CHALMERS FORMULA STUDENT

Adithya Sivakumar

Final report CFS24

Areas of responsibility

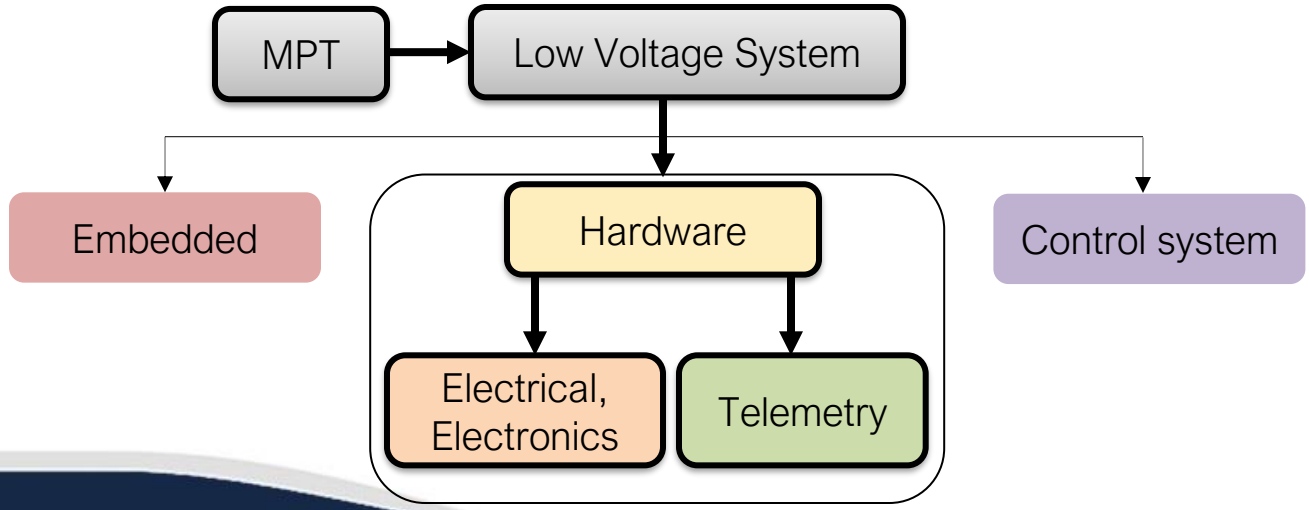
- Low Voltage - Mechanical Design
- Wiring Harness design
- Driverless PC air cooling design
- CAD responsible - MPT/LV
- Manufacturing lead - General Electronics
- Design event posters

Background

The low voltage components in the car includes all the electrical and electronic systems like the sensors, PCB's, switches, measurement points, cables etc., and autonomous systems like the PC, Lidar, antennas etc.

The wiring harness includes different connectors and cables like the power, ground and signal cables which power/recieve/send data between the different Low voltage systems in the car.

MPT-LV subgroup division



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Low Voltage - Lessons from CFS23

Longer manufacturing time because of unstructured harness design. Harness design was not planned in detail during the design phase and proven procedure were not used.

LV system tested directly on the vehicle which consumed more time in debugging. Not enough LV bench test done.

Uploading new code needed connecting to Teensy physically which took more time out of testing and made it difficult to iteratively test the software.

Extreme use of silicone in PCB enclosures for waterproofing and difficulty to mount and dismount LV components made it hard during assembly and testing.

Wiring Harness

LV test bench

Software updates

Mechanical design

Main Focus points for CFS24

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Low Voltage - Subsystem goals

Robust, streamlined, and reliable low voltage system. LV system should be easy to manufacture and debug.

This is achieved by:

- Upgrading modular wiring harness design
- Verification of the system with unit testing
- Incorporating Over-the-air software updates
- Improve enclosure mechanical design for waterproofing and mounting solution

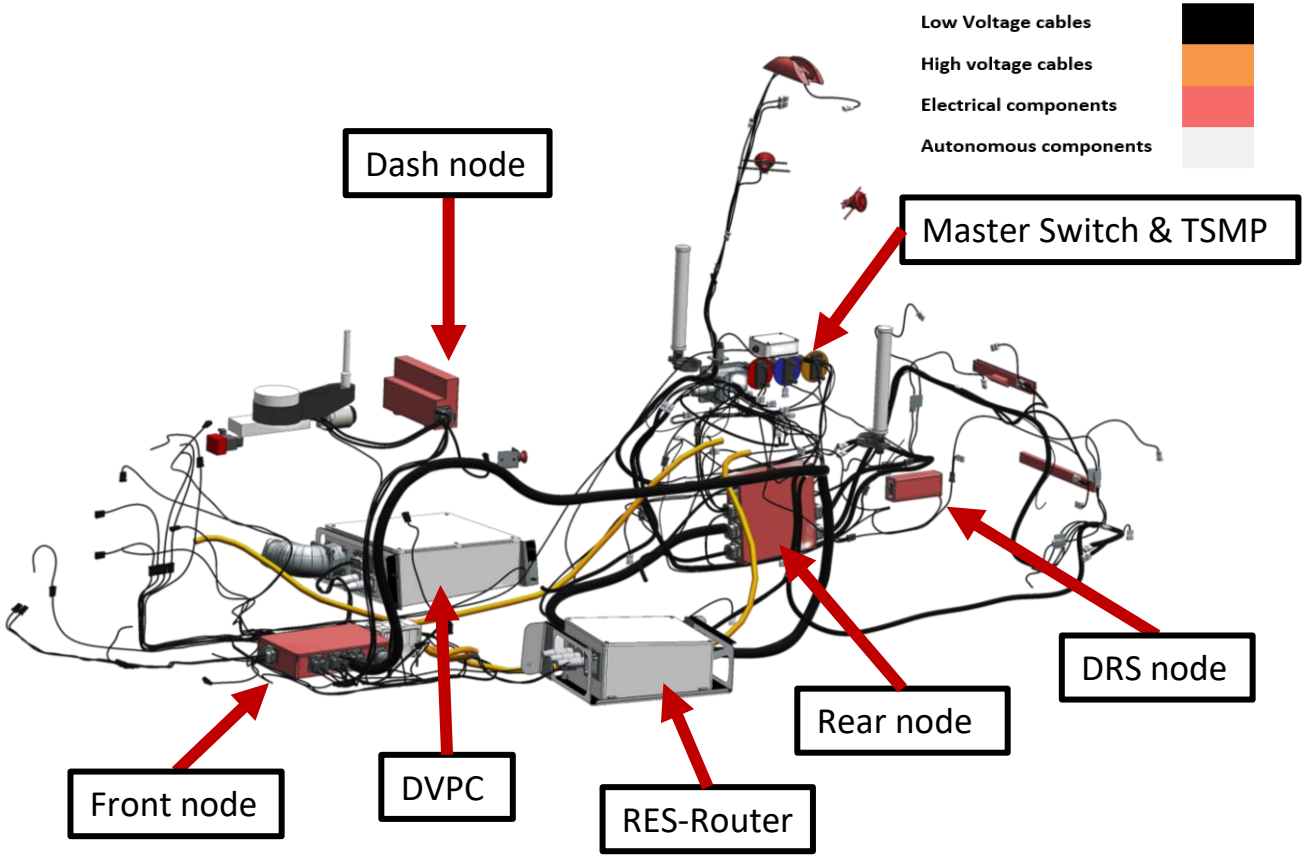
LV subgroup goals is intended towards reliability and more vehicle testing time, which aligns with the team goals.

Low Voltage Mechanical design goals

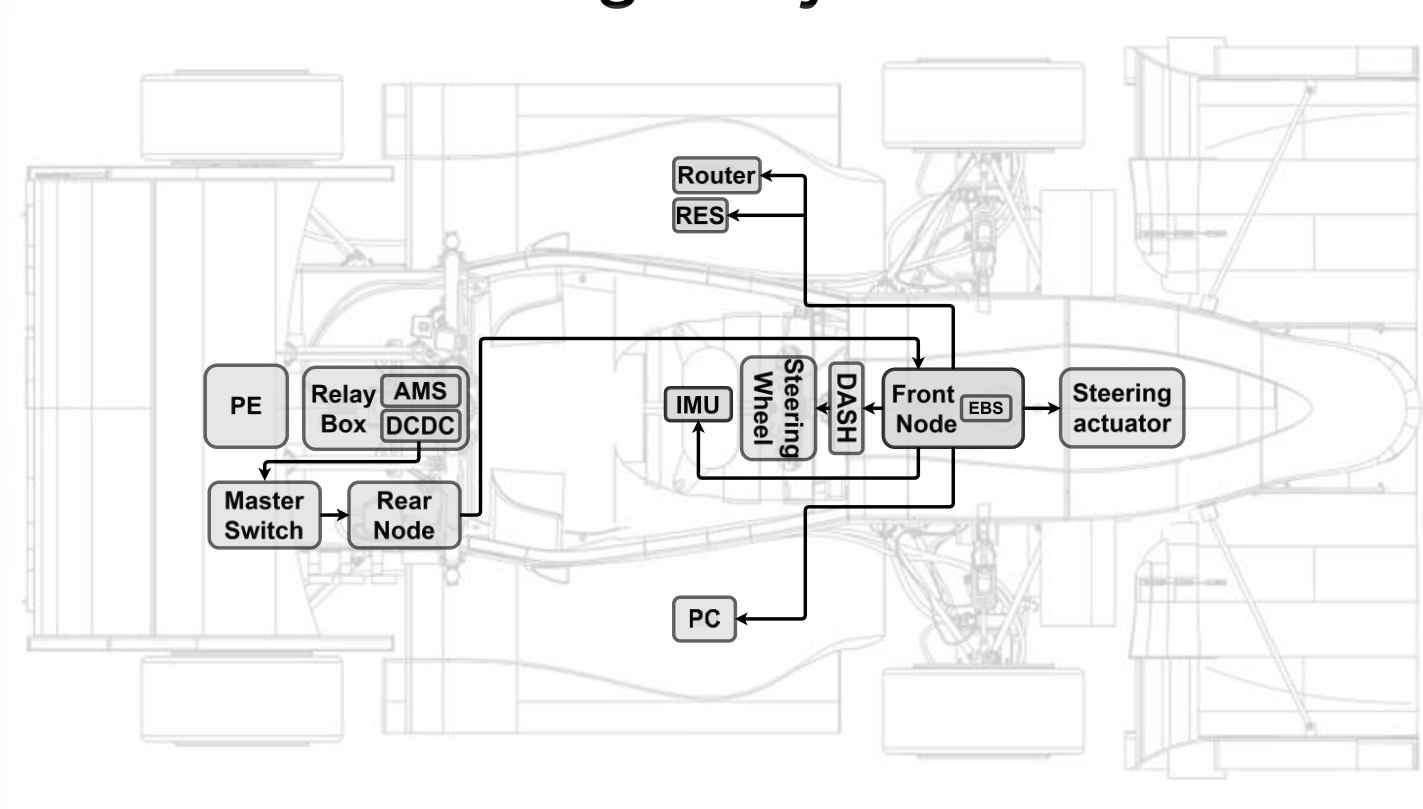
- To design and manufacture LV enclosure that are waterproof in order to minimize the silicon usage which makes it easy to assemble and test the LV components.
- Design mounting solutions which make it easy to mount/remove the LV components.
- Extract accurate length of cables from CAD and include slack. Introduce wiring harness mat to ensure harness manufacturing time is reduced and is well structured.

Low Voltage - Subsystem Highlights

- 24V low voltage system
- No separate LV battery
- **LV Power Source** – From HV Accumulator using Two stage DC-DC converter from 590V -> Vin / 16 -> 24V

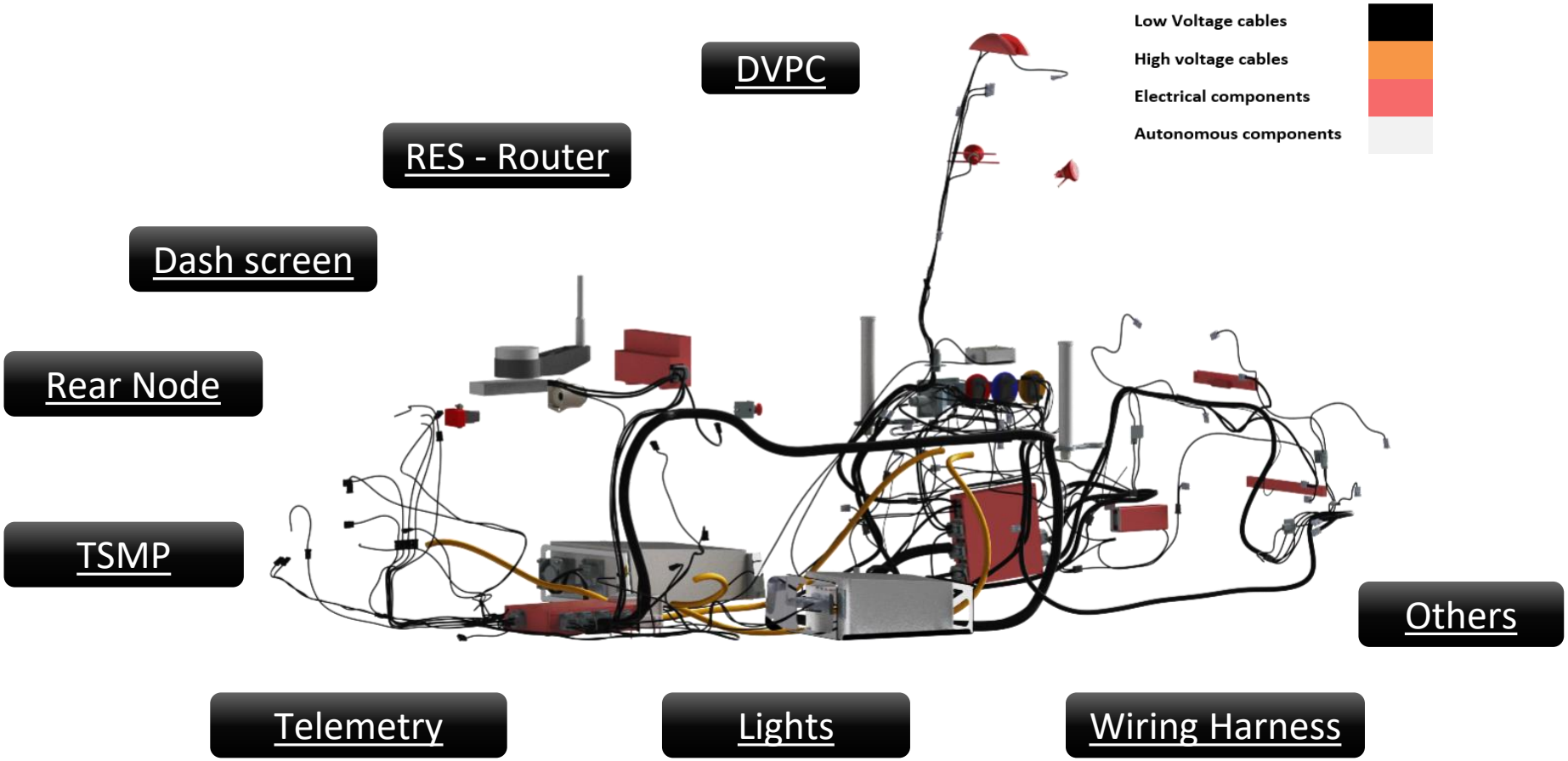


Low Voltage - System overview

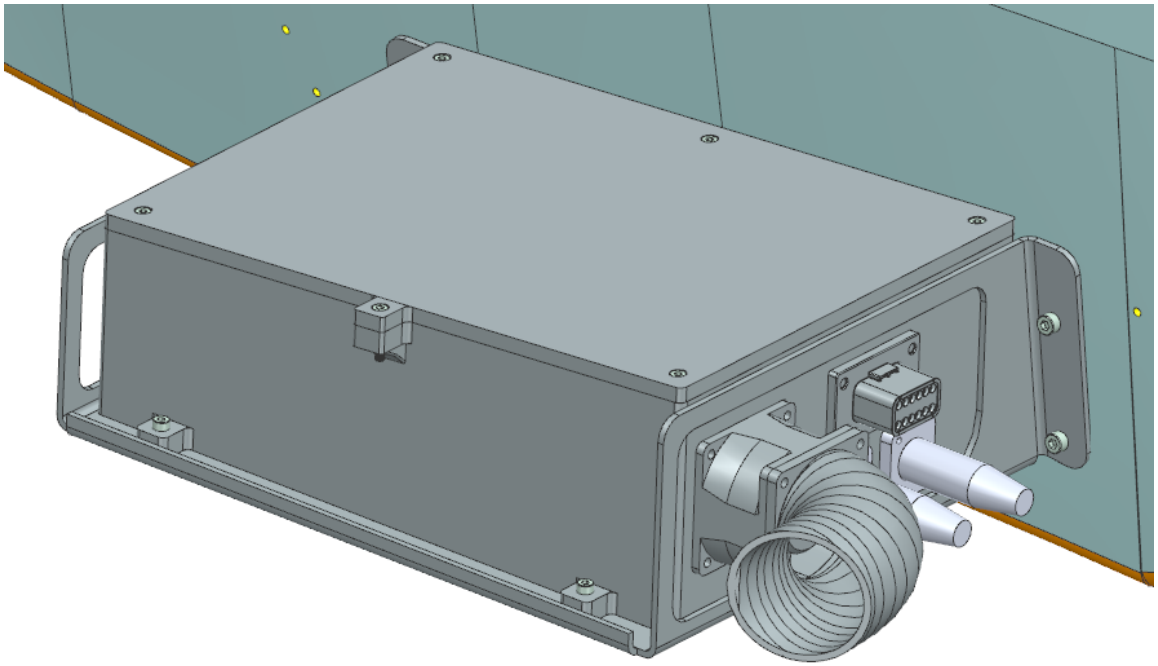


This overview shows the important LV components and the LV power distribution which begins at *Accumulator (Battery) –> DCDC in Relay box -> Master switch -> Rear node -> Front node*

Design


Low Voltage cables
High voltage cables
Electrical components
Autonomous components
DVPC
RES - Router
Dash screen
Rear Node
TSMP
Others
Telemetry
Lights
Wiring Harness

Driverless PC (DVPC) - enclosure assembly

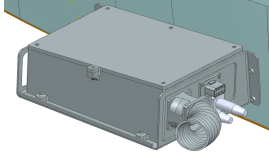


Design requirements for DVPC enclosure:

- Waterproof enclosure, air cooling system
- Higher stiffness of enclosure
- Higher temperature resistance of enclosure

Design requirements for DVPC mounting:

- Ease to manufacture and assemble
- Withstand load case
- Light weight mounting



DVPC enclosure – Material selection

PLA

Modulus of Elasticity: 3.03 Gpa
Compressive strength: 60-80 Mpa
CTE, linear - 114 µm/m-°C

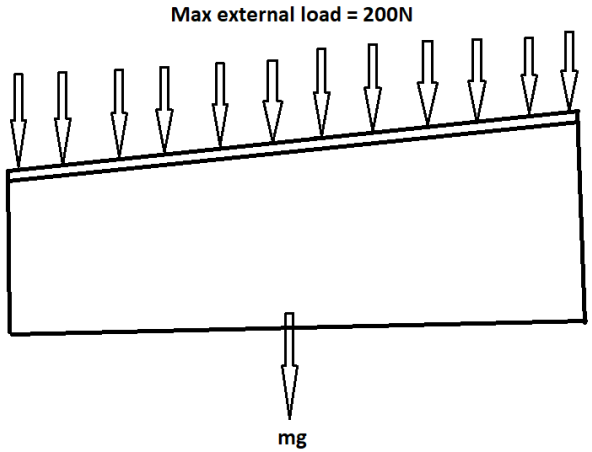
PETG

Modulus of Elasticity : 2.35 Gpa
Compressive strength: 70–100 MPa
CTE, linear - 64.6 µm/m-°C

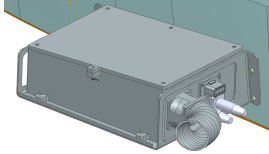
Conclusion:

- Since primary concern is the compressive load, It is evident that PETG has a better resistance to compressive load compared to PLA.
- PETG's lower Coefficient of Thermal Expansion gives higher thermal resistance to deformation.

