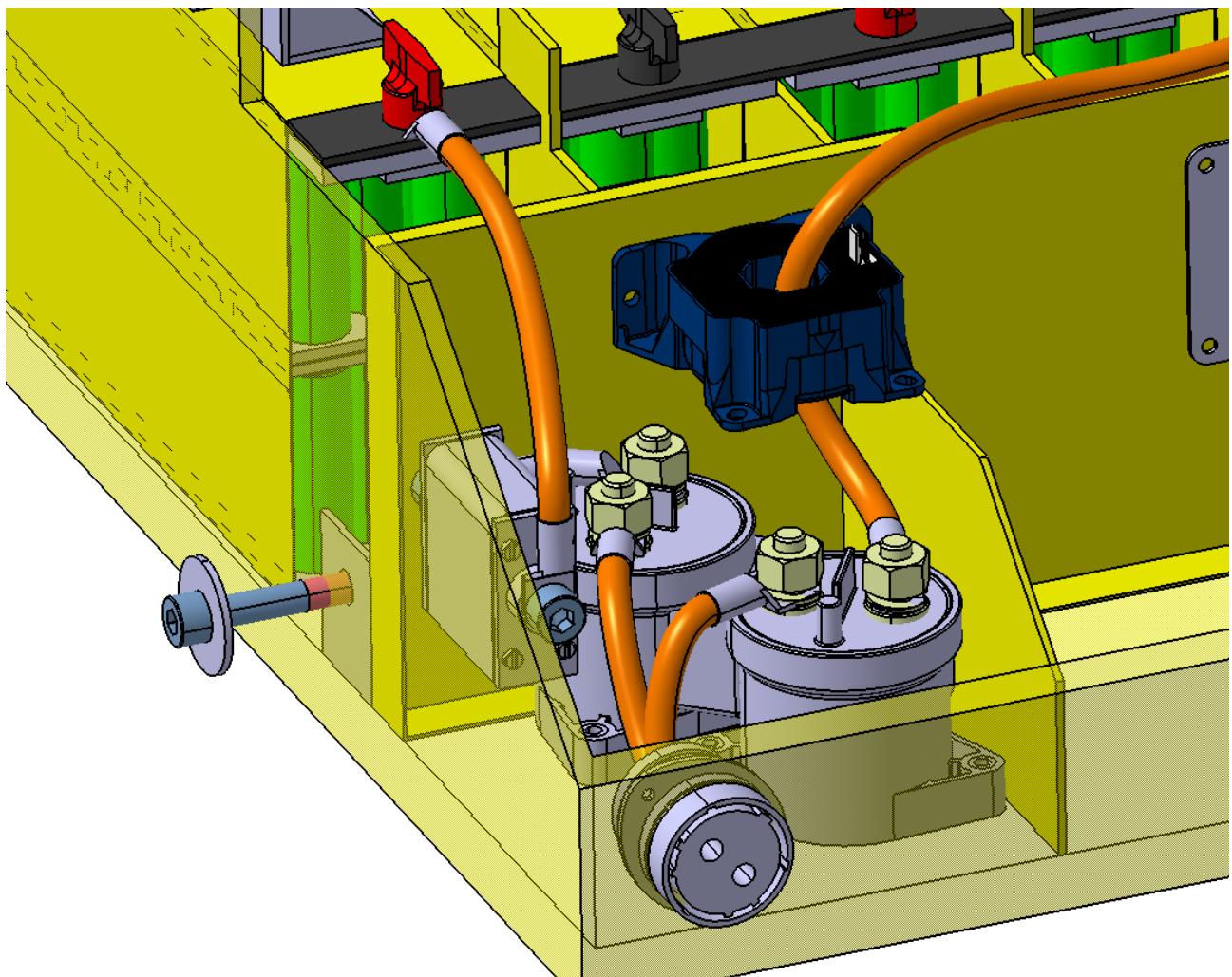


Figure 34: Accumulator pack HV wiring II.

3.1.8 Accumualtor insulation relays

Describe the AIRs used and their main operation parameters, use tables, etc. Additionally, fill out the following table:

Table 17: Basic AIR data.

Relay Type:	
Contact arrangement:	
Continuous DC current rating:	
Overload DC current rating:	
Maximum operation voltage:	
Nominal coil voltage:	
Normal Load switching:	
Maximum Load switching	

3.1.9 Fusing

Describe the fuses used and their main operation parameters, use tables, etc. Additionally, fill out the following table for each fuse type used:

Table 18: Basic fuse data

Fuse manufacturer and type:	
Continuous current rating:	
Maximum operating voltage	
Type of fuse:	
I _{2t} rating:	
Interrupt Current (maximum current at which the fuse can interrupt the current)	

Create a table with components and wires protected by the fuse(s) and the according continuous current rating, below is an example table with some potential entries. Complete this table with information for your design and add/remove additional locations as applicable. Ensure that the rating of all the components is greater than the rating of the fuse such that none of the other components become the fuse.

Table 19: Fuse Protection Table

Location	Wire Size	Wire Ampacity	Fuse type	Fuse rating
Cells to AIRs	2 AWG	XXX	MNO Fuse	XXX
AIR to Motor controller	0 AWG	XXX	2x MNO Fuse	XXX
AIR to TSAL	20 AWG	XXX	EFG Fuse	XXX
Accumulator output connector	2 AWG	XXX		
Cells to AMS				

3.1.10 Charging

Describe how the accumulator will be charged. How will the charger be connected? How will the accumulator be supervised during charging? Show schematics, CAD-Renderings, etc., if needed Additionally, fill out the table:

Table 20: General charger data

Charger Type:	
Maximum charging power:	
Maximum charging voltage:	
Maximum charging current:	
Interface with accumulator	
Input voltage:	
Input current:	

3.1.11 Mechanical Configuration/materials

The whole mechanical structure of the case is made from sandwich structure, kevlar fiber and core, designed to be alternative structure. Basically the case is divided to main box, which is outer walls and floor, five longitudinal walls and one transverse wall divided this space on chambers for six stacks and space in front is used for additional technology (ECU, IMD, AIRs, Fuse, Current sensors, connectors etc.). AIR-Box is constructed of FR4 walls. The last komponent is lid, which is also the stacks holder, you can see in the picture.

Detailed stack composition is shown below in Figure 35: Mechanical fastening of ACP. Cells are built in a support structure on each side and middle one. There are connecting plates made from welder of Ni201 alloy plate and copper CU99,99% plate and spot-welded to respective cells. The entire stack is covered with an kevlar case. Each pole of a stack is ended by a copper terminal on the top of the stack. There are also vents hole at the cover and rear outer wall at main wall and also on both sides of stack, cells are cooled by air flowing among them. BMS board is placed on the top of each stack.

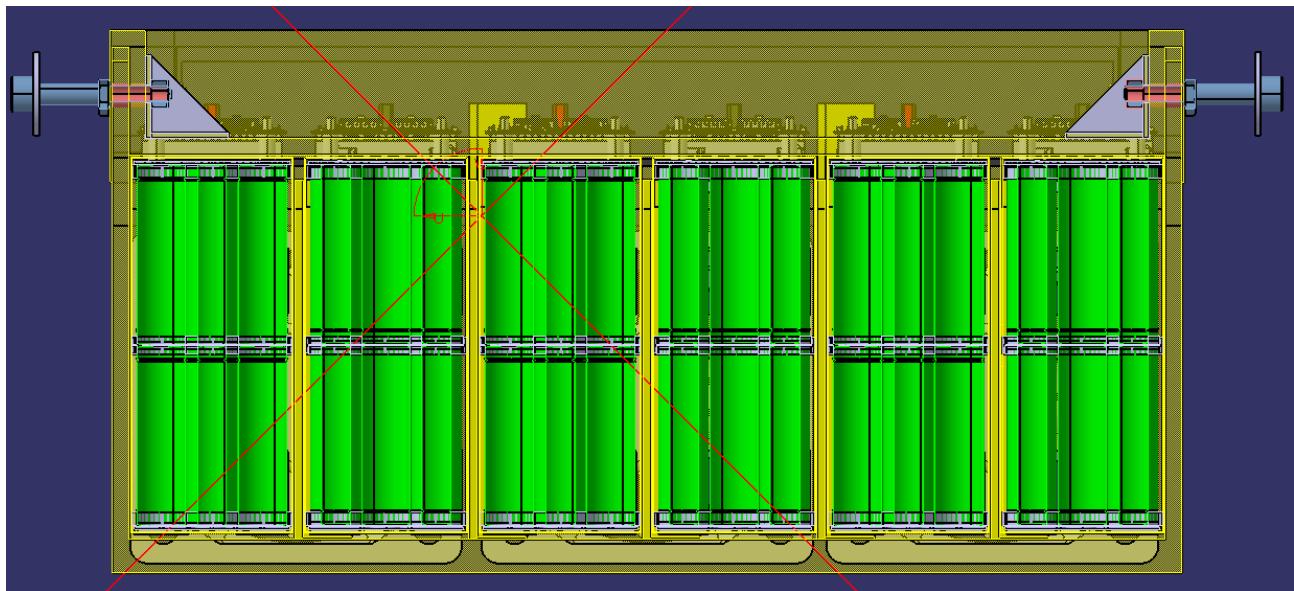


Figure 35: Mechanical fastening of ACP.