Free body diagram

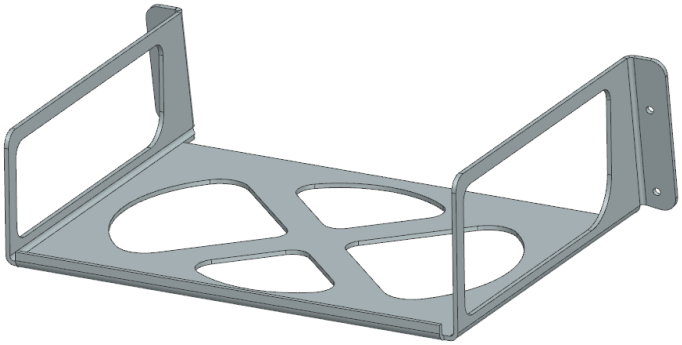


Chosen material: PETG



DVPC enclosure – Mounting material selection

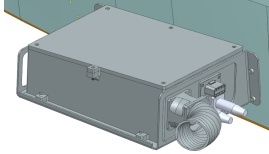
Parameter	Aluminum	Steel
Compressive strength	0	+1
Modulus of Elasticity	0	+1
Weight reduction	+1	0
Ductility (bending)	+1	0
Machinability	+1	0
Total	+3	+2



The material for DVPC mounting are compared for stress, deformation, weight, ability to bend and machinability.

Since compressive strength and young's modulus of Aluminum satisfy the design load requirements (based on the following FEM simulation) So it is chosen.

Chosen material: Aluminum

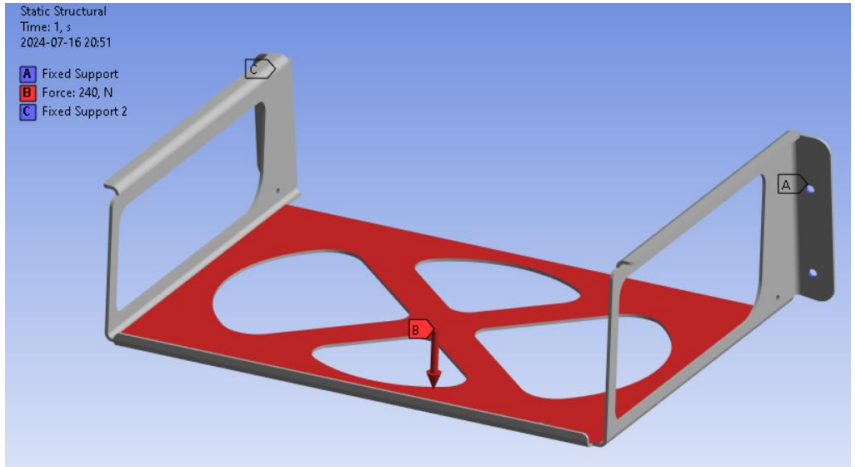


DVPC enclosure - Mounting Simulation

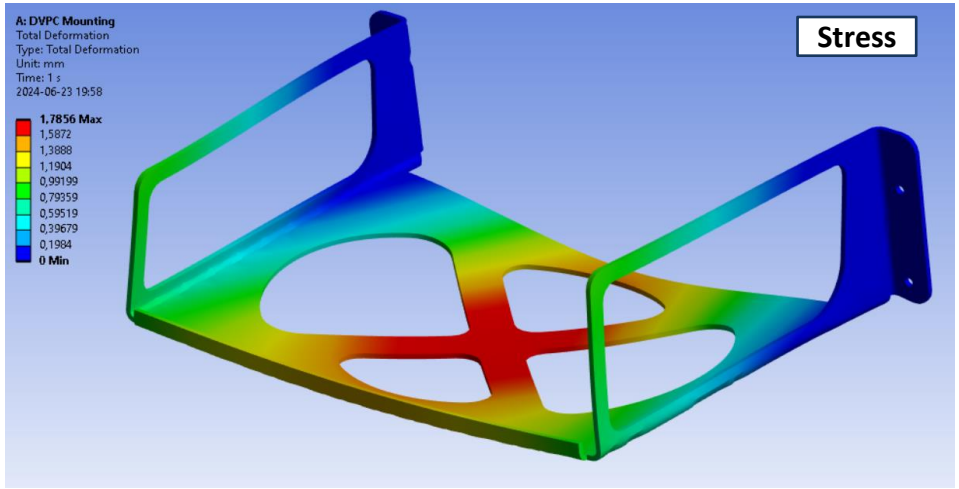
- Design load – 240N in -Z direction. Calculated based on the weight placed on the side structure during static event (20kg) and the self weight of enclosure and the PC.

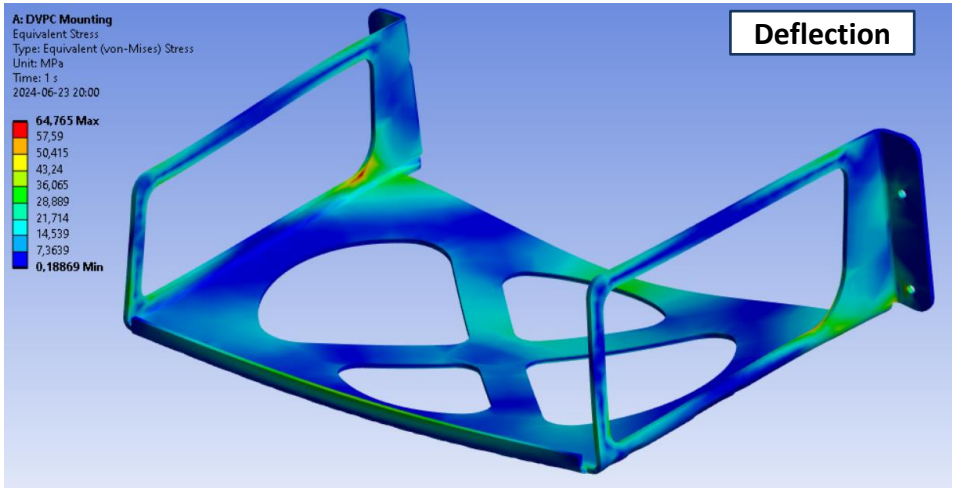
Material: Aluminum alloy T6
Yield strength of AL-T6 = 240Mpa

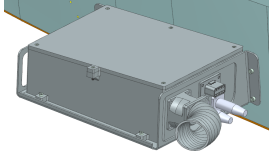
Boundary condition



Iteration 1: Thickness: 3mm, Weight = 0.55 kg

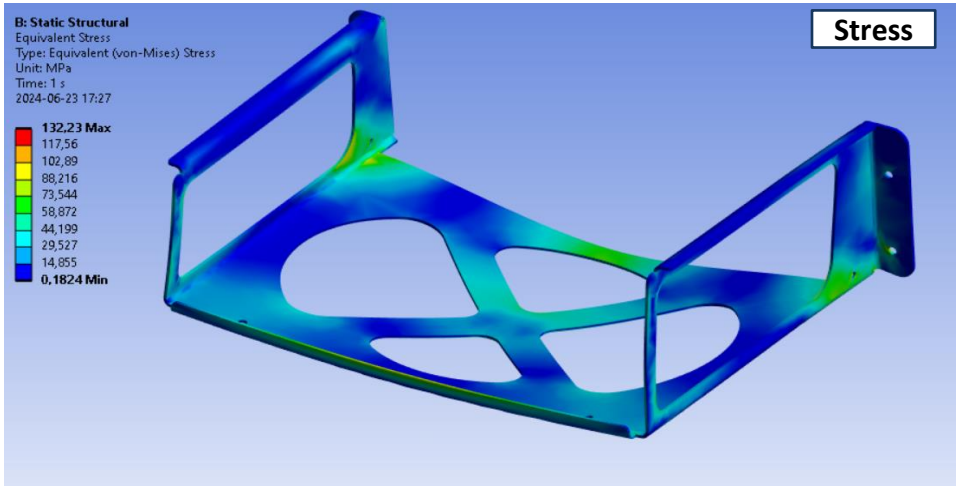


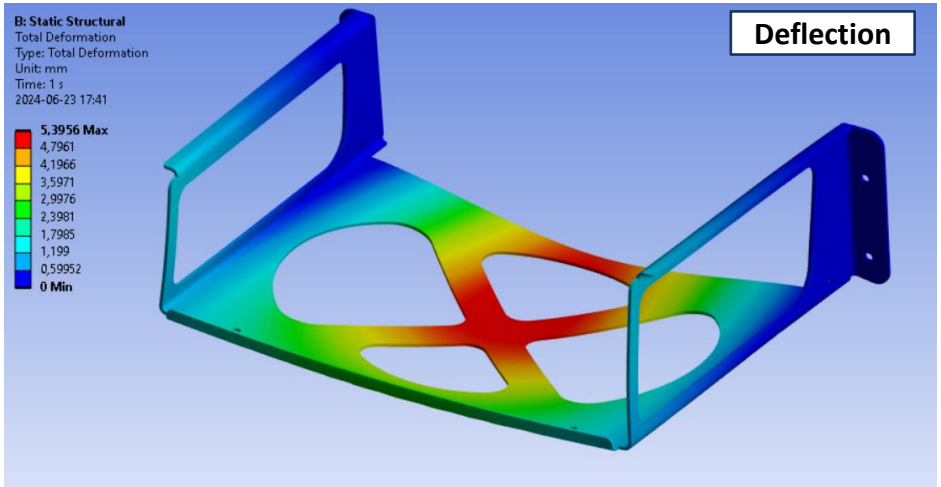




DVPC enclosure - Mounting Simulation

Iteration 2: Thickness: 2mm, Weight = 0.4 kg

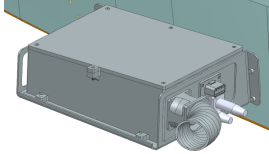




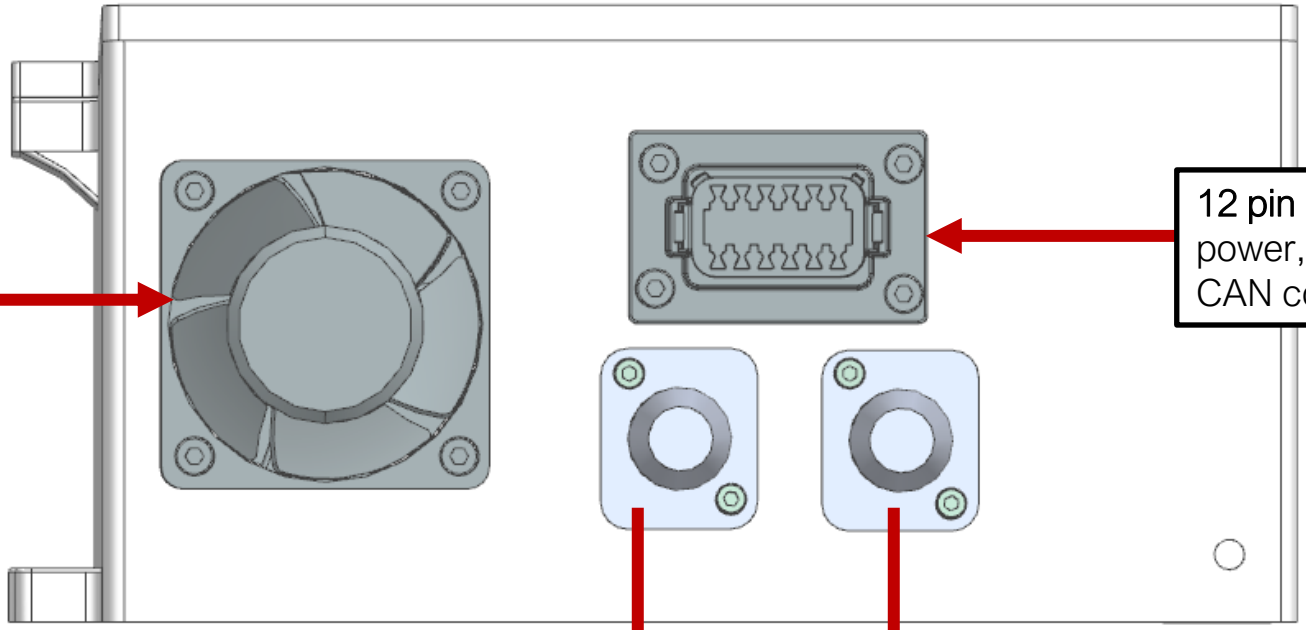
Simulation result:

Since iteration 2 with 2mm thickness Al has lower weight (saves 0.15kg) and still has a reasonable FOS of 1.81 on stress, it is chosen.

Parameters	Iteration 1	Iteration 2
Thickness	3mm	2mm
Weight (kg)	0.55	0.39
Maximum stress (Mpa)	65	132
Factor of Safety	**3.6**	**1.81**
Maximum deflection (mm)	1.8	5.4



DVPC enclosure - Connectors

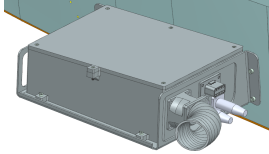


Inlet fan for air cooling DVPC

12 pin Connector for power, signal and CAN communication

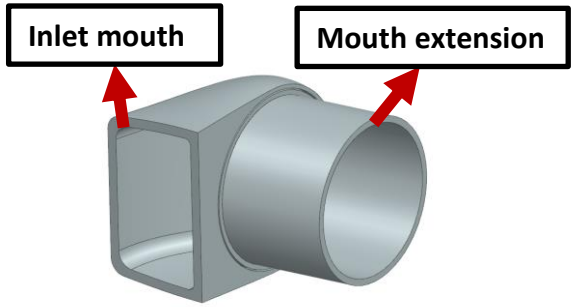
Ethernet Router – connects DVPC to router for telemetry communication

Ethernet Lidar – receives data from lidar through ethernet commutation



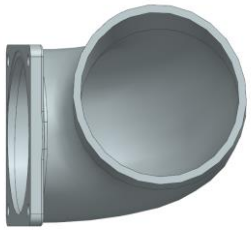
DVPC enclosure – Cooling duct

- Air cooled system was chosen over liquid cooling. Reason: If cooling plate is attached to heat sink of the PC, it becomes difficult to dismount the PC without disconnecting the cooling plate from the cooling circuit. This will require bleeding the cooling circuit every time the PC needs to be taken out.
- The DVPC air cooled system has four main components: Inlet mouth assembly, Inlet duct, Suction fan and exit duct.



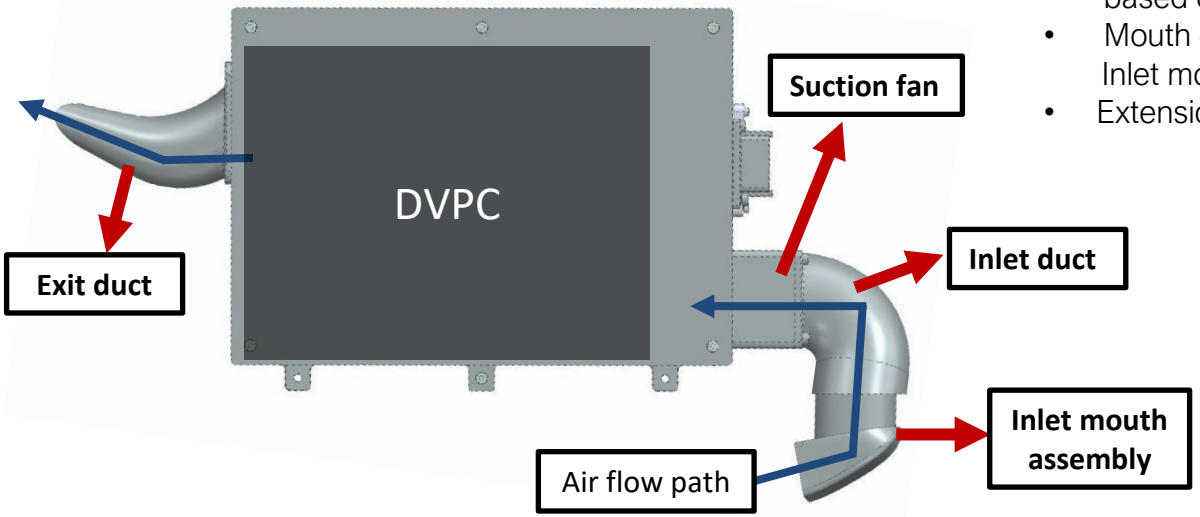
Inlet mouth assembly

- Inlet mouth area is based on calculations
- Mouth extension – TPU
  Inlet mouth – PETG
- Extension was glued



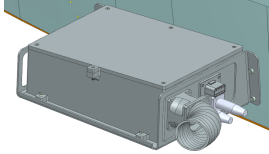
Inlet duct

- Connects Inlet mouth to the suction fan
- Made of PETG



Exit duct

- Path for air to exit enclosure
- Made of PETG



DVPC enclosure – Cooling duct calculation

A basic calculation was done to determine the area of inlet mouth required to allow maximum volume flow rate of the suction fan (data sheet).

Assumption:

- Incompressible and steady flow
- Volume flow rate is same at inlet and outlet
- Fan's CFM is taken at maximum power output

Inputs (from data sheet):

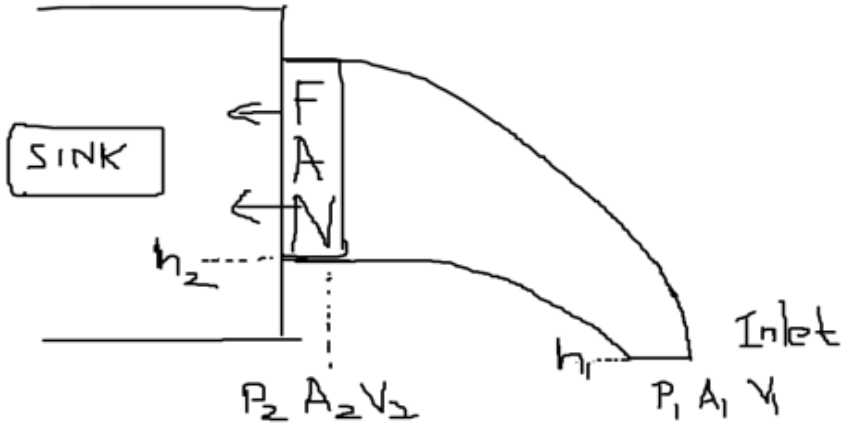
- Static pressure at fan outlet (P2) = 1.048 inchH20
- Suction area of fan (A2) = 0.0028 m^2
- Volume flow rate of suction fan = 65 CFM

Calculations are based on Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

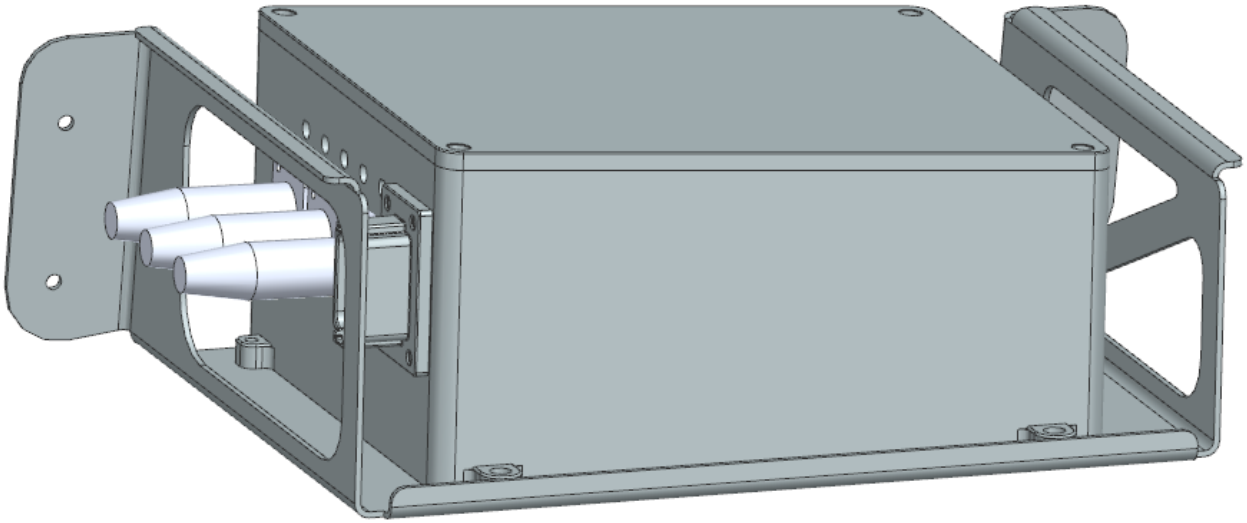
Output:

- Design Factor of Safety (FOS) = 1.4
- Diameter of inlet mouth required for maximum volume flow in the suction fan with FOS = 36.39*1.4 = **50 mm**



INLET	P1	0.00	Pa	P2-P1 = pho*g*deltaH
	V1	29.04	m/s	P1 + (0.5*pho*V1^2) = P2 +(0.5*pho*V2^2)
	A1	0.0011	m^2	A1 = V1/Vflow
		36.69	mm (dia)	
OUTLET	P2	1.747	inchH2O	Fan data sheet
		435.16	Pa	
	V2	10.86	m/s	Vflow = V2*A2
	A2	60	mm (dia)	
		0.0028	m^2	
TO HEAT SINK	Vflow	65	CFM	Fan data sheet
		110.4357	m^3/h	CFM @max power
		0.0307	m^3/s	

Remote Emergency System (RES) & Router Enclosure assembly



Design requirements for DVPC enclosure:

- Waterproof enclosure
- Higher stiffness of enclosure
- Higher temperature resistance of enclosure

Design requirements for DVPC mounting:

- Ease to manufacture and assemble
- Withstand load case
- Light weight mounting

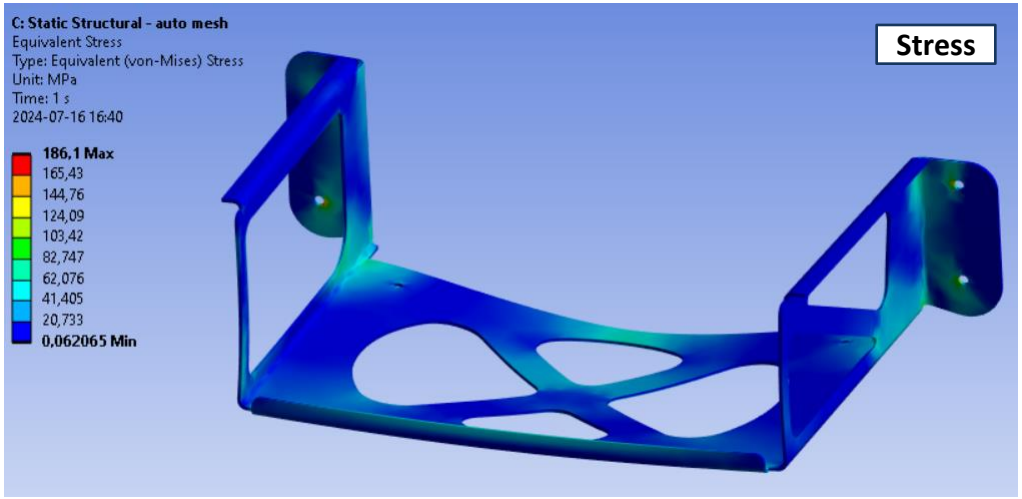
RES-Router Enclosure - Mounting Simulation

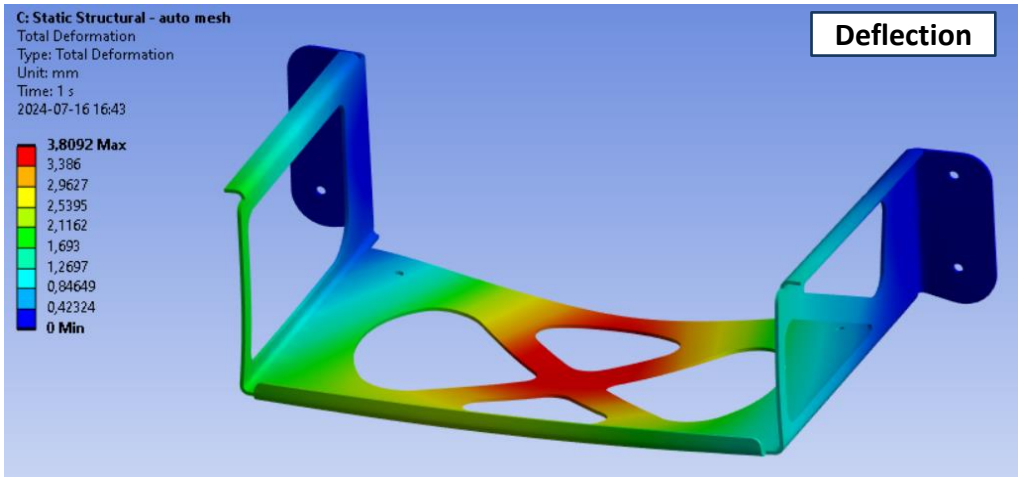
- Design load - 230N in -Z direction. Calculated based on the weight placed on the side structure during static event (20kg) and the self weight of the enclosure, RES and Router)

Material: Aluminum alloy T6
Yield strength of AL-T6 = 240Mpa

Simulation result:

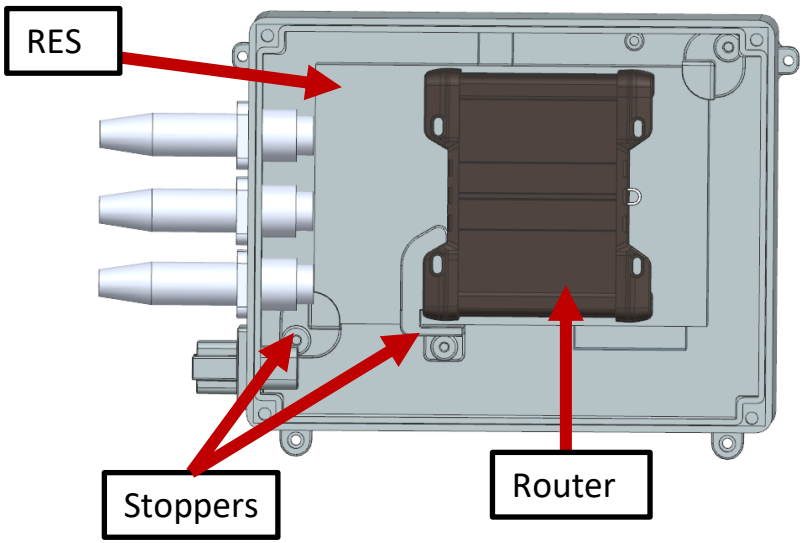
Parameters	AL mount
Thickness	2mm
Weight (kg)	0.38
Maximum stress (Mpa)	186
Factor of Safety	**1.3**
Maximum deflection (mm)	3.8

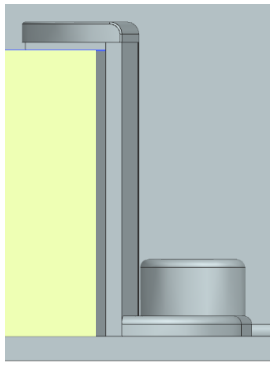




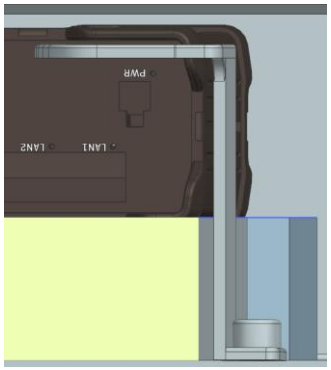
RES-Router Enclosure – Assembly

- **RES** – Triggers the EBS (Emergency brake system) during autonomous run in case emergency button is pressed on transmission module by ASR.
- **Router** – Sends real-time information from DVPC to base station through telemetry antenna.
- **Stoppers** – The mounts which hold the RES and Router inside the waterproof enclosure.
- **Enclosure Material - PETG** (Material selection same as for DVPC enclosure)



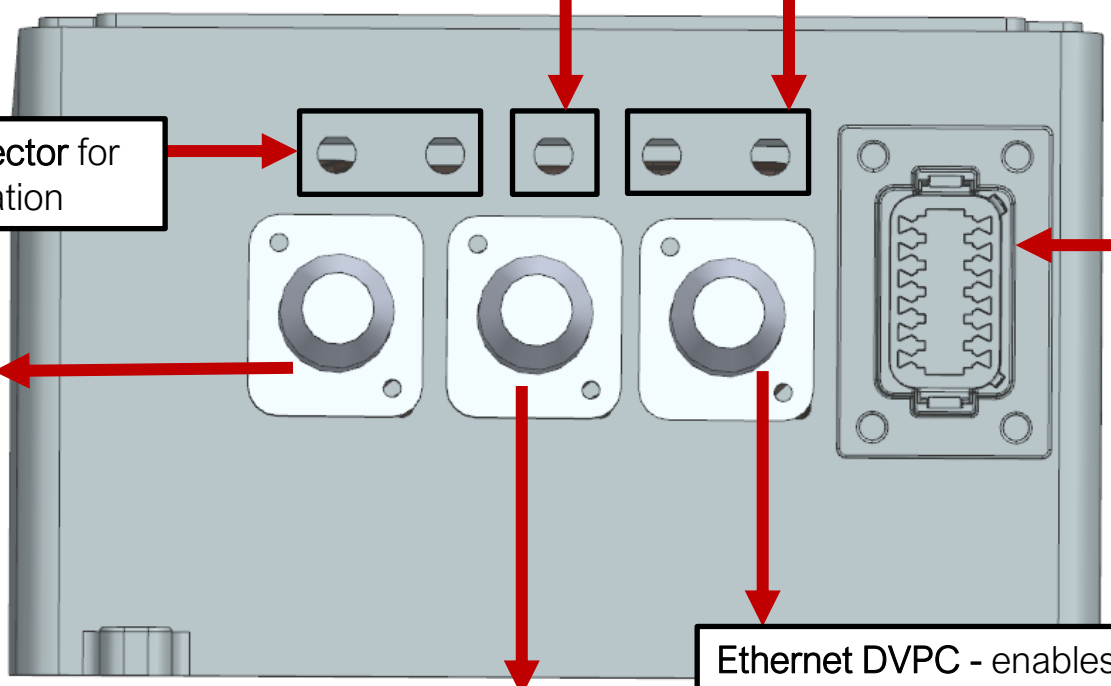


RES Stopper



Router Stopper

RES-Router Enclosure – Connectors



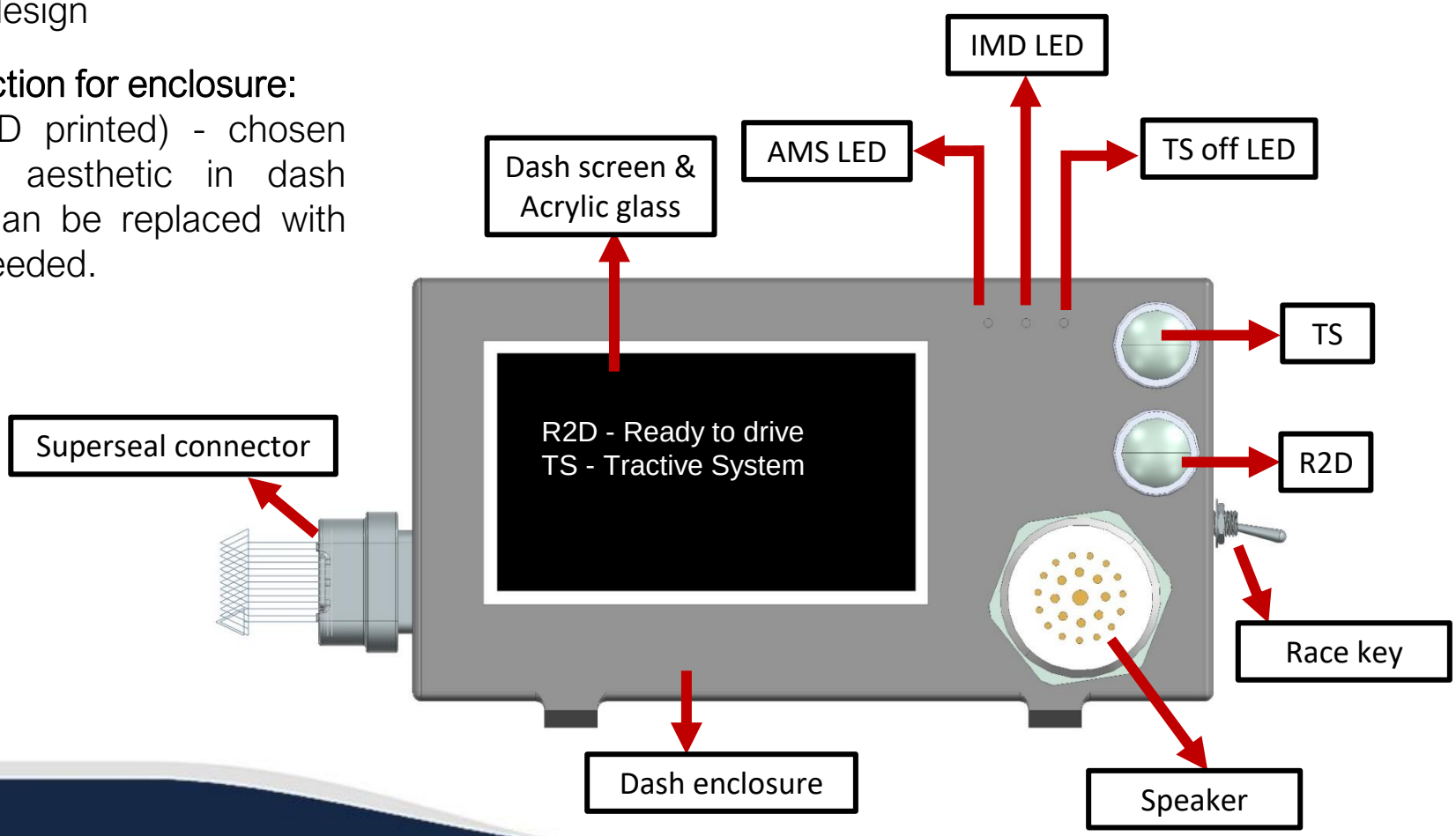
Dash screen assembly

Dash screen highlights

- Transparent acrylic dash screen protection
- Easy to assemble, mounted on steering holder
- Compact design

Material selection for enclosure:

- Nylon (3-D printed) - chosen for good aesthetic in dash screen. Can be replaced with PETG if needed.



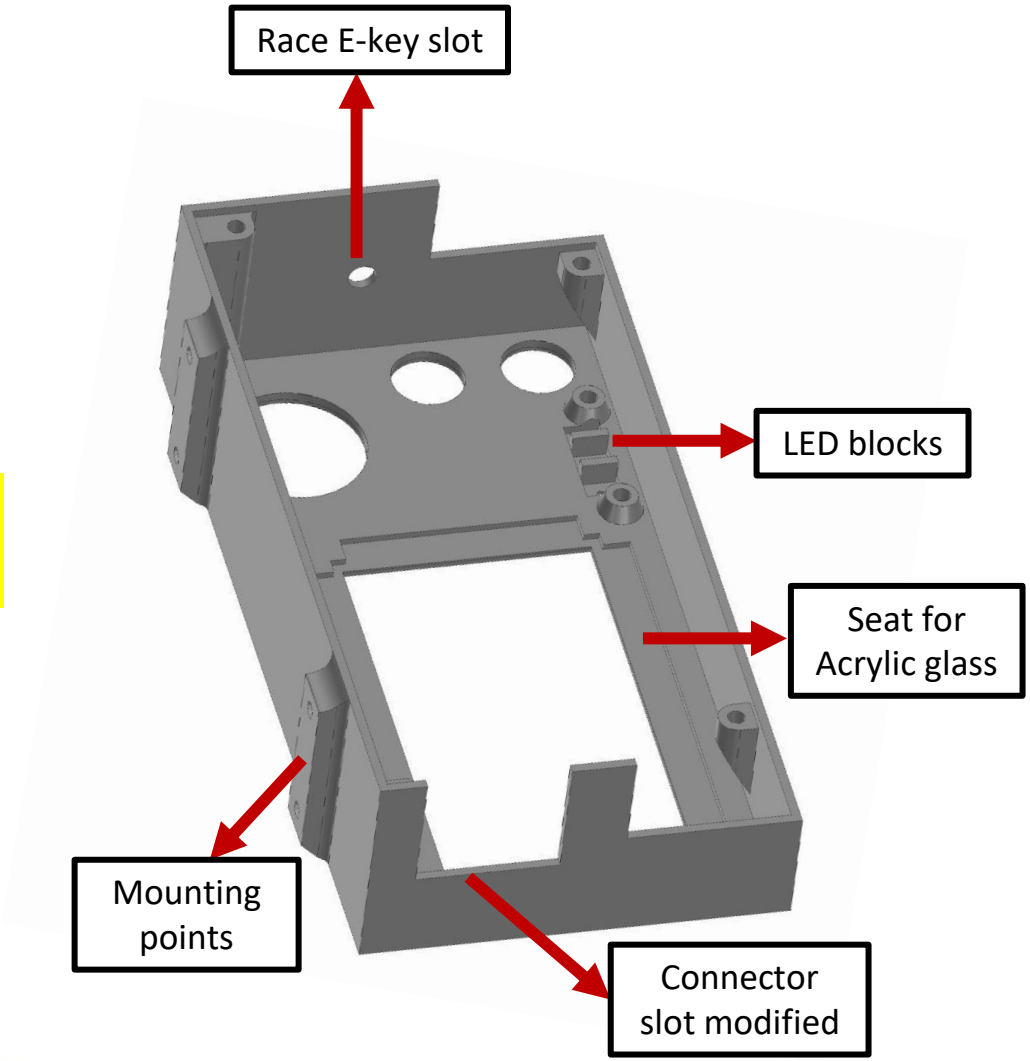
Dash screen - Modifications

Following modifications were made to CFS 23 dash screen design

- **Race E-key slot** was added in the enclosure due to rule change (as below). Race key moved from close to TSMP to dash screen.