3.1.12 Position in car

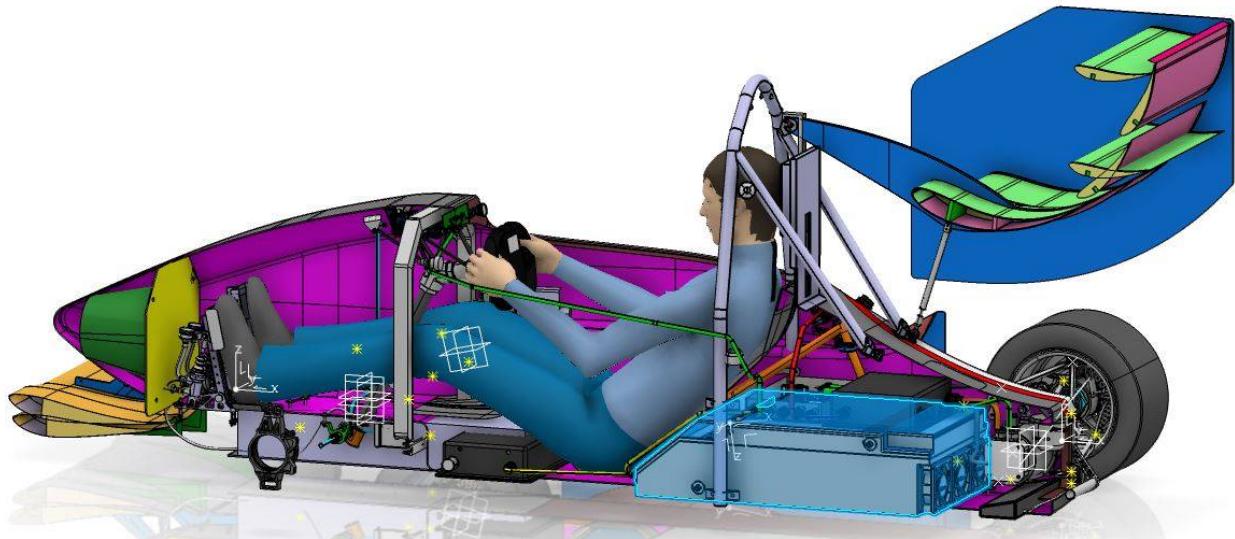


Figure 36: Position of ACP in car.

3.2 GLVS Accmulator

3.2.1 Description

Describe your concept of the GLVS Accumulator.

3.2.2 Wiring, cables, current calculations, connectors

Describe wiring, show schematics, describe connectors and cables and show useful data regarding the wiring. Include information on the working voltage and current rating of the accumulator.

Table 21: GLVS accumualtor general parameters.

Cell/Accumulator:	Li-ion
Accumulator configuration parallel:	1
Accumulator configuration series:	6
Maximum Voltage:	25.5 V
Nominal Voltage:	21.6V
Minimum Voltage:	12V
Max. Continuous Discharge Current:	
Peak Discharge Current:	
Peak Discharge Current Time:	
Max. Continuous Charge Current	
Total capacity[MJ]:	

3.2.3 Position in car

Provide CAD-renderings showing all relevant parts. Mark the parts in the rendering, if necessary.

4 Energy meter mounting

4.1 Description

Describe where the energy meter is mounted and how, etc.

4.2 Wiring, cables, current calculations, connectors

Describe the wiring, show schematics, provide calculations for currents and voltages, and show data regarding the cables and connectors used.

4.3 Position in car

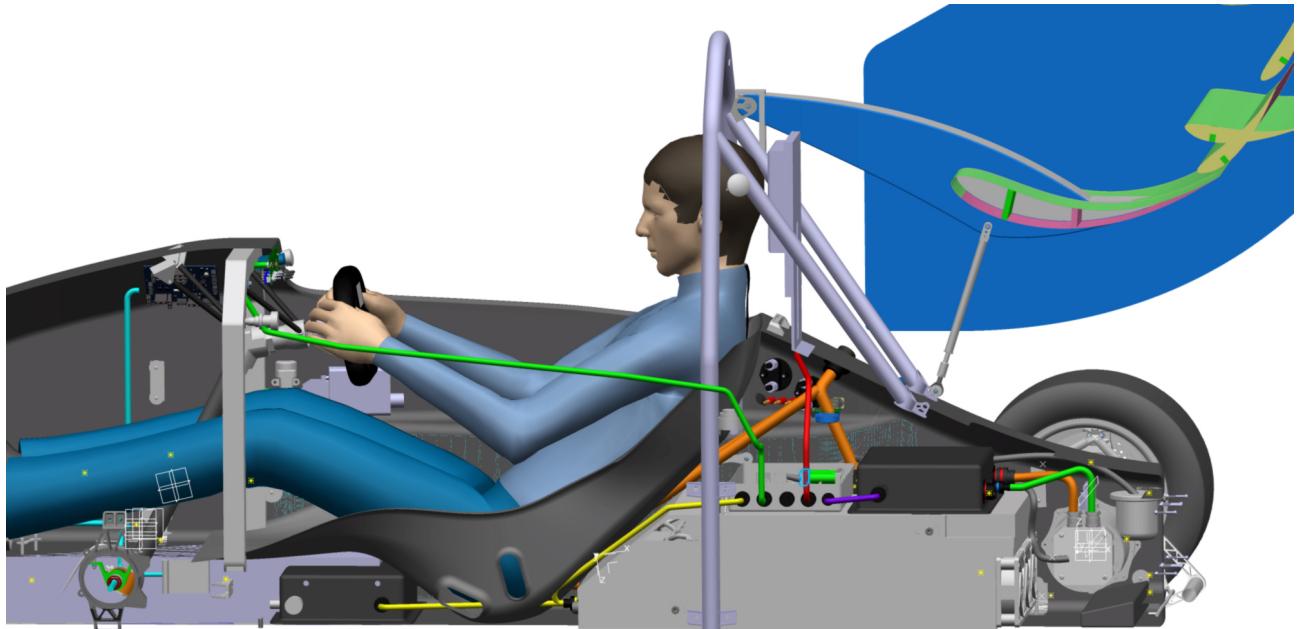


Figure 37: Service box position.

5 Motor Controller

5.1 Motor Controller 1

5.1.1 Description, type, operation parameters

Motor controller is a prototype of MiRy X-Boss Motor Controller. It is fully self-designed for driving 2 PMSM motors simultaneously with Resolver sensors as a position feedback. Field Oriented Control is implemented with galvanic isolated current sensors LEM HTFS 200-P.

Galvanic isolation on PCB is shown in Figure 50: Motor controller TOP and Figure 51: Motor controller BOTTOM. The only place where isolation is smaller than required 4mm is between pins of DC/DC NME1215SC. Real space gap is 1.54mm. The NME1215SC has rated voltage of 1kV. See Figure 49: NME1215SC isolation.

Motor Controller communicate with traction control unit by private CAN bus. If any error occurs in their communication Motor Controller stops driving both motors (error mode). It also implements discharge circuit which is activated by CAN or in case of Auxiliary supply disconnection (resistors are driven by normally-closed relay).

A current limit is set to not overload used motors. For each motor controller different. Rear motor controller has set peak current limit to 202A and temperature limit to 120C. Front Motor Controllers current limit is 70A and temperature limit also 120°C.

Table 22: General motor controller data

Motor controller type:	MiRy X-Boss
Maximum continuous power:	2 x 90kW (in:400V, out:200A)
Maximum peak power:	2 x 146kW for 5s (in:400V, out:300A)
Maximum Input voltage:	410VDC
Output voltage:	282 VAC
Maximum continuous output current:	2 x 200A
Maximum peak current:	2 x 300A for 5s
Control method:	CAN
Cooling method:	Water
Auxiliary supply voltage:	24VDC

5.1.2 Wiring, cables, current calculations, connectors

Motor controllers are connected with HVD box by high voltage cable. High current connector ASHD 0 22-24320 P N by Deutsch is used.

Table 23: Wire data of OLFLEX HEAT 180

Wire type:	OLFLEX HEAT 180 SiF
Current rating:	165A
Fuse current rating:	160A
Maximum operating voltage:	500V
Temperature rating:	180 C

5.1.3 Position in car

The position of both motor controllers is shown in Figure 38: MC position.

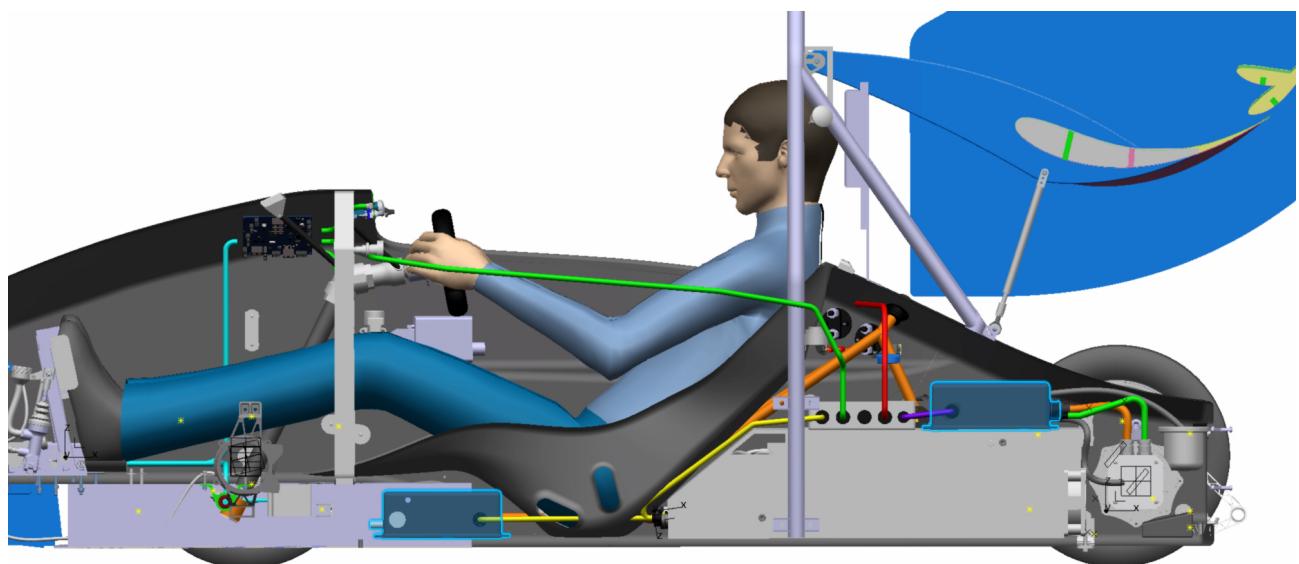


Figure 38: MC position.

5.2 Motor Controller 2

Motor controller 2 is identical as Motor controller 1.

6 Motors

6.1 Motor 1

6.1.1 Description, type, operation parameters

We are using prototype motors from company TG Drives. They developed prototype motors with special parameters and water cooling. We are using two motors on rear axle (motor 1) and two motors on front axle.

Table 24: General motor 1 data

Motor Manufacturer and Type:	TG Drives N5-1600-100-380a-h-special-v2
Motor principle	PMSM
Maximum continuous power:	11.5 kW
Peak power:	35 kW
Input voltage:	260 VAC
Nominal current:	38.2 A
Peak current:	171 A
Maximum torque:	48 Nm
Nominal torque:	11 Nm
Cooling method:	Water

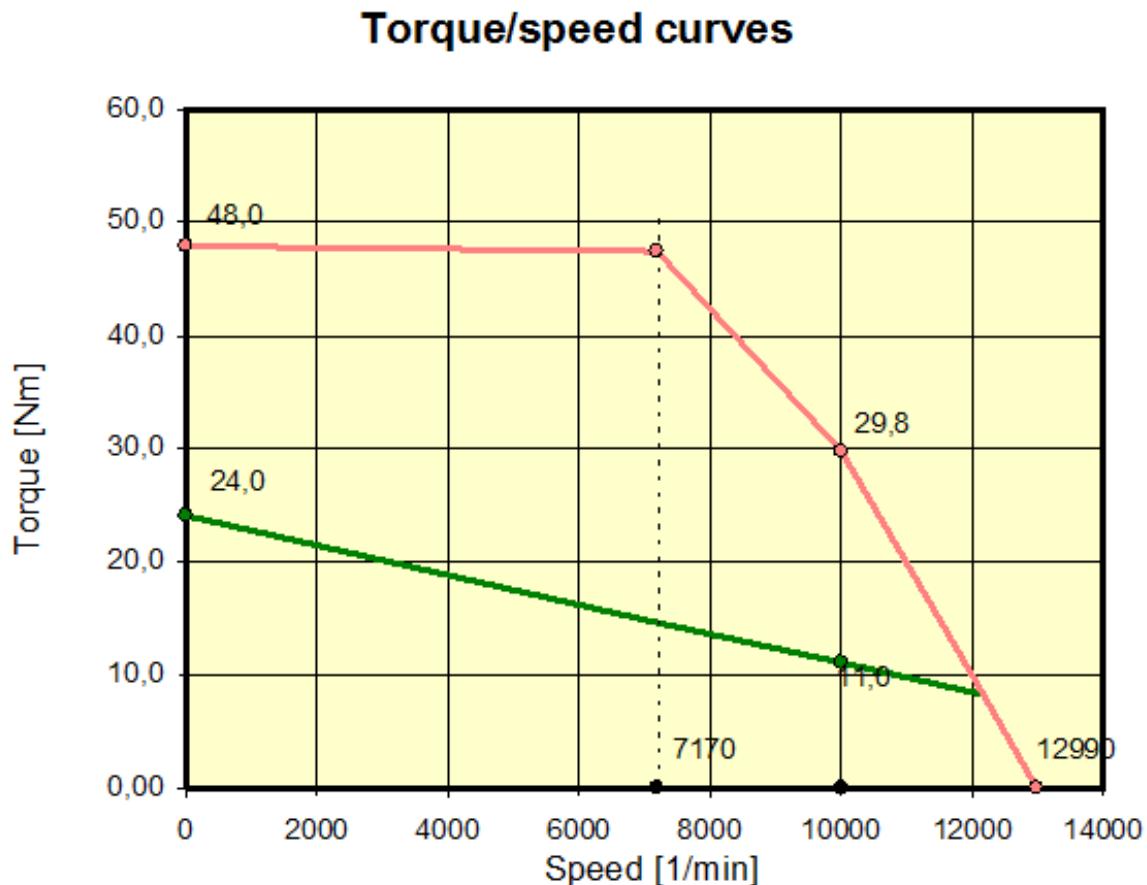


Figure 39: Rear motor characteristics.

6.1.2 Wiring, cables, current calculations, connectors

We use Raychem TR 16-10-0 and TR 16-6-0. There are leadthrough used for cables in motors and connectors Souriau 8STA 0 18 18 are used in Motor controllers.

6.1.3 Position in car

Rear motors are situated in the rear-most part of the frame.

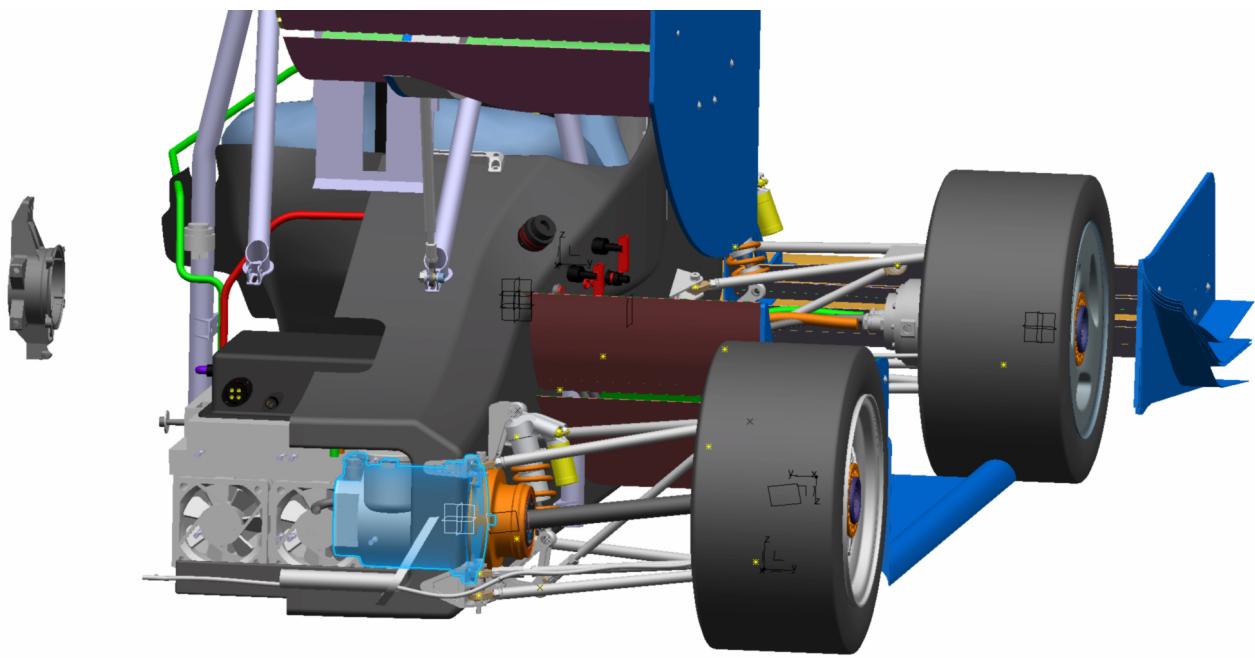


Figure 40: Rear motor position.