- **FSG handbook - DE7.4.16** In order to enable the Race E-Key frequencies at the receiver, the input "Race 1" has to be set to high (by bridging the input with supply "+Ub"). That needs to be done upon receival of the E-Key with a flip switch in proximity to the Autonomous Mission Indicator (AMI) (see T14.11).

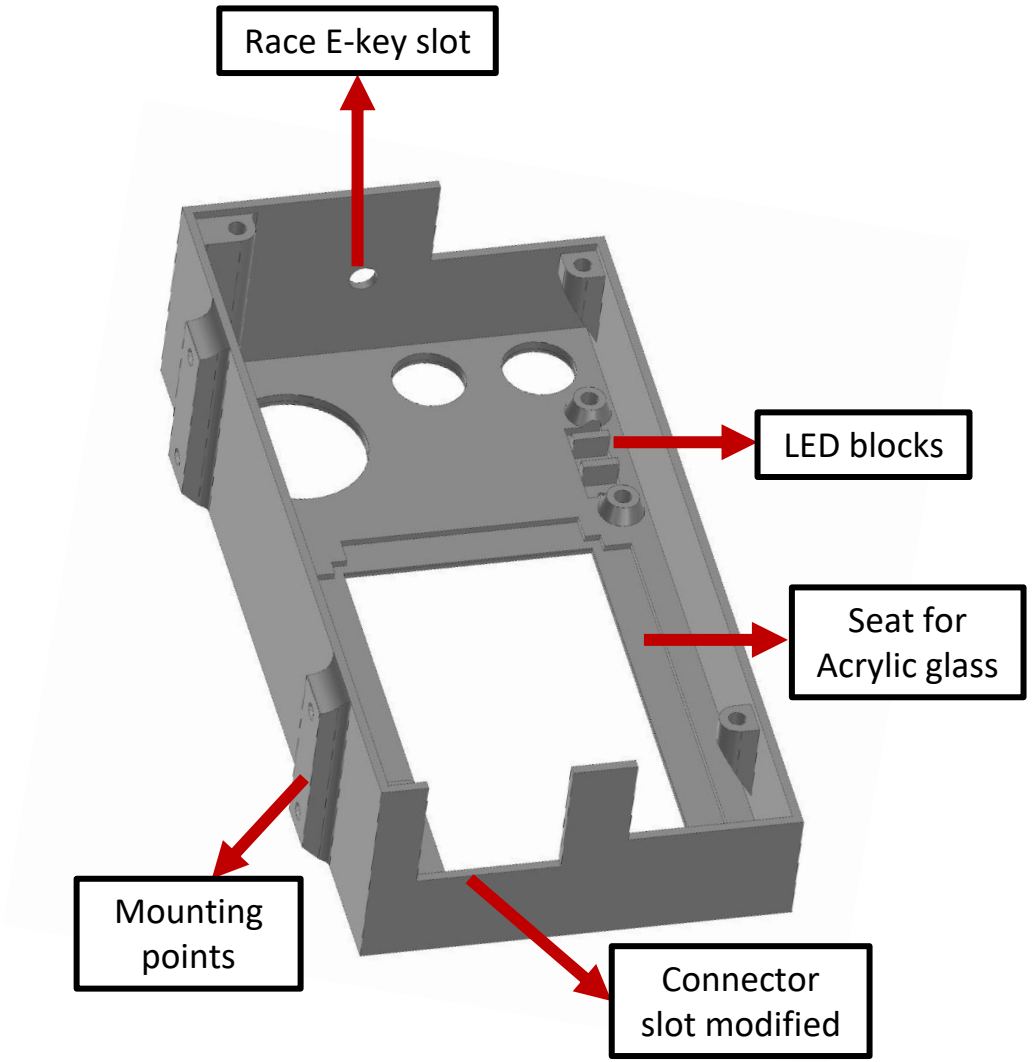
- **Mounting points** were included in the enclosure design to mount the dash on the steering holder. They have threaded brass insert for fastening.



Dash screen - Modifications

- **LED blocks** were added to avoid the light from one LED being visible from the adjacent LED hole in the enclosure. This is to avoid light dispersion.
- **Seat for acrylic glass** was designed to glue the screen protection glass inside the dash enclosure. Compared to CFS 23 where the glass was glued on the outside of the enclosure, this design was compact and aesthetic.
- Modifications were made to **connector slot** to improve the fit between the enclosure and the connector.
- **Waterproofing**: Silicone paste in the lid-enclosure interface.

Refer Appendix A for more pictures of the dash



Rear Node assembly

Highlights

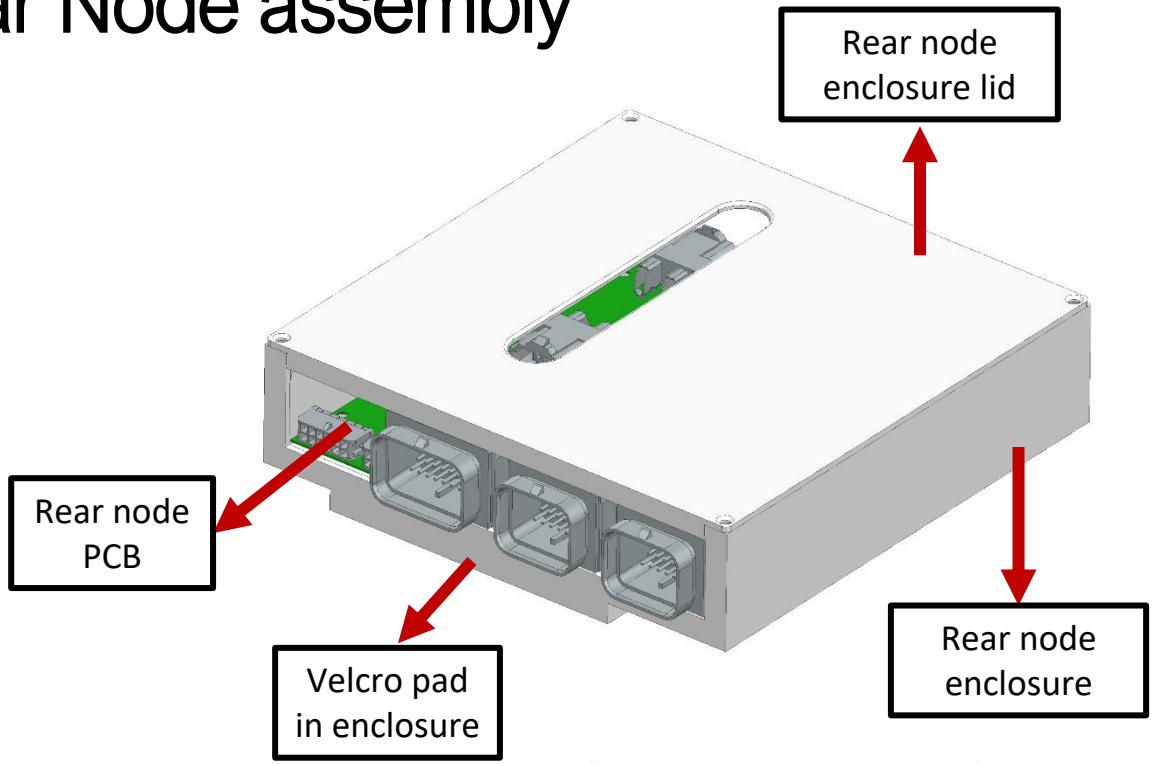
- Main node for power distribution and vehicle control. Mounted to monocoque with Velcro.
- Does not require a waterproof enclosure as it sits in the rear compartment.

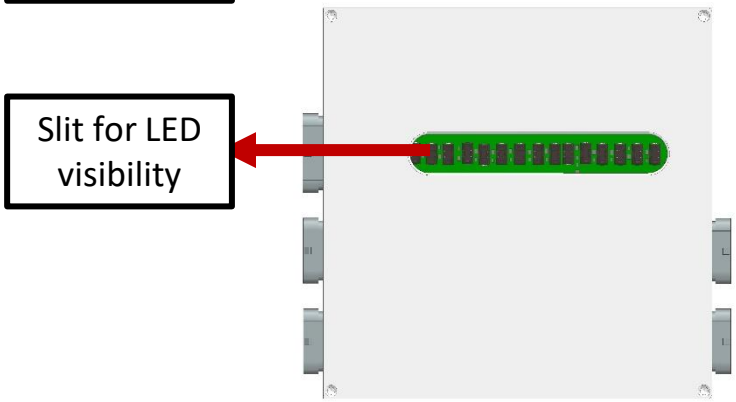
Modifications

- Slit was made in the enclosure lid for LED visibility.
- Lid was modified for better fit.

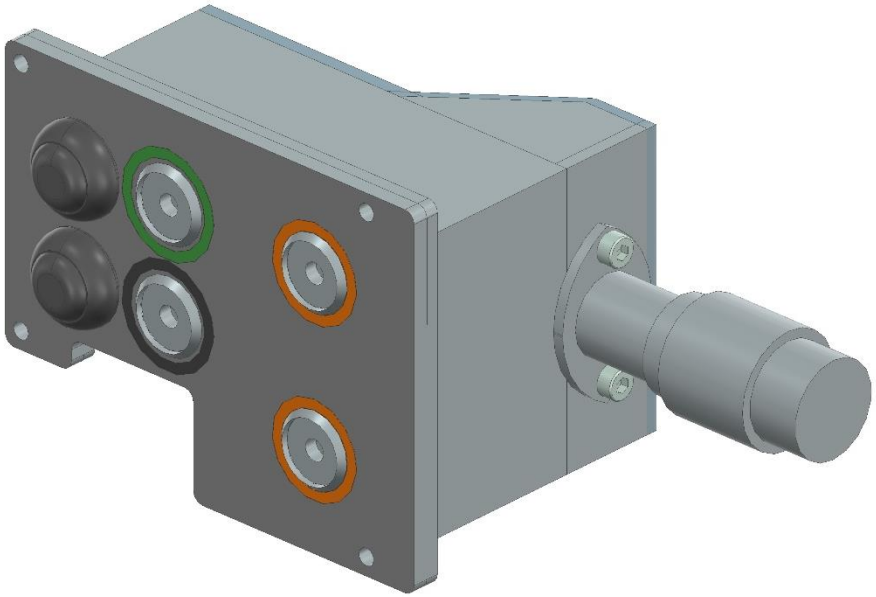
Material selection

- PETG – No specific material requirement, a fairly durable material was needed hence PETG was chosen.



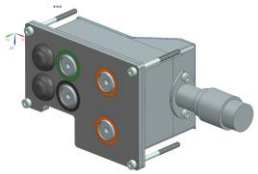


Tractive System Measurement Points (TSMP) assembly



Design requirements for TSMP enclosure:

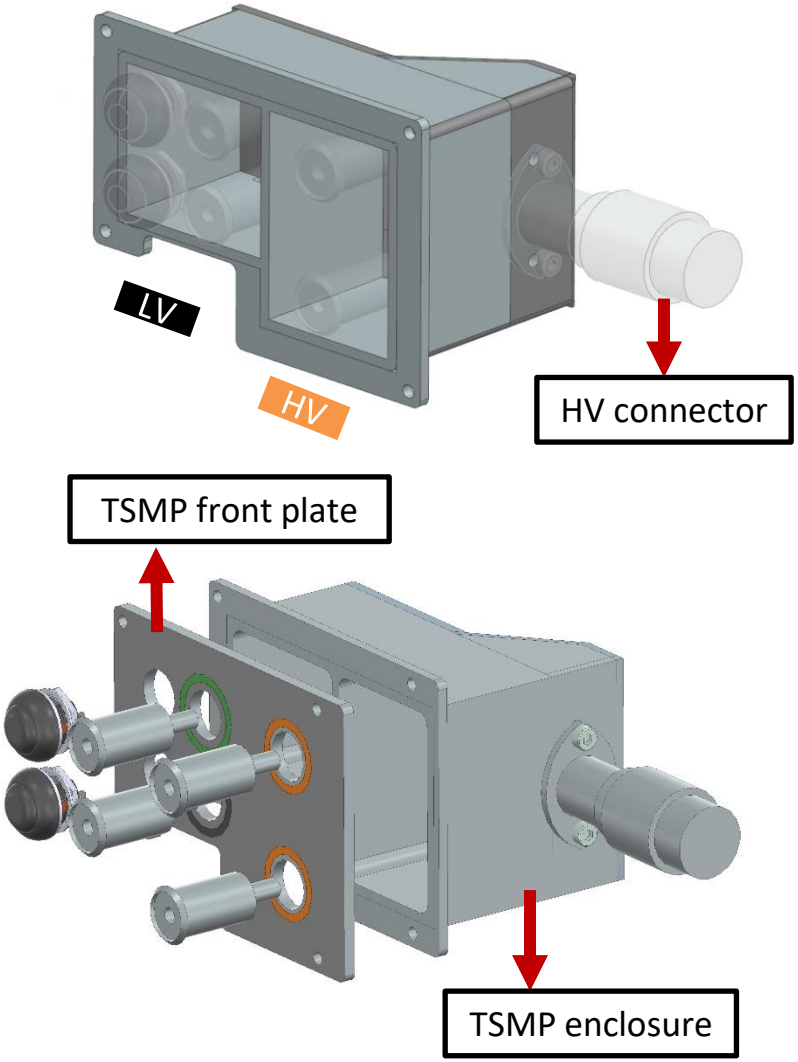
- Compact packaging of measuring points
- Rule compliant design
- HV, LV points & cables separated

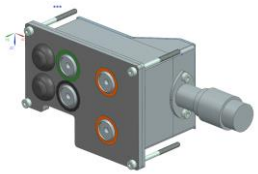


TSMP enclosure assembly

- TSMP are used to measure the Voltage of HV circuit, LV circuit and grounding.
- To comply with this Rule EV 4.5.8 a new TSMP enclosure was designed. **FSG rulebook - Rule EV 4.5.8**, all tractive system wiring that is outside a tractive system enclosure must be able to withstand a force of 200 N at each end without straining the cable and crimp.
- TSMP enclosure has the HV and LV measurement points separated by a wall. It has a wall mounted connector for HV cables and a slit in the bottom for LV cables.
- TSMP front plate holds the measuring points and helps assemble the enclosure in the monocoque before the wires from the measuring points are connected to the main harness.

Note: Follow FSG rulebook - Rule EV 4.7 which has all rules relevant to TSMP.





TSMP enclosure – Material selection

- Material for TSMP enclosure requires higher shear strength as it needs to withstand the specified load as per rules.
- Other important parameters are temperature resistance (since it is open to rear compartment), printability (ease of printing with bed adhesion and print temperatures), warping and layer adhesion which affect the print result.

Chosen material: PETG

Parameter	PLA (ref)	PETG	ABS
Shear Strength	0	+1	0
Temperature resistance	0	0	+1
Printability	0	0	-1
Warping and Layer Adhesion	0	+1	0
Total	0	+2	0

TSMP terminologies

High voltage measuring

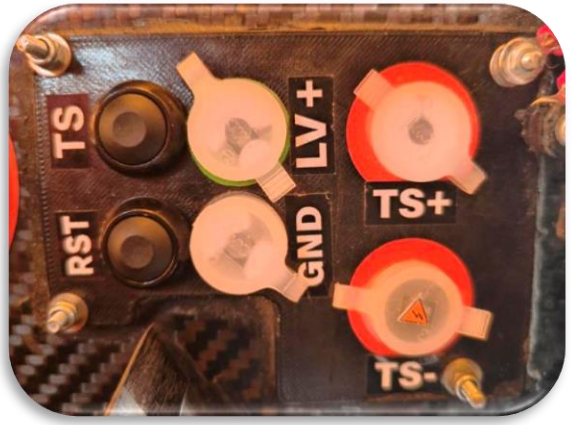
Both TS+ and TS- are connections from battery

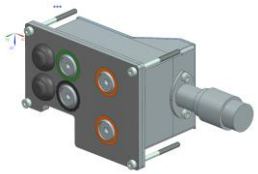
- TS+ : Tractive system positive terminal
- TS- : Tractive system negative terminal

Low voltage measuring

LV+ is the LV power output

- LV+ : Low voltage positive
- GND: Grounding terminal





TSMP enclosure – Shear calculation

- This calculation ensures PETG enclosure can withstand the shear force due to 200N load. The shearing surfaces for the enclosure are HV connector interface and the bolt fixation shear area.

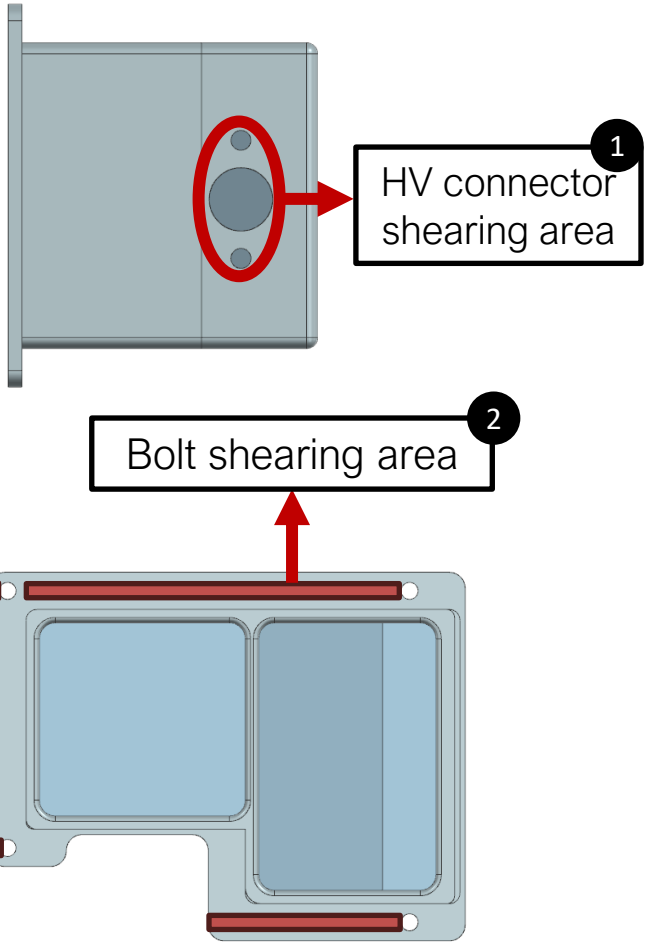
- Since the shearing area for HV connector is lower it has more failure potential and calculation for shear stress is performed for connector shearing area.

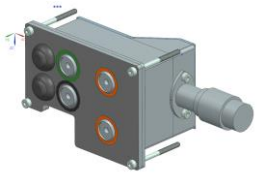
3D Printing factors

Since the part is 3-D printed, there are correction factors for mechanical properties of the material which are:

- **Anisotropy Correction Factor**: Anisotropy in 3D printing arises due to the layer-by-layer deposition process. Correction factor used is 0.5 to 0.7 for strength properties

- **Print Quality Factors:** Accounts for variations in layer adhesion, porosity, and infill density, which can significantly affect the strength. Correction Factor for Infill Density: 0.6 to 0.8 compared to a solid part. Correction Factor for Layer Adhesion: 0.5 to 0.9.





TSMP enclosure – Shear calculation

Inputs

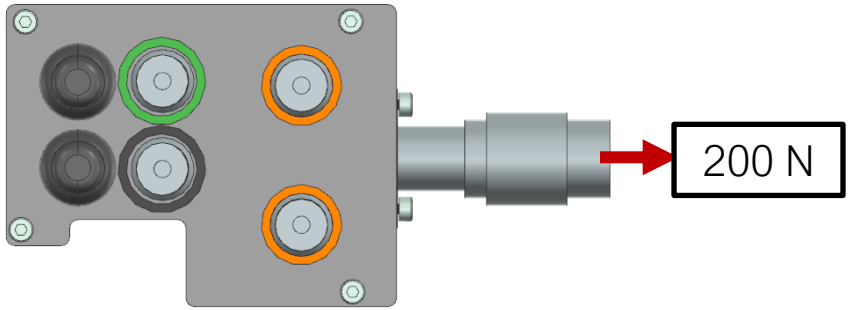
<u>Yield strength for PETG (σ_y)</u> = 39 Mpa

Force (to withstand as per rules) = 200 N

Correction factors: CF_{ACF} = 0.6, CF_{ID} = 0.7, CF_{LA} = 0.9

<u>Maximum shear strength for PETG</u>:

$T_y = (\sigma_y/\sqrt{3}) * CF_{ACF} * CF_{ID} * CF_{LA}$ = **8.5 Mpa**



Calculation

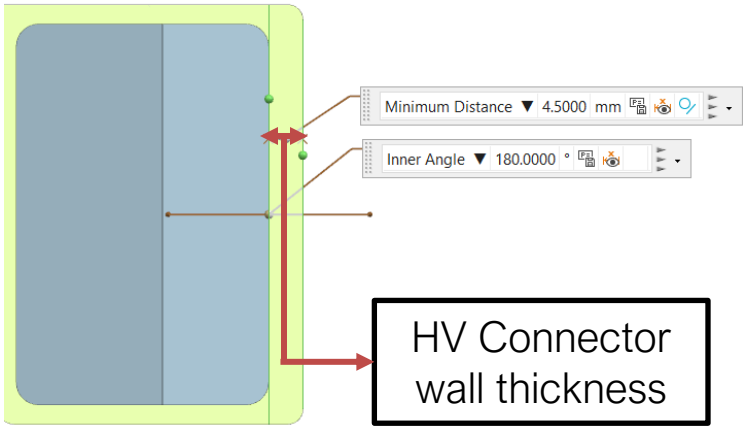
Perimeter of the HV connector interface (P_{sh}) = 57 mm

Thickness of enclosure at connector region (T_{sh}) = 4.5mm

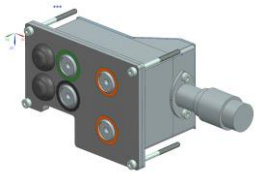
Connector shearing area = $P_{sh} \times T_{sh}$ = 256.68 mm^2

Shear stress = Force/Connector shearing area

= 200/256.68 = **0.77 Mpa**



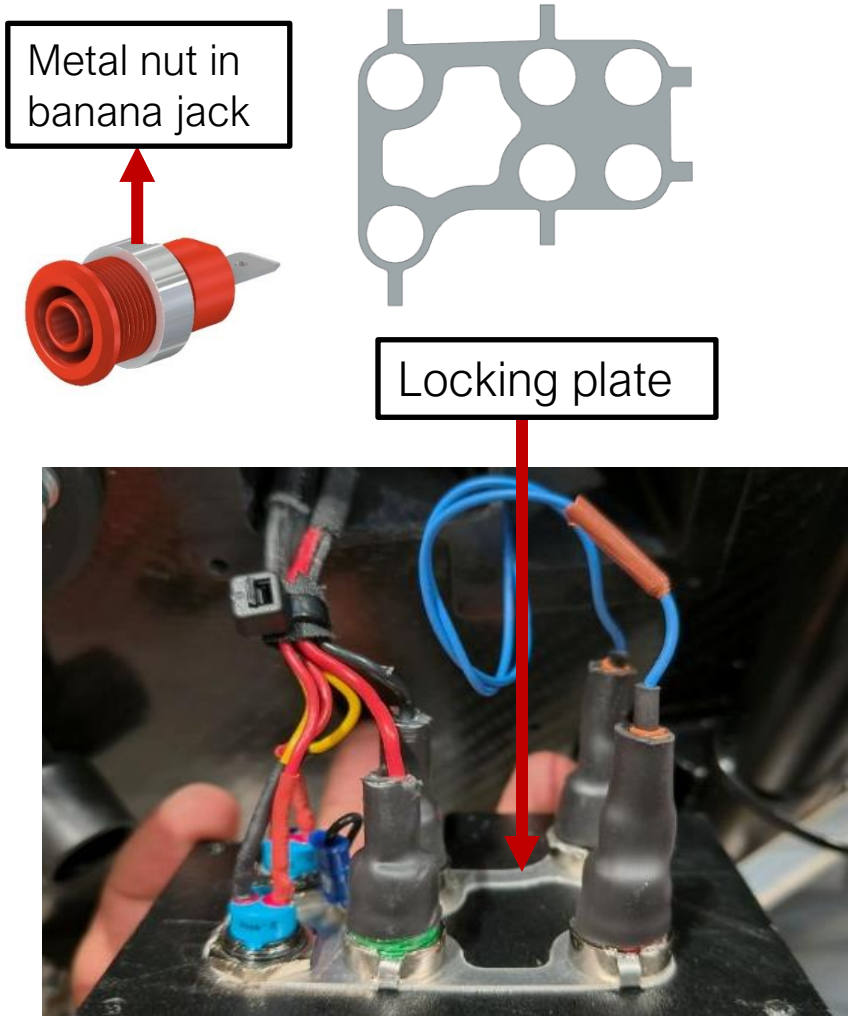
***Factor of Safety from the calculations is around 11**. Thus, the enclosure is over-designed and wall thickness can be downsized.*



TSMP enclosure – Locking plate

- The measuring points are positively locked using an Aluminum 0.5mm locking plate in compliance with Rule EV4.7.7.
- FSG rulebook - EV4.7.7 All electrical connections needed for TSMP, including bolts, nuts, and other fasteners, must be secured from unintentional loosening by the use of positive locking mechanisms. Bolted connections must follow T10.2, soldered connections EV4.5.16
- The locking plate also helps with grounding the metal nuts in the banana jacks.
- A grounding cable in contact with LV GND and the metal plate is used.

Refer Appendix B for more pictures of TSMP



Telemetry - Antenna mount

Requirement

- Sturdy and stiffer mount
- Antenna away from main hoop

Material selection

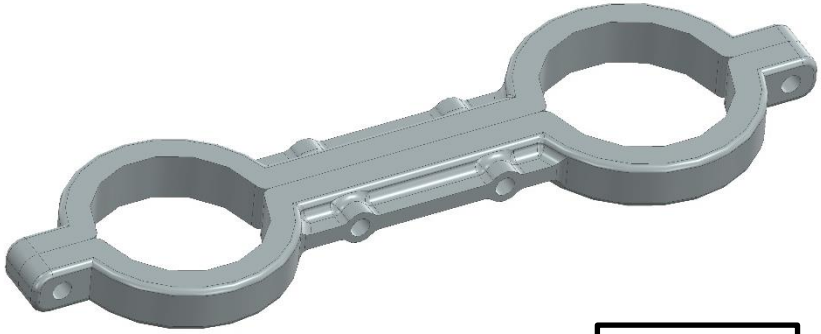
- **Nylon -** to give the mount a higher strength

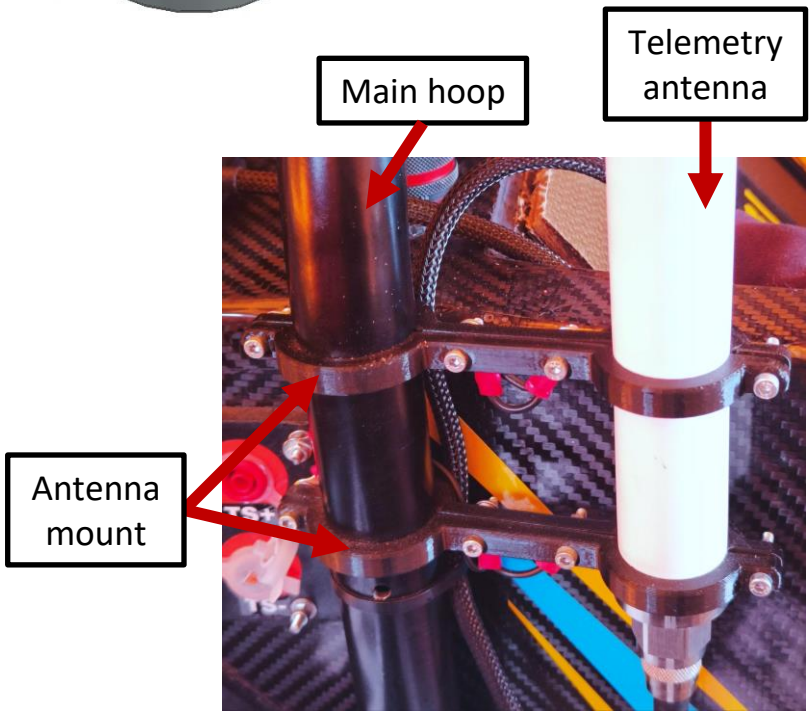
Key points

- Telemetry antenna transmits real-time data from the car to the base station using WiFi for data monitoring.

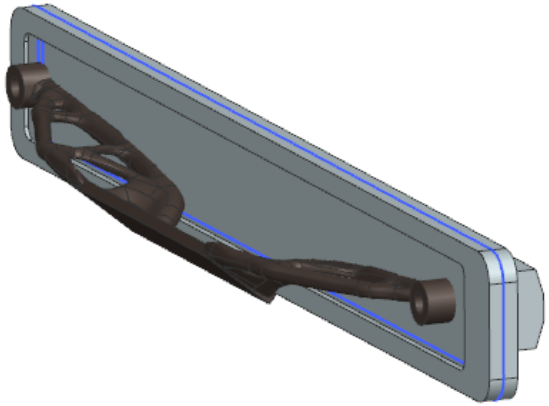
- The reason for having such a long antenna mount was to place the telemetry antenna away from the main hoop. The signals sent by the antenna are disturbed or reflected if it is close to metal bodies.

- To know more about the antenna test results and to understand more about telemetry system please refer to Ayman Alzein, Final report CFS24.

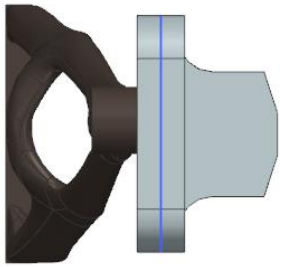




ASSI and Brake light assembly



ASSI light



Brake light

Design requirements for light enclosure and mount

- Waterproof light enclosure
- Easy to mount and dismount
- Sturdy mounting solution
- Rule compliant

Autonomous System Status Indicator

- The ASSI illuminates when the autonomous system is active. There are 3 ASSIs lights - 2 on either side of the rear wing endplate and one above the rear hatch and brake light.

- Rear ASSI assembly was designed together with Elias Håland. Design of ASSI on rear-wing can be found in Gianmarco Mancini, Final report CFS24.

Positioning of the ASSI light is based on the rules:

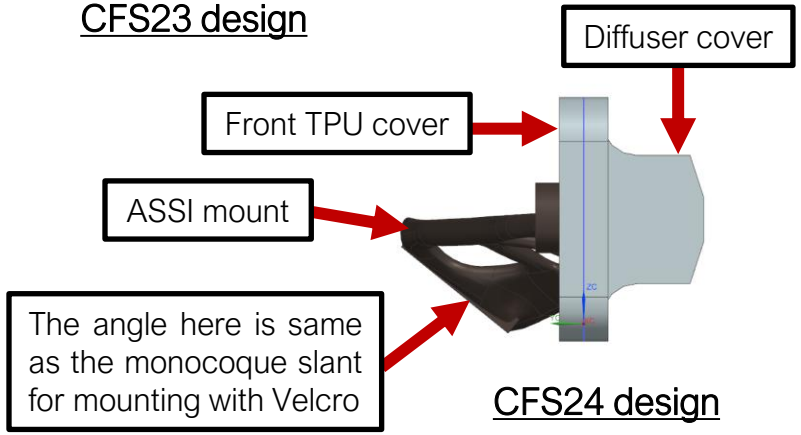
- FSG rulebook - T14.10.2 One ASSI must be located on each side of the vehicle behind the driver's compartment, in a region 160 mm below the top of the main hoop and 600 mm above the ground. The third ASSI must be located at the rear of the vehicle, on the vehicle centerline, in a region 160 mm below the top of the main hoop and 100 mm above the brake light.

- FSG rulebook - T14.10.3 At least one ASSI must be visible from any angle of the vehicle from a point 1.60 m vertically from ground level, within 3 m horizontal radius from the top of the main hoop.

Changes from CFS23 design:

- Diffuser used in CFS23 was 2mm thick aralyic glass plates that were glued together to form the 4 sides of the diffuser cover.
- This was hard to assemble and difficult to later re-open the diffuser cover if needed to access the PCB. Soldered wires are the weak points on PCB.
- Thus, a vacuum formed diffuser cover that is directly glued on the cooling plate was made.
- New mounts were designed for better stability.

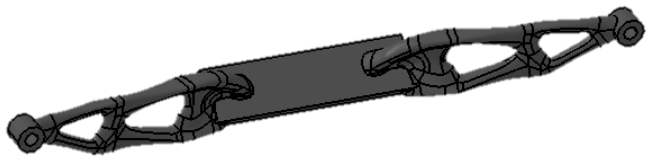
CFS23 design



CFS24 design

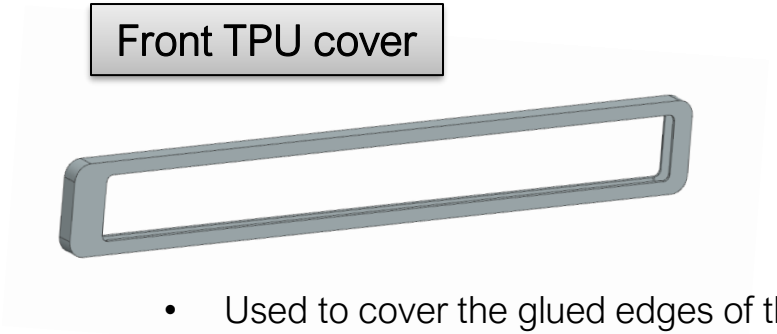
Autonomous System Status Indicator - Assembly

ASSI mount



- Topology optimized mount
- **Material: Nylon** (3-D printed) chosen for higher strength

Front TPU cover



- Used to cover the glued edges of the diffuser cover
- **Material: TPU** (3-D printed) chosen for its flexibility needed while assembling.

Diffuser cover

- Diffuser cover is 0.5mm thick and diffusion is done by sanding the cover with a sand paper.
- **Material: Acrylic sheet** (vacuum formed using a 3-D printed mould)

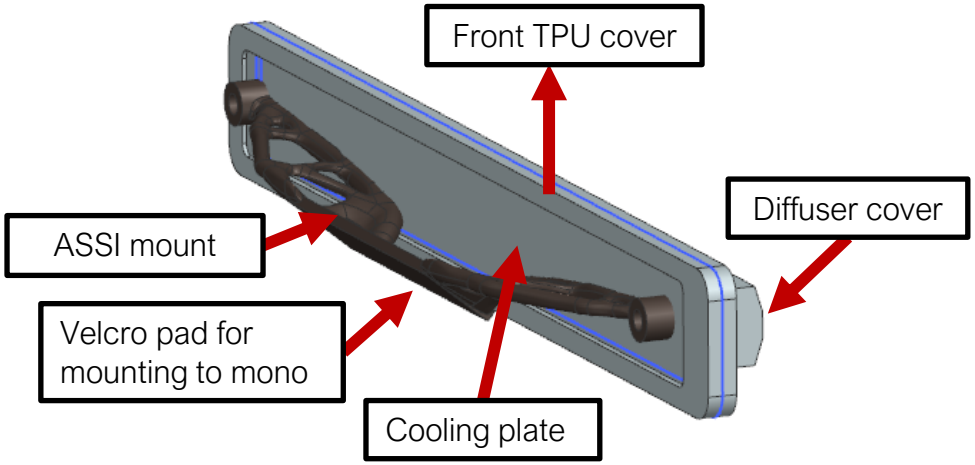
Cooling plate

- 2mm thick cooling plate is used for heat dissipation from PCB
- **Material: Aluminum** (laser cut)

Autonomous System Status Indicator light - Assembly

The following assembly procedure was followed:

1. Thermal paste is used in between the cooling plate and PCB for better thermal dissipation.
2. ASSI PCB is bolted to the cooling plate and the ASSI mount after thermal paste is applied.
3. Diffuser cover is glued on to the cooling plate.
4. Waterproofing: Silicone is applied on interface.
5. Front TPU cover was added at last to cover the glued edges of the diffuser cover.



More rules to follow while designing both ASSI and Brake light enclosure and PCB. **Rule T11.10,** Important consideration is the illuminated surface area and LED distance.

T 11.10 System status light

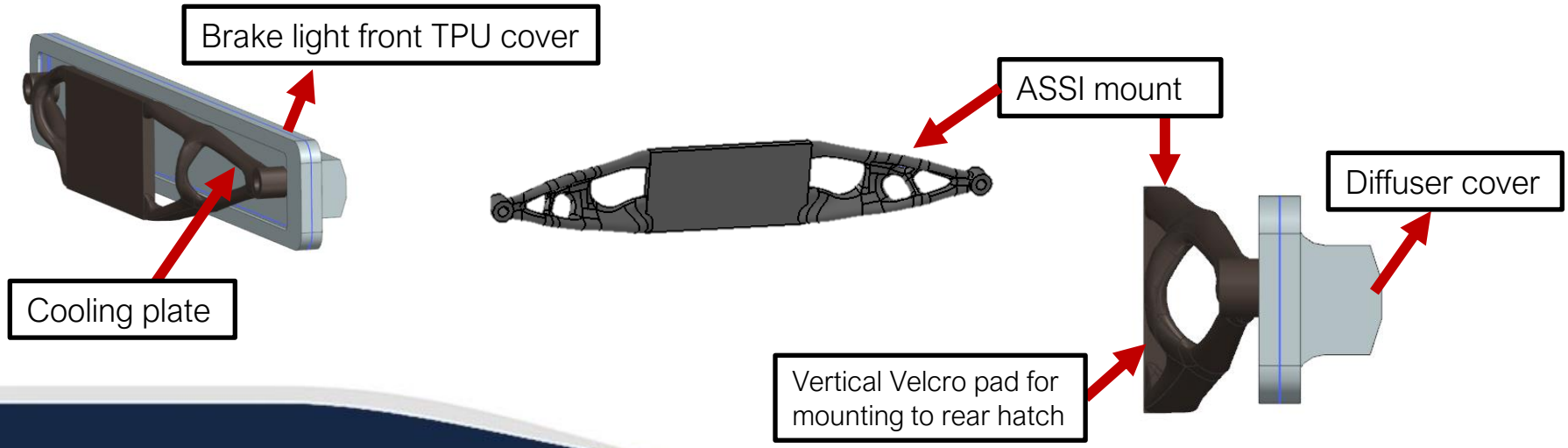
T 11.10.1 Any system status light(s), see T 6.3 and T 14.10, must meet the following requirements:

- Black background.
- Rectangular, triangular or near round shape.
- Minimum illuminated surface of 15 cm^2 with even luminous intensity.
- Clearly visible in very bright sunlight.
- If LED lights are used without a diffuser, they must not be more than 20 mm apart.
- If a single line of LED lights is used, the minimum length is 150 mm.