6.2 Motor 2

Table 25: General motor 2 data

Motor Manufacturer and Type:	TG Drives M4-0470-90-380a-h-special-water-cooling-lfe-60mm
Motor principle:	PMSM
Maximum continuous power:	4.2 kW
Peak power:	8.2 kW
Input voltage:	260VAC
Nominal current:	12.2 A
Peak current:	67 A
Maximum torque:	16.2 Nm
Nominal torque:	4.4 Nm
Cooling method:	Water

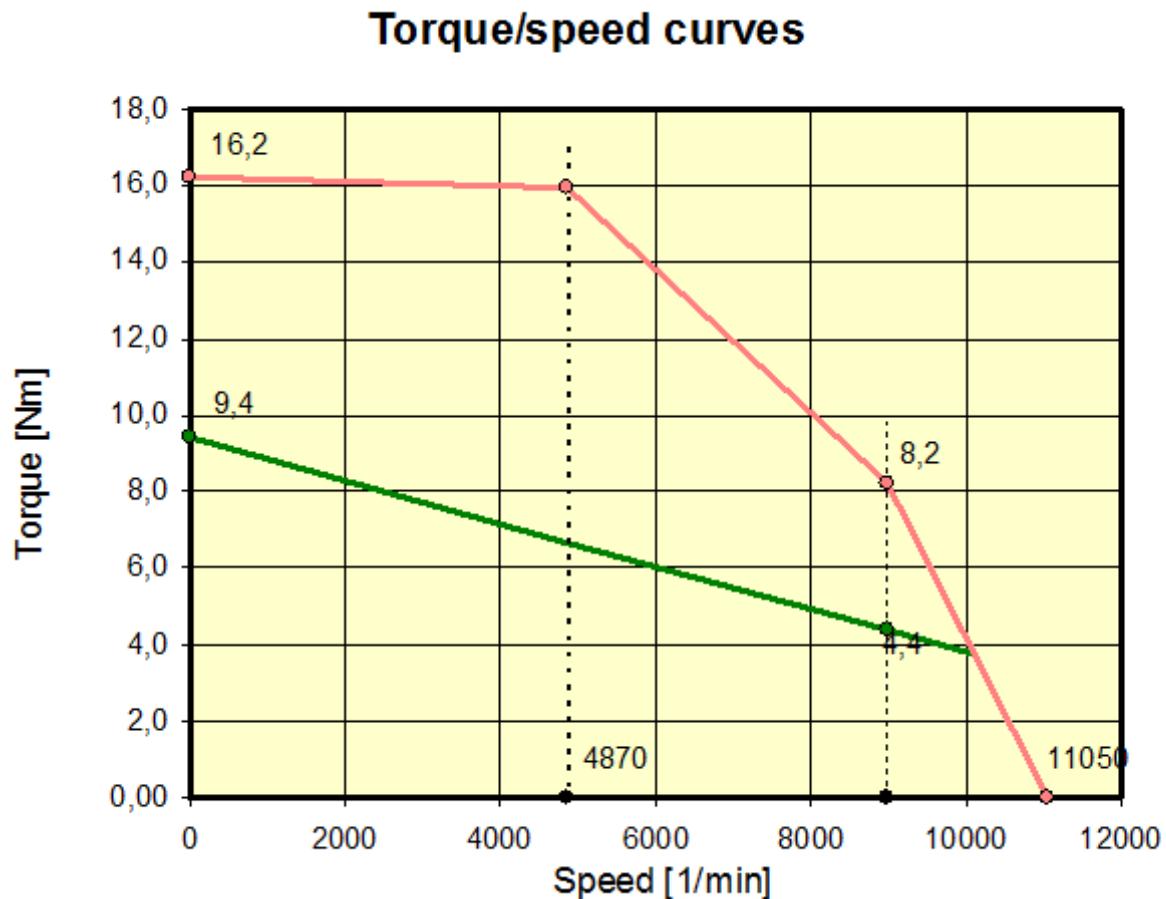


Figure 41: Front motor characteristics.

6.2.1 Wiring, cables, current calculations, connectors

We use Raychem TR 16-10-0 and TR 16-6-0. There are leadthrough used for cables in motors and connectors Souriau 8STA 0 18 18 are used in Motor controllers.

6.2.2 Position in car

Front motors are situated directly in the front uprights.

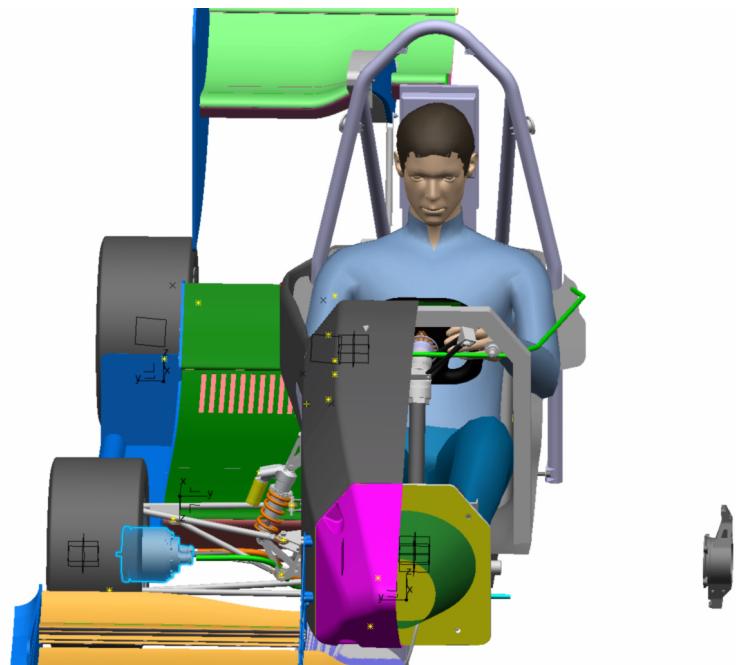


Figure 42: Front motor position.

7 Torque Encoder

7.1 Description/additional circuitry

Car is using two torque encoders for accelerator pedal. Encoders are linear potentiometers. Sensors are powered and measured by ECU-P. They output analog voltage signal equal to accelerator pedal position. Both output signals goes through Figure 43: ECU-P analog input circuit and low pass filters. Then they are fed to analog to digital converter (ADC) and analyzed by microcontroller unit (MCU) for validity and plausibility. Information about position and errors is send though controller area network (CAN).

Table 26: Torque encoder data

Torque encoder manufacturer:	TE connectivity
Torque encoder type:	MLP-50
Torque encoder principle:	linear potentiometer
Total number of Torque Encoder Sensors:	2
Supply voltage:	+5V
Maximum supply current:	1mA
Operating temperature:	-30°C to -150°C
Used output:	DC voltage 0V to 5V

Full datasheet: subsection A.7: Torque encoder datasheet

7.2 Torque Encoder Plausibility Check

Torque encoder implausibility, short circuit and open circuit checks are done by MCU. Sensors are powered from +5V. Used travel of sensors does not contain end positions. Converted analog signal ranges are normalized according to calibration. If any following sensor error is detected, motor controllers are shut down and message is send through CAN to other units.

Electrical check

Using only part of whole range of sensor excluding end positions allows detection of signal short to Ground or voltages higher or equal to sensor's power voltage.

Analog input circuitry of ECU-P is shown in Figure 43: ECU-P analog input circuit. In normal conditions, signal from sensor (RAW) goes through R_2 , then is clamped by D_1 and continues through R_1 and C_1 to filters and other circuits of ECU-P (AIN). TEST signal is held *low* but due to high resistance of R_3 has minimal impact on input signal.