Brake light - Assembly

- The brake light is illuminated when the pneumatic brakes are actuated. Placed in the rear hatch of the car.
- It has the same PCB dimensions as ASSI, so the cooling plate and diffuser cover have the same design concepts as the ASSI. Separate mount was designed for brake light.

Positioning of the brake light is based on the rule:
FSG rulebook - RuleT6.3.3 In side view the brake light must be oriented vertically and mounted between the wheel centerline and driver's shoulder level. Viewed from the back it must be positioned approximately at the vehicle's centerline.



Wiring Harness

Harness Design process

Harness layout designed in Rapid harness

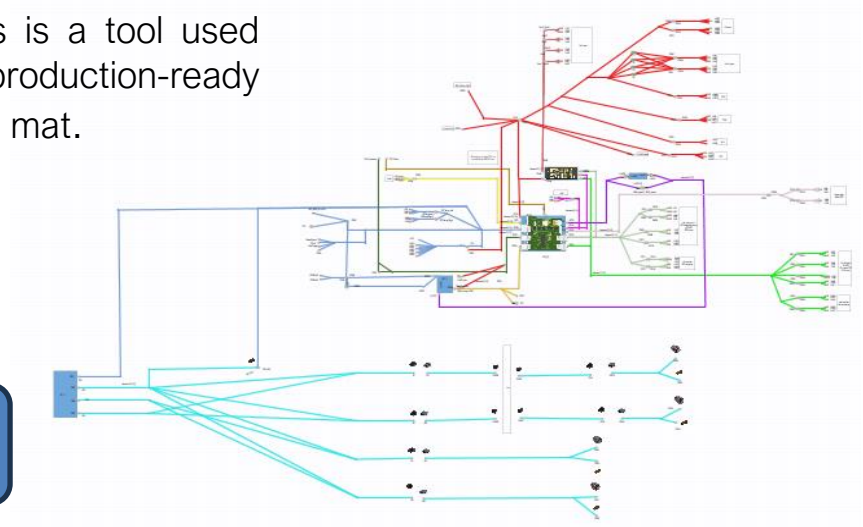
Detailed CAD of wiring harness for accurate lengths using Siemens NX

Export the lengths from CAD to Rapid Harness

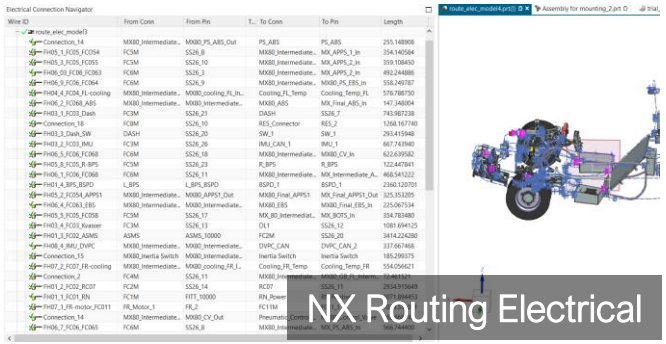
Slack estimation for the lengths using excel tool

Wiring harness mat designed in Rapid harness

- Rapid harness is a tool used for designing production-ready wiring harness mat.



Rapid Harness overview



NX Routing Electrical

Wiring Harness – Routing procedure

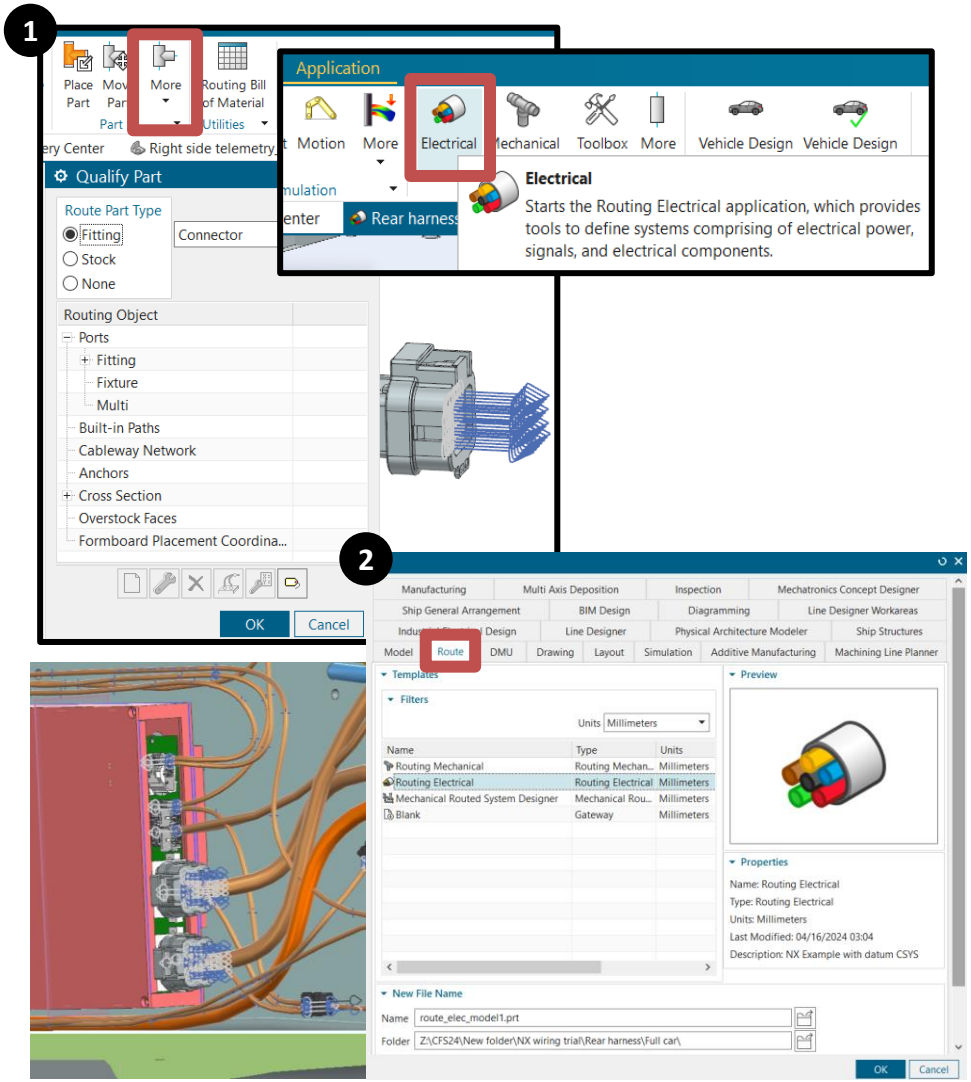
- Siemens NX routing electrical was used for wiring CAD.

STEP 1 Qualify the standard part

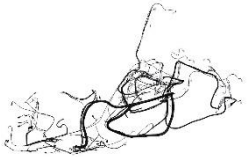
- Qualify refers to creating labelled pin outs with unique ID's for the standard connectors.
- Change application in the taskbar to electrical to qualify the connector.

STEP 2 Create electrical routing assembly, properly position components and connectors

- File – New – Route – Routing electrical for new routing assembly file
- Place the connectors in its position before starting to route the cable.



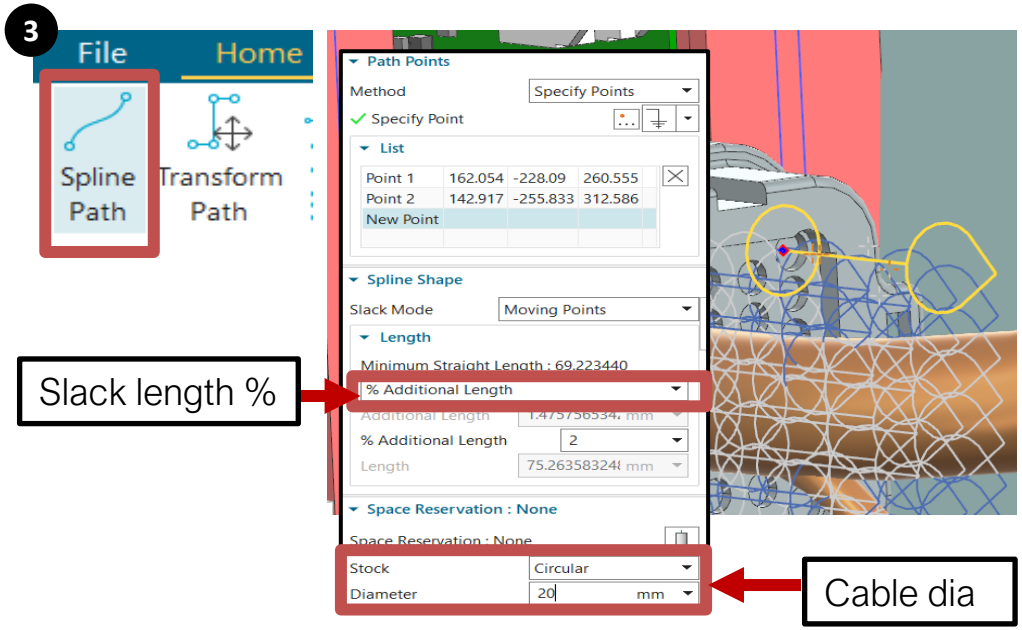
CHALMERS FORMULA STUDENT



Wiring Harness – Routing procedure

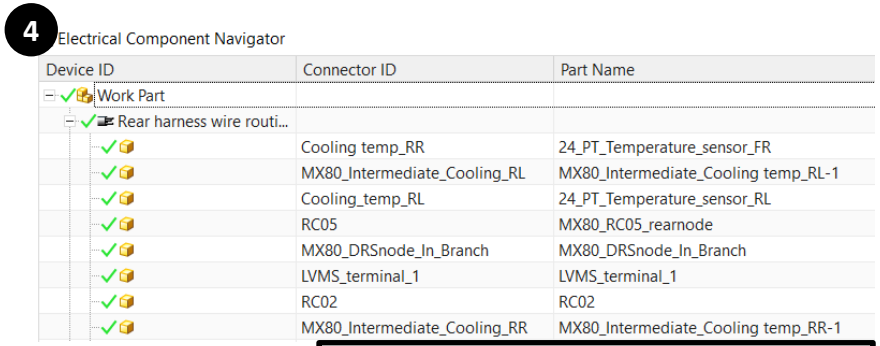
STEP 3 Drawing spline path

- Spline path is drawn between the start and end connector pin outs.
- Place the spline points along the desired routing path, use other components or monocoque as reference for spline path.
- Mention the stock type to be circular and specify the diameter of the cable.

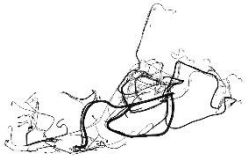


STEP 4 Create the connector list

- This step is for creating a connector list in the electrical component navigator window. The connector defined in this table is later assigned to the actual connector in the assembly.



CHALMERS FORMULA STUDENT



Wiring Harness – Routing procedure

STEP 5 Create connection list

- A connection list is created by defining from and to connector based on the electrical component navigator. Also define the connector pinouts in this list.

5 Electrical Connection Navigator

Electrical Connection Navigator

Wire ID	From Device	From Conn	From Pin
Work Part			
Rear harness wire routing_1			
Connection_66		RL-Motor-Intermedi...	RL-Motor-Intermedi...
RC01_2_RS02_LMJT		MX80_RC01_Branch	MX80_RC01_branch...
RC03_02_RS16_Rear ASSI light		MX80_Intermediate...	MX80_Intermediate...
Connection_20		RC05	RC05_1_PW
Connection_5		MX80_Intermediate...	MX80_Intermediate...
Connection_6		MX80_Intermediate...	MX80_Intermediate...
RC02_04_RS13-RR-damper		MX80_RC02_Branch	MX80_RC02_branch...
RC09_01_RS28 - RWP		RWP	MX80_RWP_1

STEP 6 Assigning connector and connections

- Either auto assign or manual assign is used to match the entry of the connector or connection to parts in the assembly. Once assigned, a tick mark appears.
- Once connections in this list is assigned to the actual spline that was drawn in step 3, the lengths of the assigned connections is displayed in this window.

Note: The connector and connection list can be imported directly to CAD as a PLMXML file

If the assign function fails to find the match between the CAD and the list, it shows a red symbol

6

Auto Assign
Automatically assigns assembly components to the selected components by using specified match criteria.
In Commands > Routing Electrical

Assign Stock
Modifies the stock (wire/cable/shield) information for the selected connections.
In Commands > Routing Electrical

Manual Assign
Manually assigns an assembly component to the selected component by allowing it to be selected from the graphics window.
In Commands > Routing Electrical

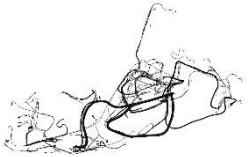
Electrical Connection Navigator

Wire ID	From Conn	From Pin	To Conn	To Pin	Length
Connection_70	FR-Motor-Intermedi...	FR-Motor-Intermedi...	PE2_Connector	FR-Motor_Temp	211.016563
Connection_80	PE_SDC connector	SDC to TSMP	TSMP-TS+,TS-	SDC from PE	293.073693
Connection_48	LVMS_terminal_1	LVMS_Terminal_1_Li...	INLINE_FUSE_FOR LI...	Inline_Fuse_Lidar-F	491.217800
Connection_64	RR-Motor-Intermed...	RR-Motor-Intermed...	PE2_Connector	RR-Motor_Temp	209.662912
Connection_84	LVMS_terminal_1	LVMS_Terminal 1_LV...	TSMP-LV	LV+_TSMP from LV	353.312718
Connection_61	CDL_Inside	CDL Inside_to FW1	FW1f-FW1- Firewall...	CDL_Inside	787.912670
Connection_83	Lidar_GND	LV_GND-TSMP	TSMP-LV	LV_GND from Grou...	117.024098
Connection_42	RC_08	SS26_16	MX80_RC08-TSMP&...	RC08-TSMP&TSMS...	190.152011
Connection_63	RR-Motor-LV conne...	RR-Motor-LV-1	RR-Motor-Intermed...	RR-Motor-Interme...	1274.399051

Cable lengths

Video links for reference

CHALMERS FORMULA STUDENT



Wiring Harness – Slack estimation

- Lengths, pin data, connector ID and wire ID are stored in the electrical connection navigator window and can be exported from Siemens NX.
- The harness layout designed in rapid harness has a wiring table which is exported to perform slack calculation.
- Slack can be added to the cables in CAD but preferred using excel sheet for slack estimation. **Reason**: The original length in electrical connection navigator is lost if slack is added in CAD and the new slack length is displayed in the electrical connection navigator.

Top Level | Notes | Bill of Materials | Wiring Table | Cutlist | Labels

rapidHARNESS

Title:	RH008 CFS24
Part Number:	RH08
Description:	RH8 connecting RN to PE temp sensorns and MSMPs

From	To	Conductor	Conductor PN	Twisted With	Size	Length	From Contact PN	Notes
CDL_f.1	LW7	W69.Green	7056/19 GR001		20 AWG		43031-0002	
CDL_f.4	LW10	W19.Blue	7056/19 BL001		20 AWG		43031-0002	
CDL_f.5	LW11	W20.Blue	7056/19 BL001		20 AWG		43031-0002	
CDL_f.6	LW12	W71.Green	7056/19 GR001		20 AWG		43031-0002	
CDL_f.7	LW13	W17.Blue	7056/19 BL001		20 AWG		43031-0002	
CDL_f.8	LW14	W18.Blue	7056/19 BL001		20 AWG		43031-0002	
CDL_f.9	LW15	W72.Green	7056/19 GR001		20 AWG		43031-0002	
CDL_f.10	LW16	W73.Green	7056/19 GR001		20 AWG		43031-0002	
PETempLeft_f.1	LW1	W56.Red	5876 RD001		20 AWG		MX80P10K4F1	
PETempLeft_f.2	LW2	W61.Black	3053/1 BK001		20 AWG		MX80P10K4F1	
PETempLeft_f.3	LW3	W36.Violet	1553 VI001		20 AWG		MX80P10K4F1	
PETempRight_f.1	LW4	W58.Red	5876 RD001		20 AWG		MX80P10K4F1	
PETempRight_f.2	LW5	W63.Black	3053/1 BK001		20 AWG		MX80P10K4F1	
PETempRight_f.3	LW6	W66.Violet	1553 VI001		20 AWG		MX80P10K4F1	
RC08.1	TSMS.1	W39.White	20 AWG White		20 AWG	245 mm	3-1447221-4	SDC out to TSMS
RC08.2	PE_CANf.2	W22.Green	7056/19 GR001	W13	20 AWG		3-1447221-4	PE CAN Low
RC08.3	PE_CANf.1	W13.Blue	7056/19 BL001	W22	20 AWG		3-1447221-4	PE CAN High
RC08.4	CDL.1	W21.Green	7056/19 GR001	W11	20 AWG		3-1447221-4	CDL Main CAN Low out
RC08.5	CDL.5	W11.Blue	7056/19 BL001	W21	20 AWG		3-1447221-4	CDL Main CAN High out
RC08.6	CDL.9	W25.Green	7056/19 GR001	W15	20 AWG		3-1447221-4	CDL RES CAN Low in
RC08.7	CDL.10	W26.Green	7056/19 GR001	W16	20 AWG		3-1447221-4	CDL RES CAN Low out
RC08.8	CDL.7	W15.Blue	7056/19 BL001	W25	20 AWG		3-1447221-4	CDL RES CAN High in
RC08.9	CDL.8	W16.Blue	7056/19 BL001	W26	20 AWG		3-1447221-4	CDL RES CAN High out
RC08.10	RS62.5	W47.Yellow	3073 YL001		20 AWG		3-1447221-4	BSPD Test enable

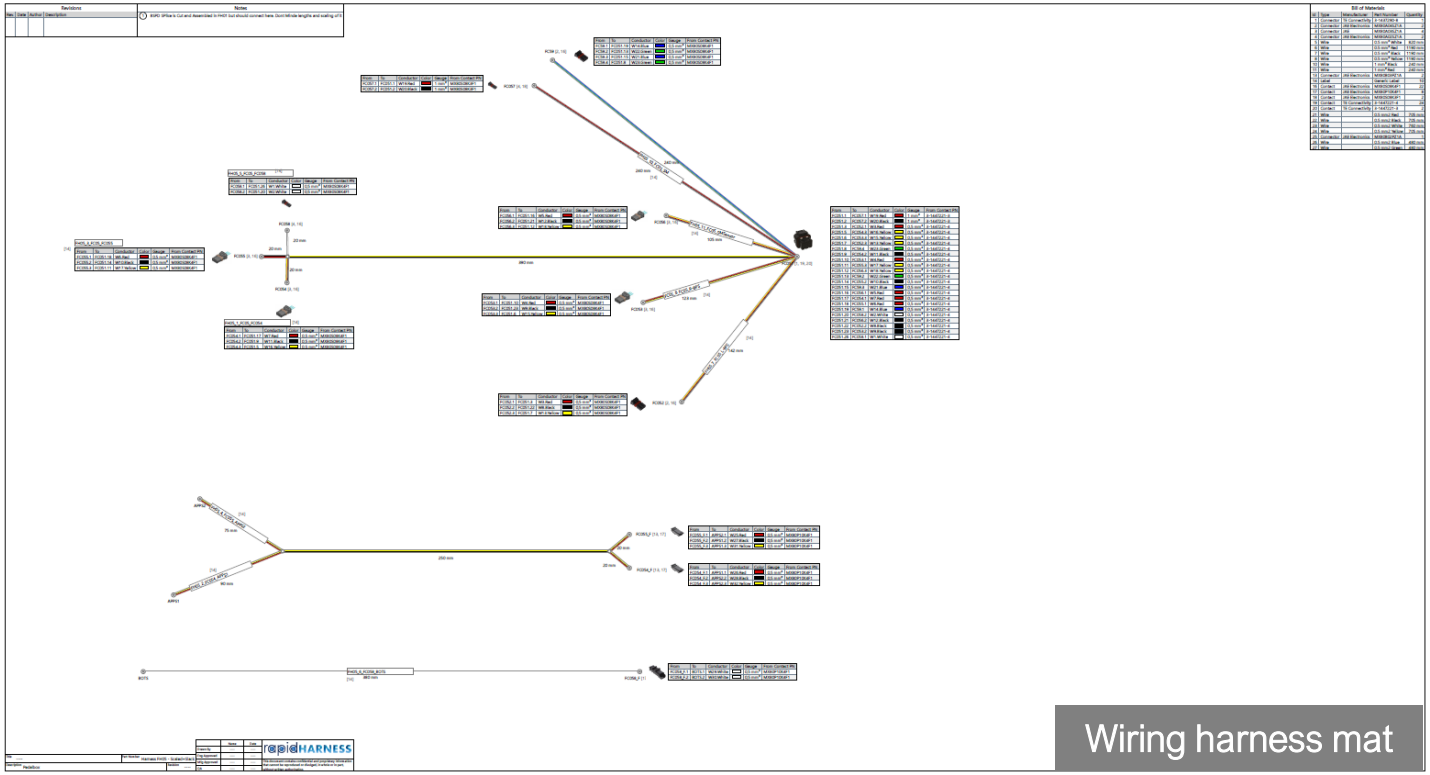
Rapid Harness

	From	To	Conductor	Conductor PN	Twisted	Gauge	CAD(mm)	Slack	Slack length (mm)	Added (mm)	Vehicle (mm)	CAN (mm)	From Contact PN	To Contact PN	Notes
8															
9	From	To	Conductor	Conductor PN	Twisted	Gauge	CAD(mm)	Slack	Slack length (mm)	Added (mm)	Vehicle (mm)	CAN (mm)	From Contact PN	To Contact PN	Notes
10	ASMS.1	FC2.13	W9.Red	1.0 mm2 Red		1 mm²	3415	5%	3586	171				3-1447221-3	ASMS
11	FW.1	FC2.6	W6.Blue	0.5 mm² Blue	W2	0,5 mm²	3140	6%	3319	179	3071	**3817**	85990707900	3-1447221-4	Main CANH - FN to FW/CAM
12	FW.2	FC2.7	W2.Green	0.5 mm² Green	W6	0,5 mm²	3140	6%	3319	179	3071	**3817**	85990707900	3-1447221-4	Main CANL - FN to FW/CAM
13	PEC_SDC.1	FC1.3	W45.White	0.5 mm² White		0,5 mm²	4000	-	-	-			MX80P10K4F1	66566-7	SDC in from RN to EBS
14	PEC_SDC.2	FC1.4	W46.White	0.5 mm² White		0,5 mm²	4000	-	-	-			MX80P10K4F1	66566-7	SDC out to TSMS/RN from EBS
15	RC7.1	FC2.2	W7.Blue	0.5 mm² Blue	W3	0,5 mm²	2935	7%	3140	205	3051	**3612**	3-1447221-4	3-1447221-4	CDL CANH to Rear
16	RC7.2	FC2.4	W8.Blue	0.5 mm² Blue	W4	0,5 mm²	2935	7%	3140	205	3051	**3612**	3-1447221-4	3-1447221-4	CDL CANH - FN to RN
17	RC7.3	FC2.3	W3.Green	0.5 mm² Green	W7	0,5 mm²	2935	7%	3140	205	3051	**3612**	3-1447221-4	3-1447221-4	CDL CAN L to rear
18	RC7.4	FC2.5	W4.Green	0.5 mm² Green	W8	0,5 mm²	2935	7%	3140	205	3051	**3612**	3-1447221-4	3-1447221-4	CDL CANL - FN to RN
19	RC7.7	FC2.21	W12.Yellow	0.5 mm² Yellow		0,5 mm²	2935	7%	3140	205	3051		3-1447221-4	3-1447221-4	LED IMD
20	RC7.8	FC2.1	W14.Yellow	0.5 mm² Yellow		0,5 mm²	2935	7%	3140	205	3051		3-1447221-4	3-1447221-4	TS Ext Button
21	RC7.13	FC2.22	W11.Yellow	0.5 mm² Yellow		0,5 mm²	2935	7%	3140	205	3051		3-1447221-4	3-1447221-4	LED AMS
22	RC7.14	FC2.20	W13.Yellow	0.5 mm² Yellow		0,5 mm²	2935	7%	3140	205	3051		3-1447221-4	3-1447221-4	LED TS OFF
23	RC7.25	FC2.8	W15.White	0.5 mm2 White		0,5 mm²	2935	7%	3140	205	3051		3-1447221-4	3-1447221-4	SDC end RN to FN
24	RC7.26	FC2.14	W10.White	0.5 mm2 White		0,5 mm²	2935	7%	3140	205	3051		3-1447221-4	3-1447221-4	SDC FN To RN
25	RN_PWR.1	FC1.1	W1.Red	6.0 mm2 Red		6 mm²	3072	7%	3287	215			42815-0[illegible]	211841-3	14V LVS PWR
26	RN_PWR.2	FC1.2	W5.Black	6.0 mm2 Black		6 mm²	3072	7%	3287	215			42815-0[illegible]	[illegible]	[illegible]
27	FC052.4	BSPD_Splice	W14.Yellow	0.5 mm² Yellow		0,5 mm²	2372	6%	2514	142	2491				

Slack calculation

Wiring Harness - Production Diagram

- Slack lengths of the harness from excel sheets are manually added to rapid harness.



Wiring harness mat

Wiring harness mat was designed for the first time in CFS!! ☺

Firewall roof connector & monocoque slit

Both these concepts were introduced to simplify cable routing.

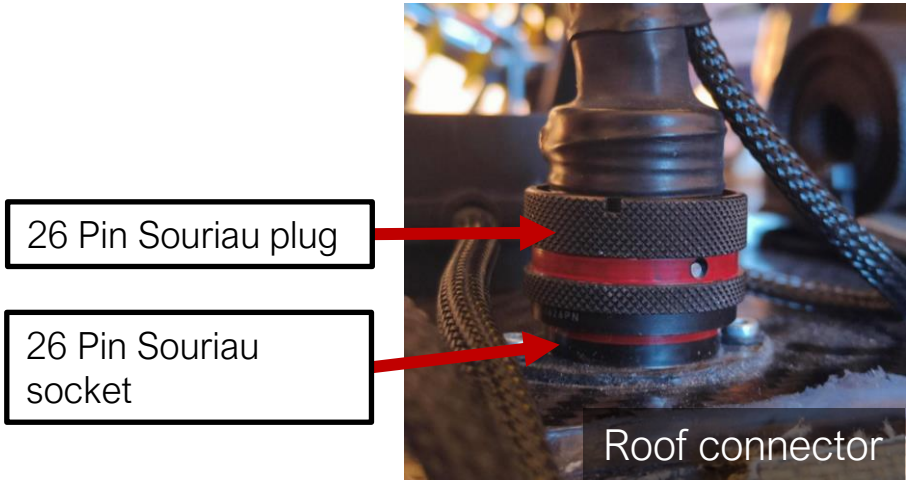
Monocoque slit

- Decision for mono slit was made to help re-route the LV cables away from the HV cables and avoid EMI issues.
- Except for the motor encoder and lidar cables all other LV cables from rear to front are routed through the slit.
- The slit in the monocoque is part of SES. So the dimensions of the slit was decided upon discussion with frame subgroup and approximated cable bundle diameter that needs to pass through the mono slit.

Firewall roof connector

- The firewall connector was placed in the roof of rear compartment to route the cables for the LV components close to the main hoop.

Monocoque slit



Roof connector

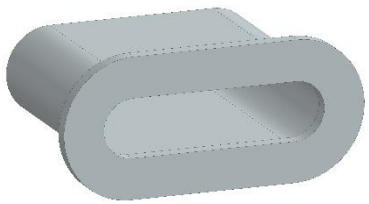
Cable grommets

Requirement:

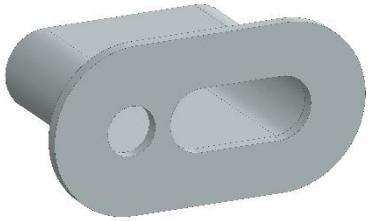
- Flexible material to accommodate grommet holes in the monocoque and cable strain relief.
- Hole dimension should be based on cable bundle diameter.
- HV, LV and Brake lines separated.

Material: TPU (Thermoplastic polyurethane)

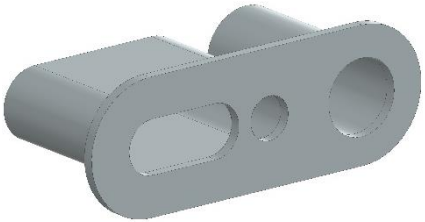
- **Note:** The holes for the cable grommet in the monocoque are part of SES. Verified hole dimensions with frame subgroup to make sure the size of the grommet hole in the particular CF panel satisfies SES.



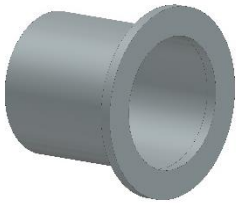
DVPC/RES



Front LvBr

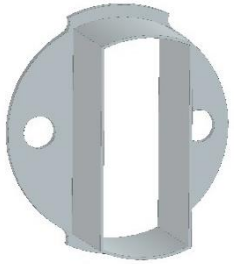


Rear HvLvBr

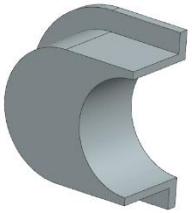


Firewall roof

Rear Lights



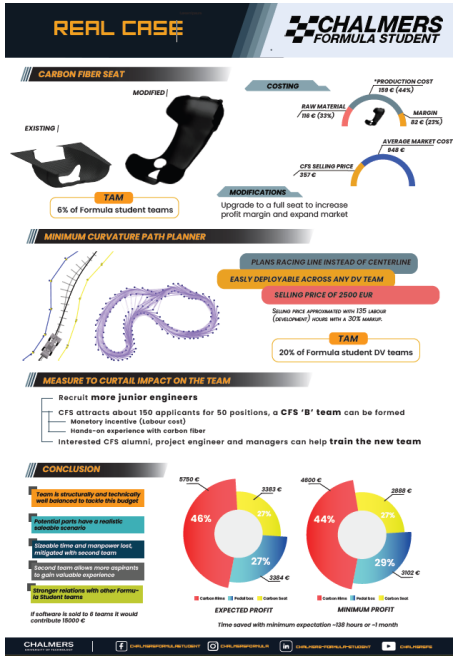
Master switch

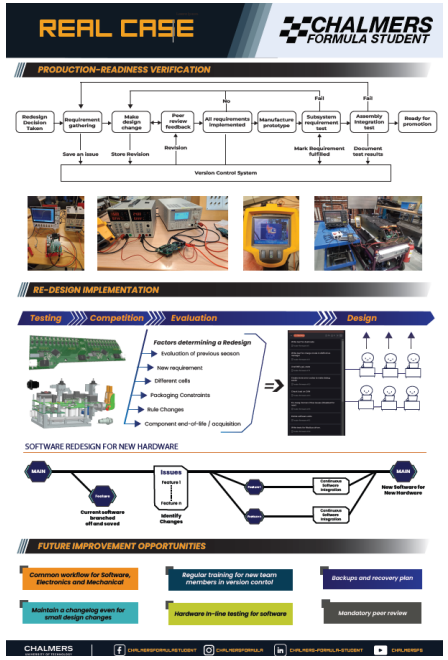


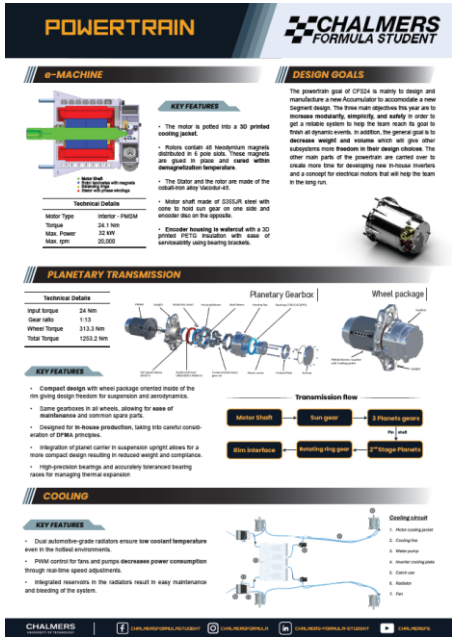
Firewall mono slit

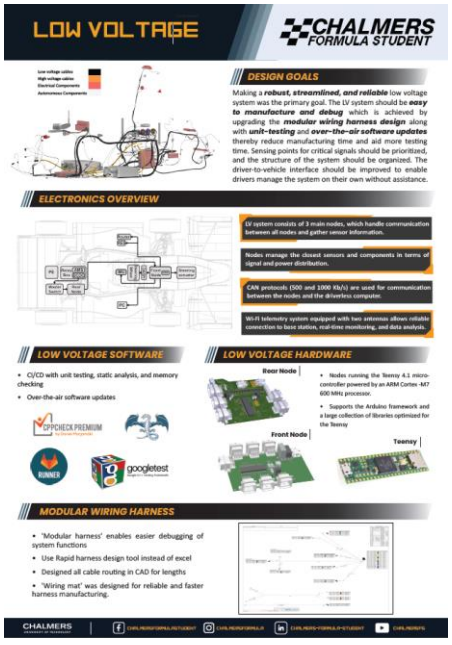
Other miscellaneous design work

- The intention of the design poster is to display the overview and highlights of each subsystem.
- It helps with easier visualization of the components and is important as it gives the first impression to the design judges about the subsystems.









- Designed all posters for design and cost event along with Maulik Rajput.
- Posters were designed in Adobe illustrator
- Important to start focusing on this early, and represent data in easily understandable way. Good to avoid long texts in the poster.

CHALMERS FORMULA STUDENT

Manufacturing

Wiring harness

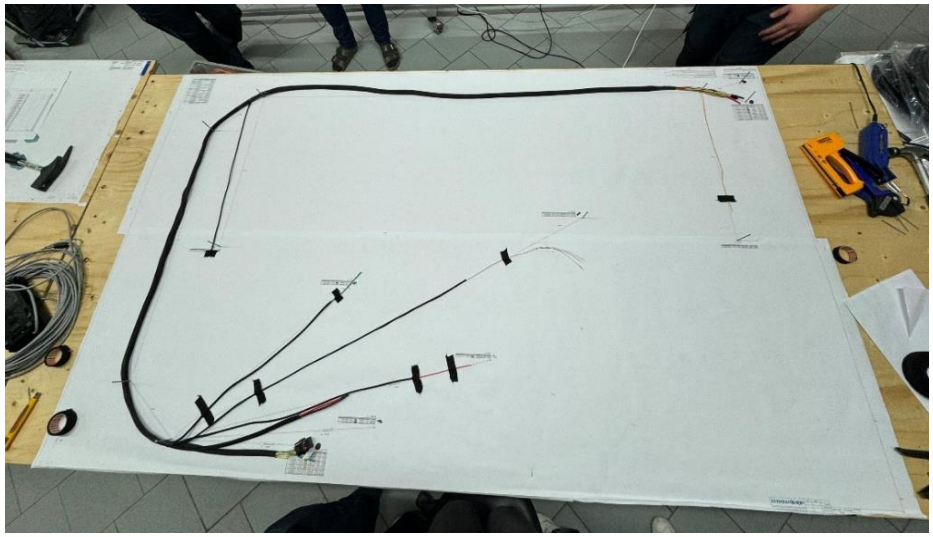
3-D Printing

Wiring Harness manufacturing

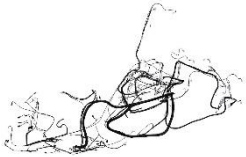
- Majority of harness manufacturing was done at Wiretronic AB, our sponsors. The harness mats were printed at Wiretronic's 1.1m width printer.

- We made three visits to the company during manufacturing and one visit early during design in November to know the company and Patrik, our Point of Contact for CFS. (He's amazing!!!)

- First visit - End of February, we had a goal to complete the entire front harness manufacturing but ended up completing 60% of the front harness. We were provided a workspace and we also took time to understand the tools as it was the first time for us.



CHALMERS FORMULA STUDENT

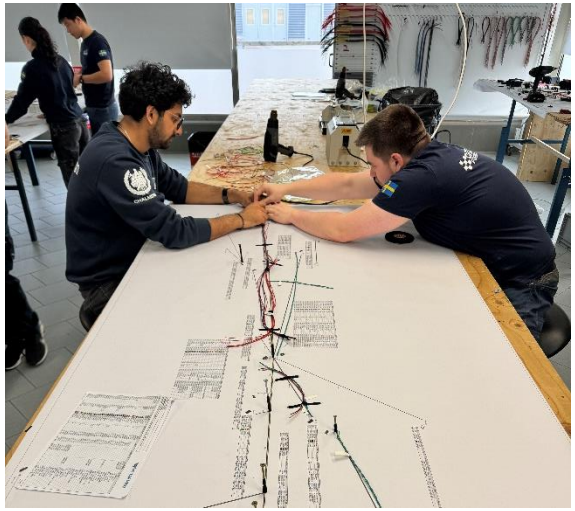


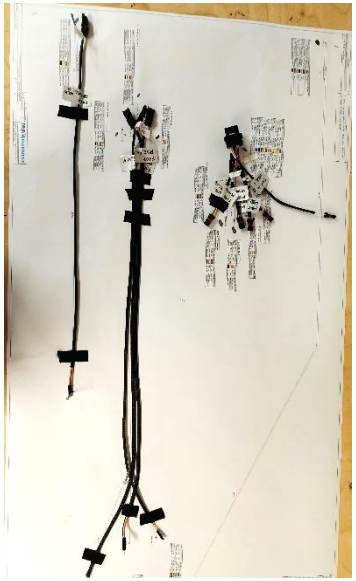
Wiring Harness manufacturing

- After first visit we tested the front harness for lengths in the actual car and found we had added too much of slack and we re-worked on slack estimation for the rear harness.

- Second visit - Early march, we finished the entire front harness in this trip and started feeling like home (SR) when working at Wiretronic as we had access to all raw materials and most of the machines and tools at the company.

- Third visit – Early April, we had a good plan to distribute workload and it worked efficiently. We were able to finish almost 80% of the rear harness and they were generous to give us all the materials required to complete it at home.





Wiring Harness manufacturing

- We had completed most of the harness manufacturing by the mid April and started working on the LV test bench for testing and verification.

Key takeaways:

- More detailed the harness design is done, the faster the harness manufacturing goes.
- Earlier completion of harness manufacturing allowed more time for test bench.
- At Wiretronic, their hospitality, the freedom they give us to use industry tools and the food they get us are something that should not be missed. Rating: 11/10

Semi-Automatic crimping machine

Cable twisting machine

Some of the machines that we got to use while manufacturing at Wiretronic

3-D printing

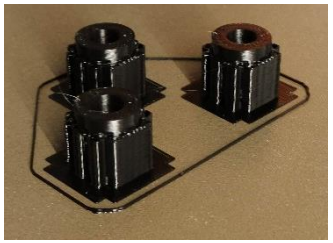
- 3-D printed a lot of plastic parts for prototyping and final parts in the car.