When ADC measures 0V or value close to 0V, TEST signal logic level is switched *high* to charge C_1 through R_3 . After short while, logic level of TEST signal is read back. If *high* logic level is read, sensor input is evaluated as *open circuit*, otherwise it is *short circuit* to GND. If measured value is close to power voltage of sensor or above measurable range, it is evaluated as *short circuit* to power voltage or higher.

Implausibility

Position values difference is calculated and compared with maximal allowed error threshold (10%).

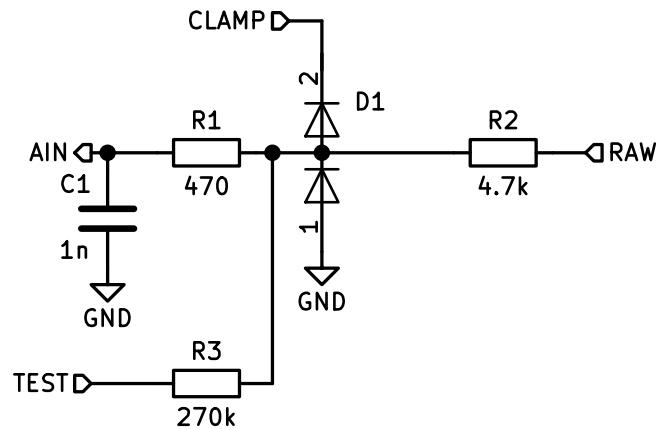


Figure 43: ECU-P analog input circuit

7.3 Wiring

Figure 44: ECU-P sensor wiring is diagram of wiring between accelerator pedal sensors and ECU-P.

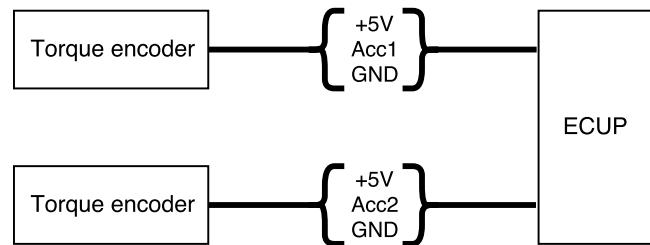


Figure 44: ECU-P sensor wiring

7.4 Position in car/mechanical fastening/mechanical connection

In Figure 45: Torque encoder position is shown position of two torque encoder sensors (piston shape objects).

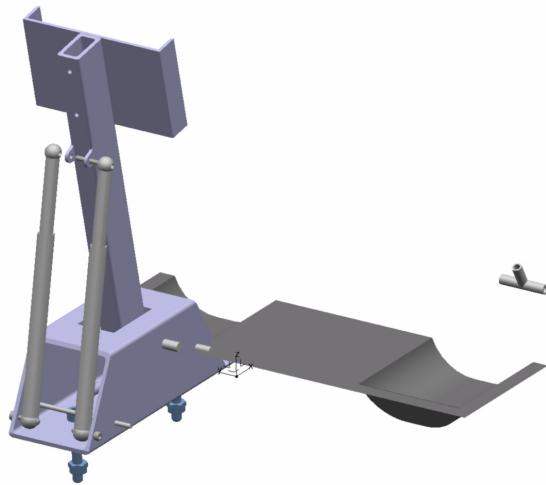


Figure 45: Torque encoder position

8 Brake Encoder

8.1 Description/additional circuitry

Car is using two pressure sensors as encoders for brake pedal. Each one is for separate brake system. Sensors are powered and measured by ECU-P, same unit as section 7: Torque Encoder. Pressure sensors output analog voltage signal equal to brake system pressure.

Table 27: Brake encoder data

Torque encoder manufacturer:	Keller
Torque encoder type:	PA-21 Y
Torque encoder principle:	pressure sensor
Total number of Torque Encoder Sensors:	2
Supply voltage:	+24V
Maximum supply current:	4mA
Operating temperature:	-40° to 100°C
Used output:	DC voltage 0,5V to 4,5 V

8.2 Brake Encoder Plausibility Check

Implausibility is not checked, because eForce does not use brake pedal information to control motor controllers.

9 Additional LV-parts interfering with tractive system

9.1 VDCU(Vehicle Dynamics Control Unit)

VDCU is a vehicle dynamics control unit. It manipulates torque request from driver pedal to calculate final torque for all 4 motors. The calculated torque never exceed driver request as driver request is processed as torque limitation. Traction control can only decrease the total amount of requested torque.

9.1.1 Description

Board uses only LV and 2x CAN bus.

HW :

- Texas Instruments C2000 Delfino F28377 MCU
- 5V can transceiver TJA1049

SW:

Board is programmed using simulink embedded coder. Advantage is that we can use our developed code for IPG Carmaker simulation (MIL) directly into our formula. VDCU uses pedal position, inertial measurement, steering wheel sensor, wheel speed sensor and motor encoders to manipulate the torque. Measurements are fed into our yaw rate control system. Output is a torque vector fed to torque vectoring algorithm that calculates the torque distribution for all wheels. The resultant torque for individual wheels is lowered by traction control algorithm if needed and fed to motors.

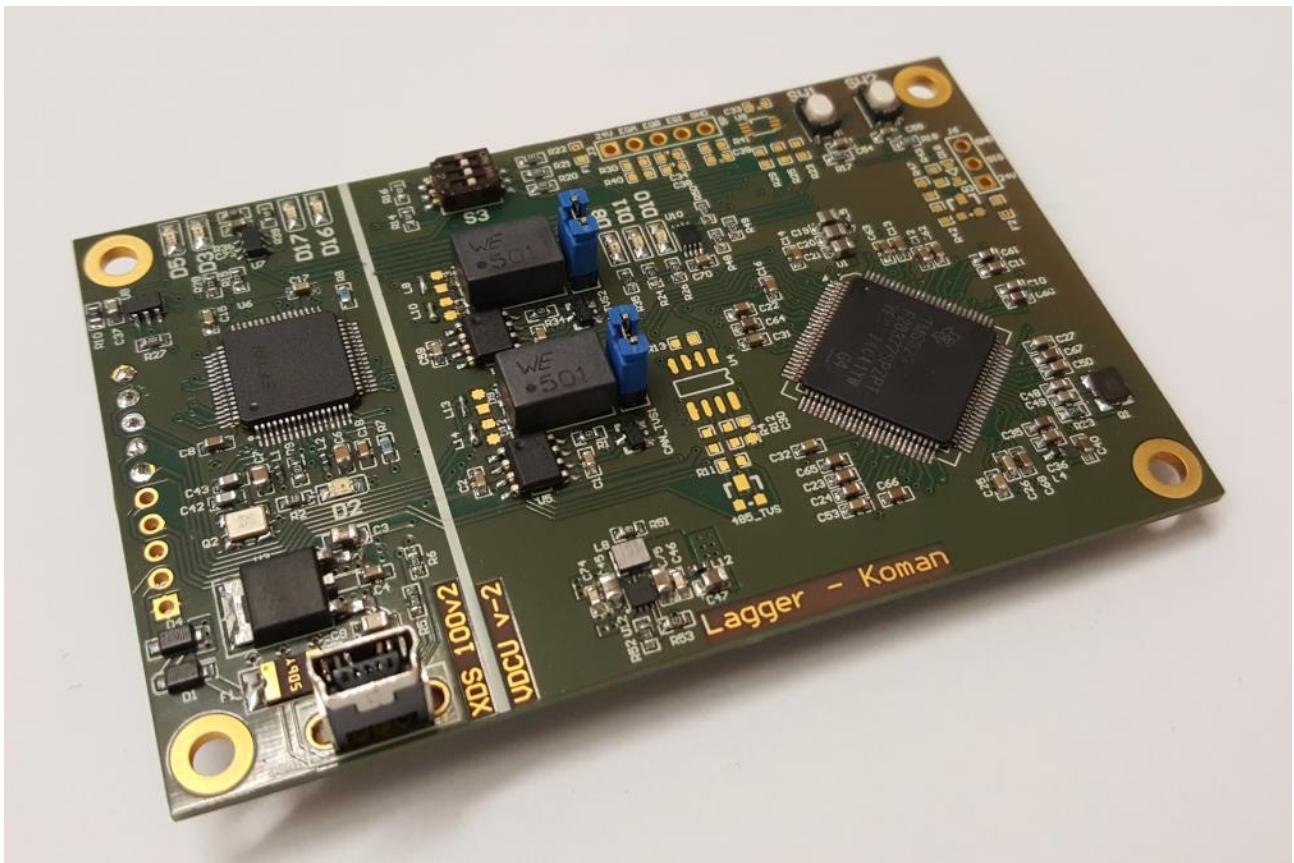


Figure 46: PCB of VDCU.

9.1.2 Wiring, cables

Module is connected using headers to ECUB.

9.1.3 Position in car

Inside ECUB box.

9.2 LV part 2

Describe those parts here which interfere or influence the tractive system, for example a controlling unit that measures wheel speeds and steering angle and calculates a target torque for each motor or a DC/DC-Converter providing power for the LV-system, etc.

9.2.1 Description

Describe the parts used and their circuitry, and provide main operation parameters, use tables or figures, etc.

9.2.2 Wiring, cables

Describe the wiring, show schematics, etc.

9.2.3 Position in car

Provide CAD-renderings showing the relevant parts. Mark the parts in the rendering, if necessary.

10 Overall Grounding Concept

10.1 Description of the Grounding Concept

We are using net of thin wires from grounding point laminated into composite.

10.2 Grounding Measurements

For measuring we are using 4 point method with current power supply to ensure 5 Ohms. In carbon fiber we have copper wires.

11 Firewall

11.1 Description/materials

We are using standard concept of firewall as described in the rules (T4.5.4). So the firewall is made from 2 layers. The first one is 0,5 mm thick aluminum sheet and the second one is 0,8 mm thick glass fiber/polyester plastic sheet with UL 94-V0 certificate (type: UPM 203 / UPM 71/S included in appendix). These are glued together and bended to the shape of final firewall. Aluminum sheet is oriented to the dangerous side and glass fiber to the driver side.

11.1.1 Position in car

Firewalls are located behind the seat and above the front motor controller (under drivers knees). These firewalls are connected with "firewall tunnel" where are located the high voltage cables.

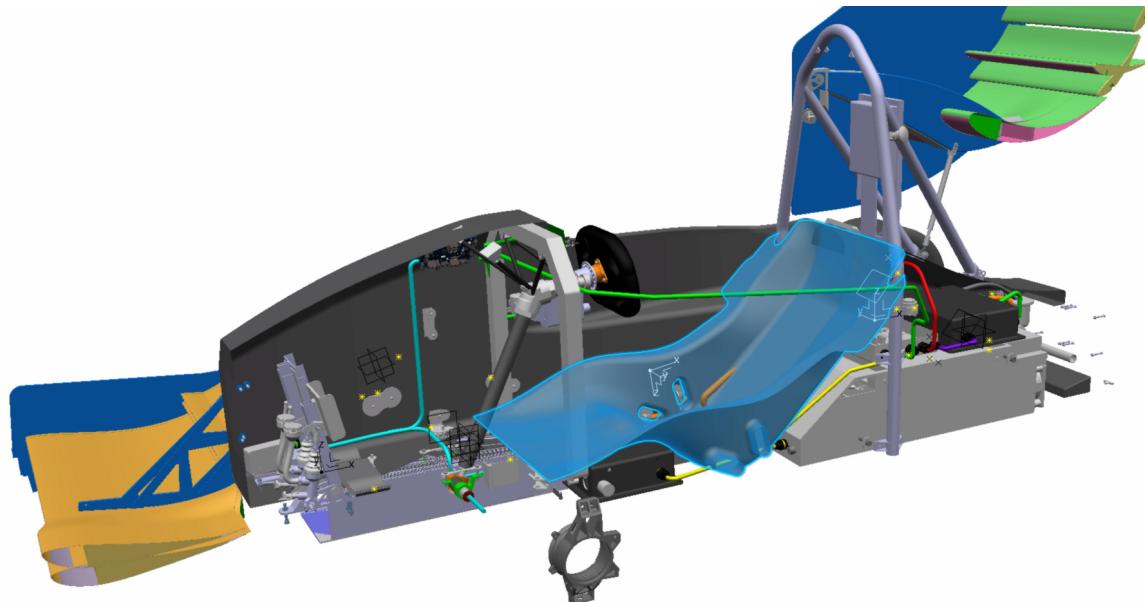


Figure 47: Firewall position.

A Appendix

A.1 HV Disconnect (HVD)

AS Heavy Duty (ASHD) Series Connectors



Autosport design for high current motorsport applications

- Early break / Late mate on data contacts to support safety
- Cable accommodation from 16mm² - 70mm²
- Positive locking coupling mechanism

High performance materials

- Environmentally sealed
- Thermal cycle tested
- Heavy duty rated
- Crimp type solid and gold plated copper contacts



SuperASHD Single
70mm contact

ASHD14-I
(1x AWG 4)

AS 22-24520
(2x AWG 4, 3x AWG 20)

AS 24-34220
(3x AWG 4, 2x AWG 20)

AS 24-44420
(4x AWG 4, 4x AWG 20)

All dimensions are in mm unless otherwise stated.

Appendix 48: HVD interlock datasheet.

Full datasheet http://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=1-1773721-8_as_interconnection&DocType=DS&DocLang=EN

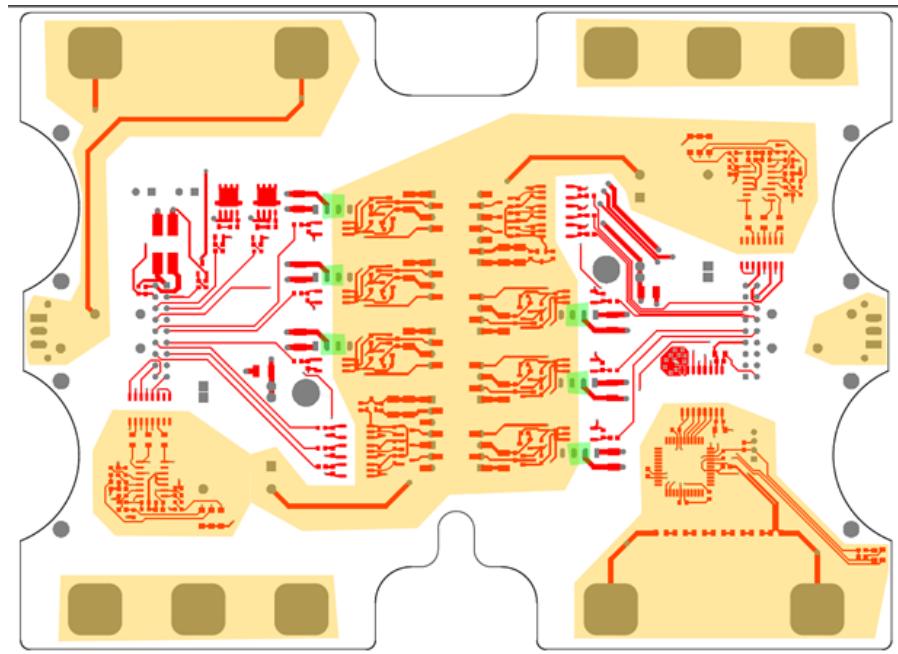
A.2 Motor controller

Datasheet of NME1215SC, refered from section 5: Motor Controller.

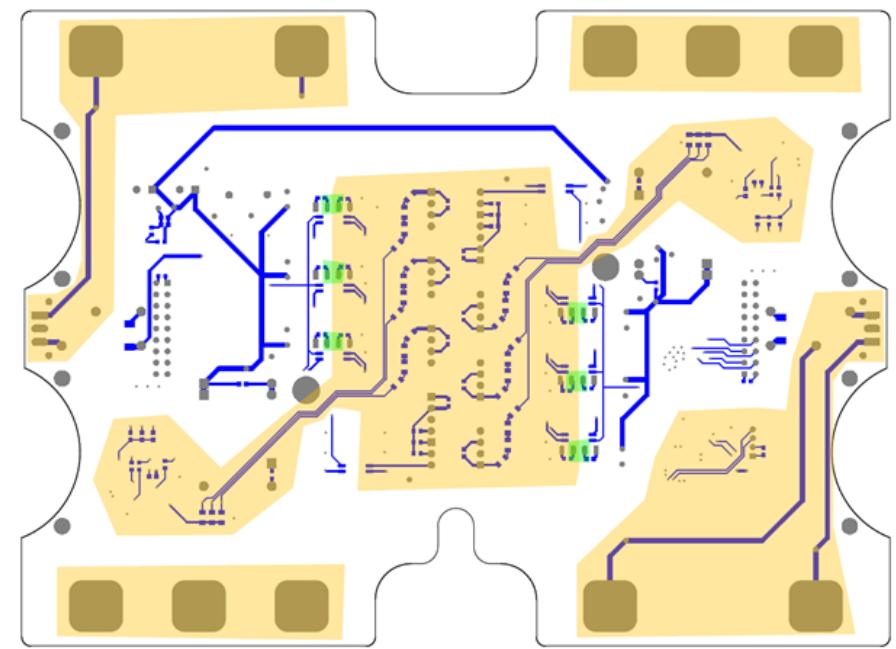


Appendix 49: NME1215SC isolation.

Full datasheet to be found at http://power.murata.com/data/power/ncl/kdc_nme.pdf



Appendix 50: Motor controller TOP.



Appendix 51: Motor controller BOTTOM.

A.3 Motor

RATED DATA				
Motor type	M4	0470	90	380
Preliminary data				
Rated Speed	n_n	9000 min ⁻¹		
DC Bus Voltage	U_{dc}	380 V		
Nominal AC Voltage	U_n	260 V		
Rated Motor Voltage	U_m	228 V		
Rated Torque	M_n	4.4 Nm		
Rated AC Current	I_n	12.2 A		
Stall Torque	M_0	9.4 Nm		
Stall AC Current	I_0	24.2 A		
Peak Torque	M_{max}	16.2 Nm		
Peak Current	I_{max}	67 A		
Max. Speed	n_{max}	9000 min ⁻¹		
EMF Constant	K_E	23.5 V/1000		
Torque Constant	K_T	0.39 Nm/A		
Terminal Resistance	R_{2ph}	0.24 Ω		
Terminal Inductance	L_{2ph}	1.30 mH		
Number of poles	$2p$	10		
No Load Speed	n_0	11050 min ⁻¹		
Torque at I_{max}/U_n	M_z	16.0 Nm		
Speed at I_{max}/U_n	n_z	4870 min ⁻¹		
Max. Torque at n_n	M_x	8.2 Nm		
El. Time Constant	T_{el}	5.4 ms		
Mech. Time Constant	T_{mech}	0.80 ms		
Thermal Time Constant	T_{th}	35 min		
Rotor Inertia	J	2.9 kgcm ²		

Appendix 52: Datasheet motor front.

RATED DATA				
Motor type	N5	1600	100	380
Water cooling				
Rated Speed	n_n	10000 min ⁻¹		
DC Bus Voltage	U_{dc}	380 V		
Nominal AC Voltage	U_n	260 V		
Rated Motor Voltage	U_m	197 V		
Rated Torque	M_n	11.0 Nm		
Rated AC Current	I_n	38.2 A		
Stall Torque	M_0	24.0 Nm		
Stall AC Current	I_0	73 A		
Peak Torque	M_{max}	48 Nm		
Peak Current	I_{max}	171 A		
Max. Speed	n_{max}	9000 min ⁻¹		
EMF Constant	K_E	20.0 V/1000		
Torque Constant	K_T	0.33 Nm/A		
Terminal Resistance	R_{2ph}	0.04 Ω		
Terminal Inductance	L_{2ph}	0.33 mH		
Number of poles	$2p$	10		
 				
No Load Speed	n_0	12990 min ⁻¹		
Torque at I_{max}/U_n	M_z	47 Nm		
Speed at I_{max}/U_n	n_z	7170 min ⁻¹		
Max. Torque at n_n	M_x	30 Nm		
 				
El. Time Constant	T_{el}	8.3 ms		
Mech. Time Constant	T_{mech}	0.73 ms		
Thermal Time Constant	T_{th}	55 min		
Rotor Inertia	J	11.5 kgcm ²		

Appendix 53: Motor controller BOTTOM.

- A.4 Overall Grounding Concept
- A.5 Firewall
- A.6 Discharge resistors datasheet



Features

- TO-220 housing
- Low inductance
- Ceramic backplane
- High power rating
- AEC-Q200 qualified
- RoHS compliant*

Applications

- Power supplies
- Motor drives
- Test and measurement
- Rectifiers

PWR221T-30 Series Power Resistor

General Information

Bourns® PWR221T-30 Series is a TO-220 style power resistor made using thick film on alumina ceramic technology. It is used in current limiting, capacitor discharge or current measurement circuits in power supplies for telecom and industrial applications.

Electrical & Thermal Characteristics

Parameter	Value(s)
Resistance (See Popular Resistance Values table)	0.02 Ω to 130 KΩ
Power Rating @ 25 °C Case Temperature	30 W**
Tolerance	±1 %***, ±5 %
TCR	
0.100 Ω < R < 130.0 KΩ	±100 PPM/°C
0.050 Ω < R < 0.100 Ω	±300 PPM/°C
0.020 Ω < R < 0.050 Ω	±600 PPM/°C
Thermal Resistance - R _{thj}	4.2 °C/W
Inductance	0.1 μH maximum
Operating Voltage	√P * R with a maximum of 250 V
Dielectric Strength	2 KV AC
Insulation Resistance	10 GΩ
Operating Temperature	-55 °C to +150 °C

** Power rating of 2.25 W when mounted free to air (no heat sink).

*** Available for most values. Check Popular Resistance Values table.

Popular Resistance Values

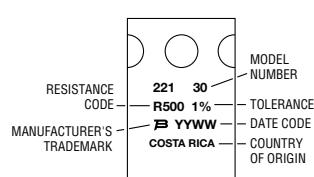
Code	Resistance Value	Code	Resistance Value
R020	0.02 Ω***	1000	100 Ω
R025	0.025 Ω***	1200	120 Ω
R030	0.03 Ω***	1500	150 Ω
R033	0.033 Ω***	2000	200 Ω
R040	0.04 Ω***	2500	250 Ω
R050	0.05 Ω***	3000	300 Ω
R075	0.075 Ω***	3300	330 Ω
R100	0.1 Ω	4000	400 Ω
R150	0.15 Ω	4700	470 Ω
R200	0.2 Ω	5000	500 Ω
R250	0.25 Ω	5600	560 Ω
R300	0.3 Ω	7500	750 Ω
R330	0.33 Ω	1001	1.0 KΩ
R400	0.4 Ω	1501	1.5 KΩ
R500	0.5 Ω	2001	2.0 KΩ
R750	0.75 Ω	2501	2.5 KΩ
1R00	1 Ω	3001	3.0 KΩ
1R50	1.5 Ω	3301	3.3 KΩ
2R00	2 Ω	4001	4.0 KΩ
2R50	2.5 Ω	5001	5.0 KΩ
3R00	3 Ω	7501	7.5 KΩ
3R30	3.3 Ω	1002	10 KΩ
4R00	4 Ω	1502	15 KΩ
5R00	5 Ω	2002	20 KΩ
7R50	7.5 Ω	2502	25 KΩ
8R00	8 Ω	3002	30 KΩ
10R0	10 Ω	3302	33 KΩ
12R0	12 Ω	4002	40 KΩ
15R0	15 Ω	4702	47 KΩ
20R0	20 Ω	5002	50 KΩ
25R0	25 Ω	5602	56 KΩ
27R0	27 Ω	6802	68 KΩ
30R0	30 Ω	7502	75 KΩ
33R0	33 Ω	8202	82 KΩ
40R0	40 Ω	1003	100 KΩ
47R0	47 Ω	1153	115 KΩ
50R0	50 Ω	1203	120 KΩ
56R0	56 Ω	1253	125 KΩ
75R0	75 Ω	1303	130 KΩ

*** 5 % Tolerance

Material Characteristics

Resistor Thick film
 Substrate Alumina (AL203)
 Housing Epoxy
 Pins..... Tinned Copper (Sn/Cu)
 Flammability Conforms to UL-94V0

Typical Part Marking



Packaging

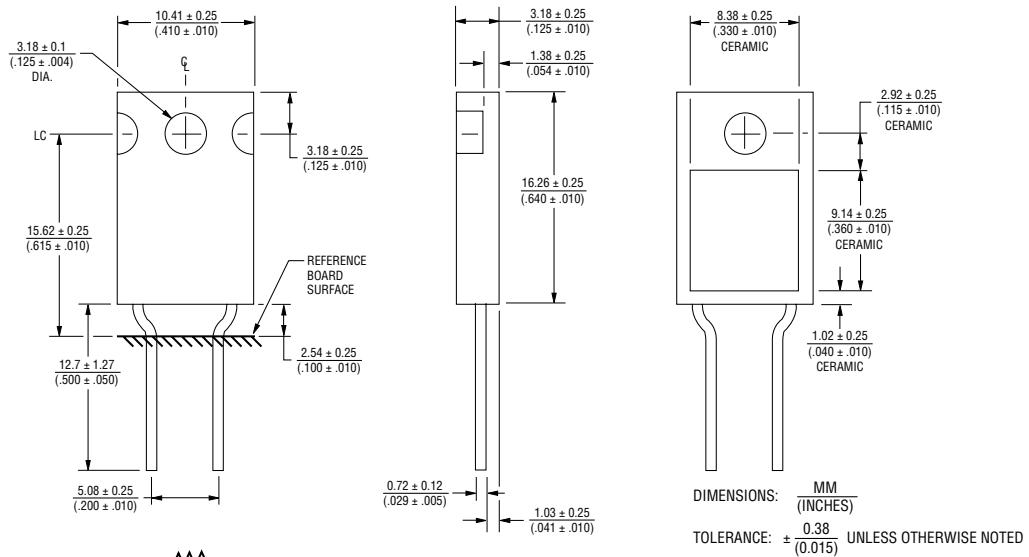
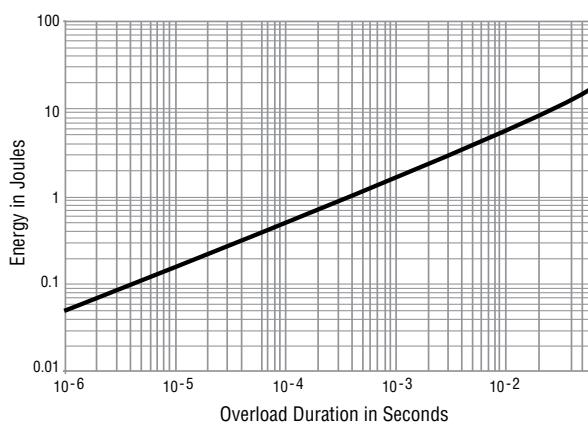
..... 50 pcs./tube

*RoHS Directive 2002/95/EC Jan. 27, 2003 including annex and RoHS Recast 2011/65/EU June 8, 2011.

Specifications are subject to change without notice.

The device characteristics and parameters in this data sheet can and do vary in different applications and actual device performance may vary over time.

Users should verify actual device performance in their specific applications.

PWR221T-30 Series Power Resistor**BOURNS®****Product Dimensions****Pulse Power Rating**

The energy absorbed by the resistor expressed in Joules can be calculated by multiplying the peak power of the pulse in watts times the length of the pulse in seconds.

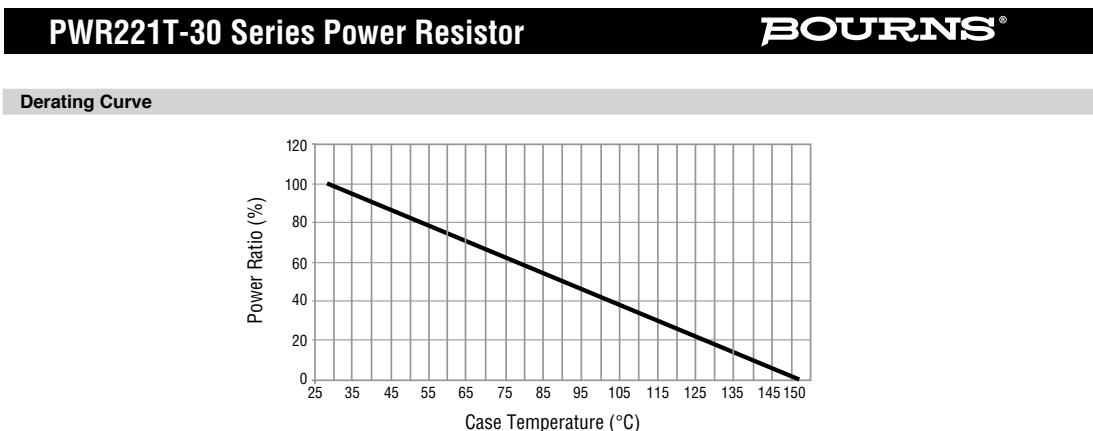
The energy should not exceed the limits shown in the graph. The overload voltage should not exceed 1.5 times the maximum operating voltage.

How to Order**PWR 221 T - 30 - 10R0 F**

Model _____
PWR = Power Resistor
Package _____
220 = TO-220 Style
Pin Style _____
T = Through-hole
Power _____
30 = 30 W
Resistance Value _____
<100 ohms ... "R" represents decimal point (examples: 7R50 = 7.5 Ω; R500 = 0.5 Ω)
≥100 ohms.... First three digits are significant, fourth digit represents number of zeros to follow (examples: 2000 = 200 ohms; 3002 = 30K ohms)

Absolute Tolerance _____
J = 5 %
F = 1 %

Specifications are subject to change without notice.
The device characteristics and parameters in this data sheet can and do vary in different applications and actual device performance may vary over time.
Users should verify actual device performance in their specific applications.



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www.bourns.com

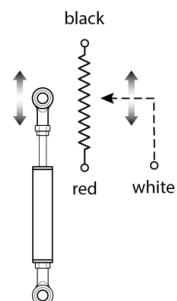
REV. 07/16

Specifications are subject to change without notice.

The device characteristics and parameters in this data sheet can and do vary in different applications and actual device performance may vary over time.

Users should verify actual device performance in their specific applications.

A.7 Torque encoder datasheet



Our miniature MLP series linear potentiometers offer unrivaled performance in an amazingly small size. Though small, the MLP is environmentally robust (IP67), operates over a broad temperature range (-22° to 300°F) and is long lasting (>25 million cycles).

These features make our miniature MLP linear potentiometer the perfect solution for many applications including industrial, medical, automotive, and motion control.

MLP

Miniature Linear Potentiometer

Absolute Linear Position to 6 inches (150 mm)

1.25K - 10K ohms • High Cycle Applications

Industrial Automation, Test and Robotics Applications

IP67 Protection • Extended Temperature Range

General

Full Stroke Ranges	0-0.5 to 0-6 in. (0-12.5 to 0-150 mm)
Output Signal	voltage divider (potentiometer)
Linearity	.5% to 1%, see ordering information
Repeatability	0.01 mm
Resolution	essentially infinite
Life Expectancy	> 25 million cycles
Operating Speed	400 inches (10 M) per second max.
Enclosure Material	aluminum
Sensor	conductive plastic linear potentiometer
Weight	1.6 oz. (46 g) max., see ordering information

Electrical

Input Resistance	see ordering information
Recommended Maximum Input Voltage	42 VDC
Recommended Operating Wiper Current	< 10µA
Electrical Cable	24 AWG Raychem 55M wire with VITON sleeve
Electrical Cable Length	19 inches (500mm)

Environmental

Enclosure Design	IP67
Operating Temperature , Continuous	-22° to 300°F (-30° to 150°C)
Operating Temperature, Short Term	350°F (175°C)
Vibration	up to 10 g to 2000 Hz maximum

MLP

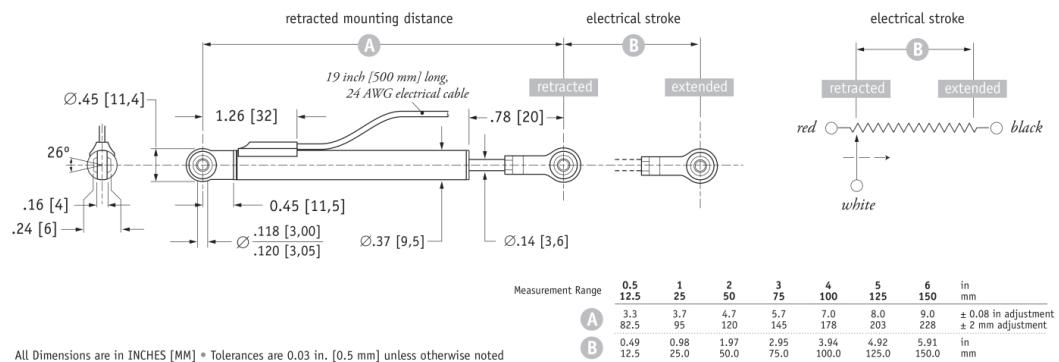
Miniature Linear Potentiometer

Ordering Information

Item Number:	MLP-12	MLP-25	MLP-50	MLP-75	MLP-100	MLP-125	MLP-150
measurement range, in. [mm]:	0.5 [12.5]	1 [25]	2 [50]	3 [75]	4 [100]	5 [125]	6 [150]
resistance, ohms ($\pm 20\%$):	1.25K	2.5K	5K	7.5K	10K	10K	10K
linearity, %:	$\pm 1\%$	$\pm 1\%$	$\pm 1\%$	$\pm 0.5\%$	$\pm 0.5\%$	$\pm 0.5\%$	$\pm 0.5\%$

weight, oz. [grams]:

.8 [24] .9 [26] 1 [29] 1.2 [33] 1.3 [37] 1.5 [43] 1.6 [46]

Outline Drawing**NORTH AMERICA**

Measurement Specialties, Inc.,
a TE Connectivity company
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Tel +1 818 701 2750
Fax +1 818 701 2799
info@celesco.com

TE.com/sensorsolutions

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MLP 12/01/2015