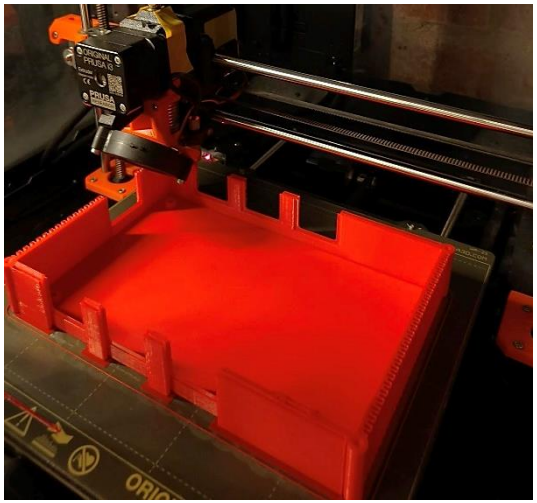
A lot of 3-D printed parts were re-printed especially due to print failure or bad finished product. Major problems faced were:

- **Warping:** Not enough adhesion of the first layer to the bed causing the layer to raise up in the edges which causes the second layer go wrong. **Mitigation**: Use print bed according to material and use glue on the bed if needed. Lower print speeds also helps avoid warping and layer misalignment.

- **Nozzle clogging:** The material gets clogged in the nozzle while melting and stops pushing out material from the nozzle and prints in thin air. **Mitigation**: Unclog the nozzle by purging a couple of times before new print and check nozzle temperature.

- More about 3-D printing can be found in David Prytz Arcombe, Final report CFS24.





Bought-out parts

- Emergency button for mainhoop
- Emergency button for cockpit
- Nitrile O-ring for DVPC waterproofing
- Threaded brass insert, for LV enclosures
- Velcro, for mounting LV components
- Cable ties (standard and flexible)

CHALMERS FORMULA STUDENT

Testing & Verification

LV test bench

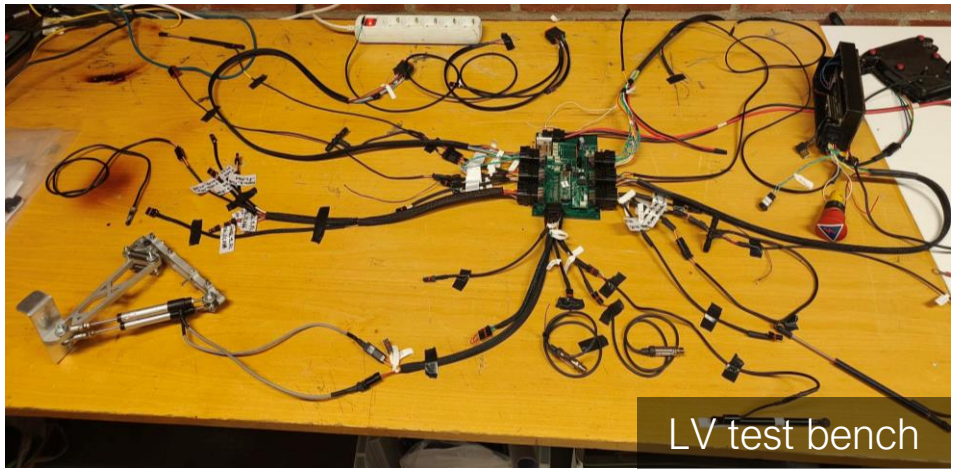
DVPC cooling test

DVPC prototyping

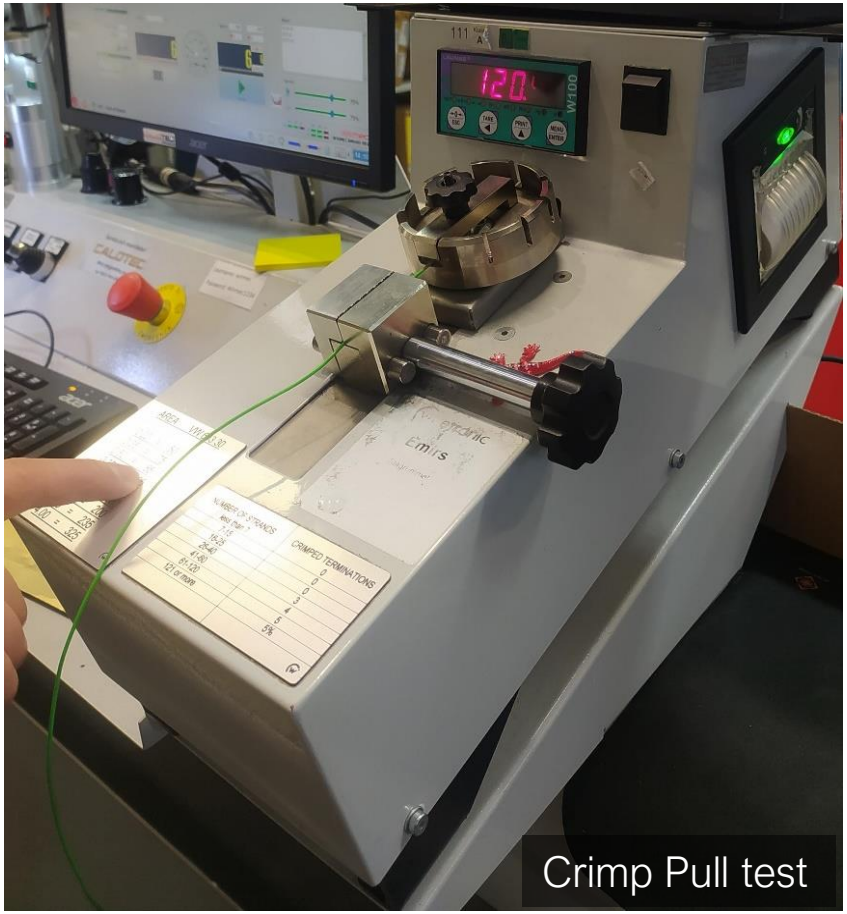
DVPC waterproofing

LV test bench & Harness Verification

- Performed Pull test on crimps at Wiretronic. This helps verify if the crimping is done properly and withstands the pull force for the particular wire gauge.
- Tested 0.5 mm2 cables for current carrying capacity and temperature.
- Verified the harness on the LV test bench before installing it in the car.



LV test bench



Crimp Pull test

CHALMERS FORMULA STUDENT

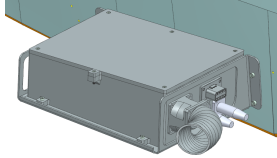
LV test bench work-flow

Tested individual unit level functionalities of the front node and rear node separately

Verify all sensor input pins on teensy by monitoring voltages from a testing sensor with the teensy and confirming the read value with a multi-meter

Assembled entire system with the harness to perform system level testing

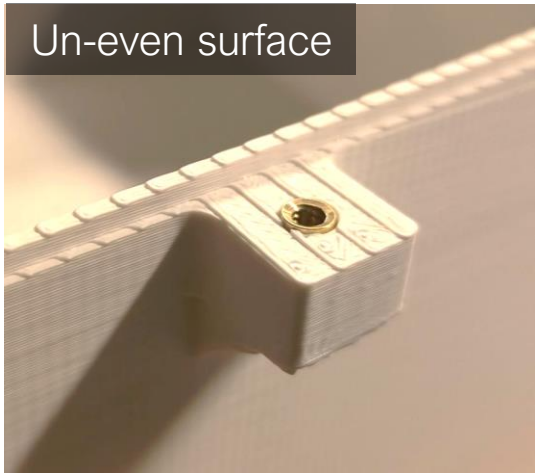
Debugging procedure: Identifying the faults by disconnecting or connecting individual unit level functionalities in the nodes.



DVPC enclosure – Prototype

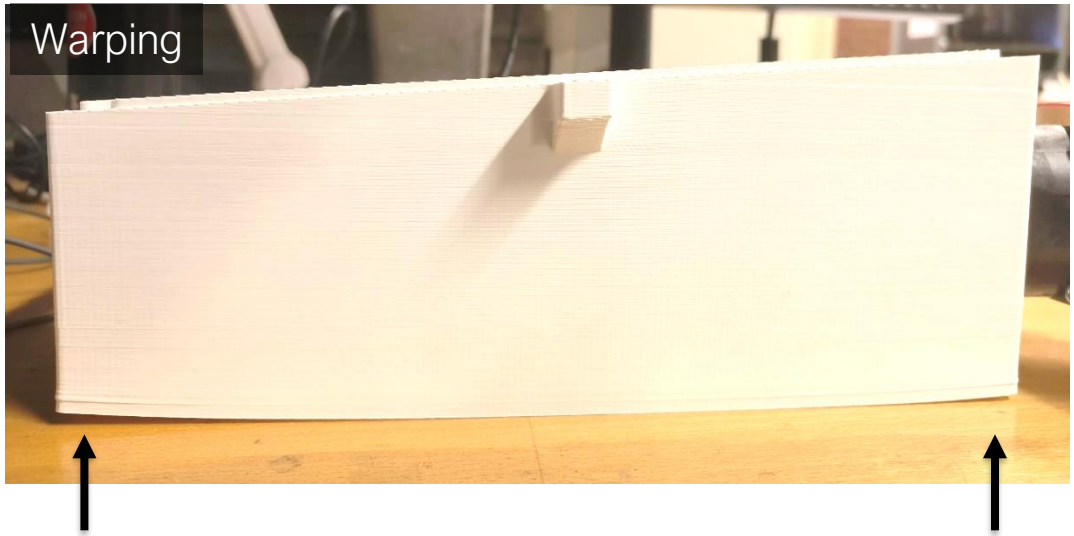
- Dimensions of the prototype were correct
- As a result of warping while 3-D printing the bottom of the enclosure was not flat to the edges (as shown with arrows in the image)
- Wall of the enclosure has an un-even surface. This might be due to printing the angled top surface of the enclosure.

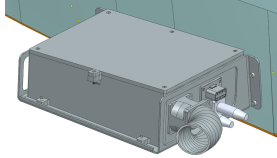
The enclosure was printed in CASE lab due to limitation in 3-D printer bed size in the CFS printers



Mitigations in 3-D printing

- Add supports in the slicer to the bottom ends of the enclosure to reduce warping.
- Reduced printing speed to ensure better quality of print layers.





DVPC enclosure – Water-proof test on Prototype

- **Procedure:** The test was performed by exposing tap water in the enclosure-lid interface and in all 6 mounting points of the enclosure. Also, the upper portion of the enclosure was partially dipped in water.

- **Result:** Test failed as traces of water were found inside the box and tissues filled inside were found wet.

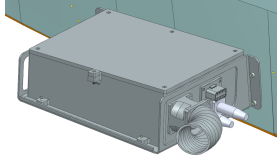
Potential reasons:

- It was found that O-ring groove dimensions on the lid was big compared to the O-ring despite using the dimensions for liquid sealing from the O-ring technical handbook.

- Due to wall of the enclosure having a very uneven surface from the 3-D print.

Table 3.C-1 Gland Dimensions Static Application-Face Seal Glands-Metric

W O-ring cross section		E Gland Depth		F Groove Width		R Groove Radius
Diam. mm	Tol. +/- ISO 3601-1B		Tol. -0/+	Liquids Tol. -0/+0,13	Vacuum/ gases	
0,90	0,08	0,68	0,02	1,30	1,10	0,2
1,0 - 1,02	0,08	0,75	0,02	1,45	1,20	0,2
1,20	0,08	0,90	0,02	1,75	1,45	0,2
1,25 - 1,27	0,08	0,94	0,02	1,80	1,50	0,2
1,42	0,08	1,07	0,02	2,05	1,70	0,2
1,50	0,08	1,13	0,02	2,20	1,80	0,2
1,60 - 1,63	0,08	1,20	0,03	2,35	1,90	0,2
1,78 - 1,80	0,08	1,34	0,03	2,60	2,15	0,2
1,90	0,08	1,43	0,03	2,75	2,30	0,2
2,0	0,08	1,51	0,04	2,90	2,40	0,2



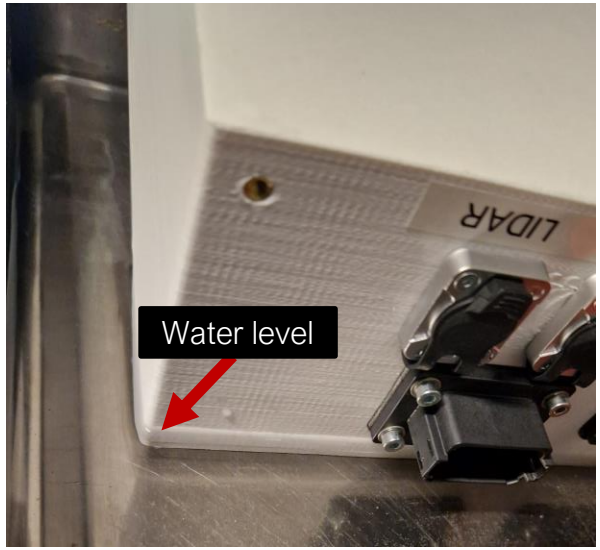
DVPC enclosure – Water-proof test on Final part

Design modifications from prototype

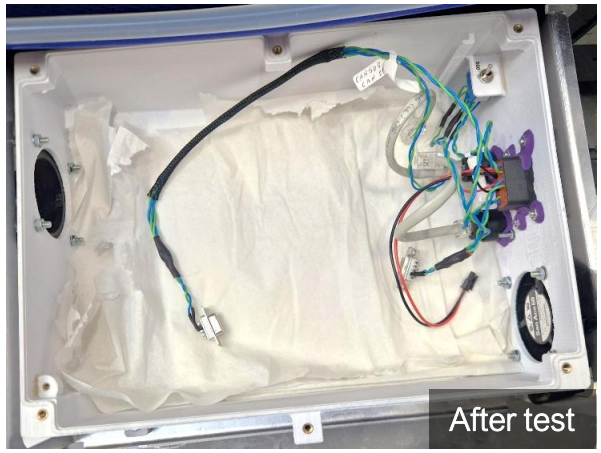
- Moved from 1.6mm O-ring dia to 2.4mm dia to have more region covered by the O-ring in the interface to prevent water seepage.
- O-ring groove width for vacuum/gases was used instead of liquid. It is the 3-D printing tolerance that caused us to make this change.
- The uneven surface in the wall of the enclosure was sanded to have a more even interface.

Result

- **Test passed** as no trace of water found inside the DVPC enclosure



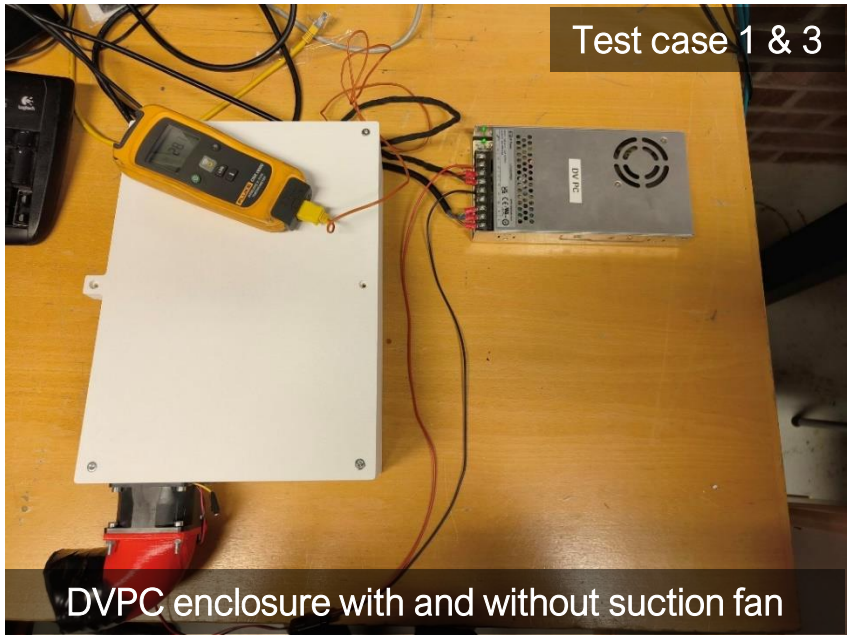
Water test on connectors

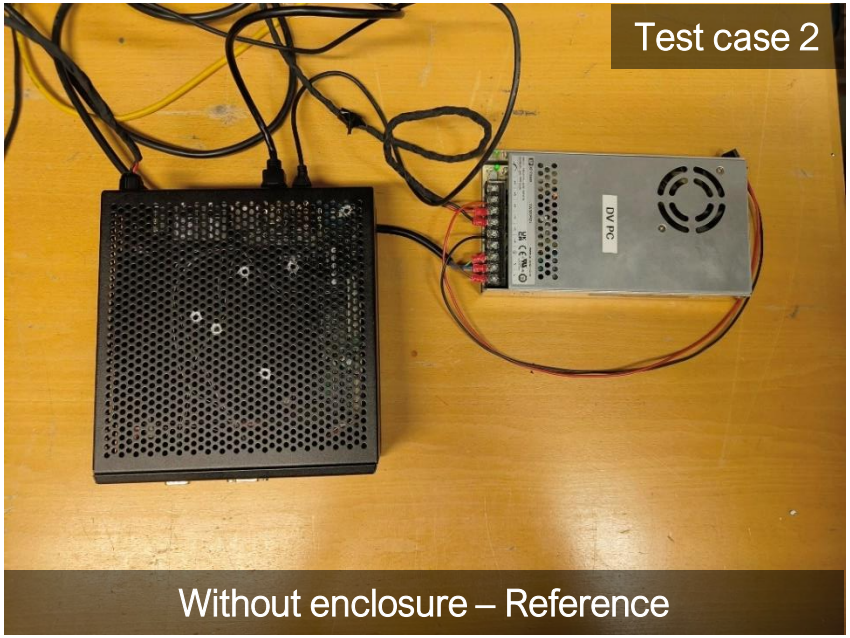


After test

Water test on Interface

DVPC cooling test – Experiment setup





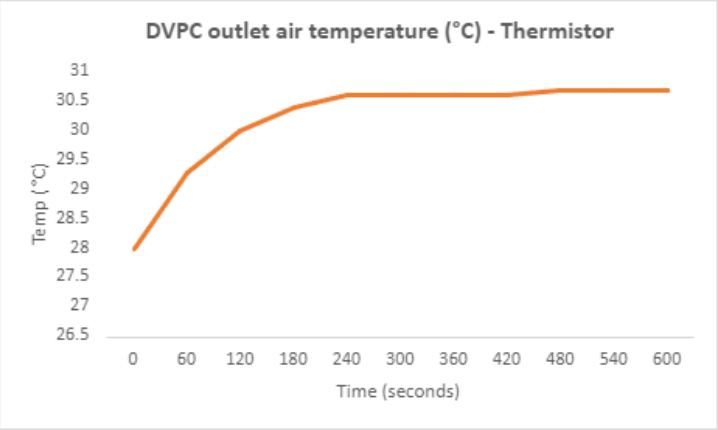
Bench test was conducted in three different settings by running the PC at full capacity of 16 threads for twice the time period required (10 minutes). A thermistor was used to measure the air temperature at the DVPC outlet. The following tests were performed together with Ayman Alzein.

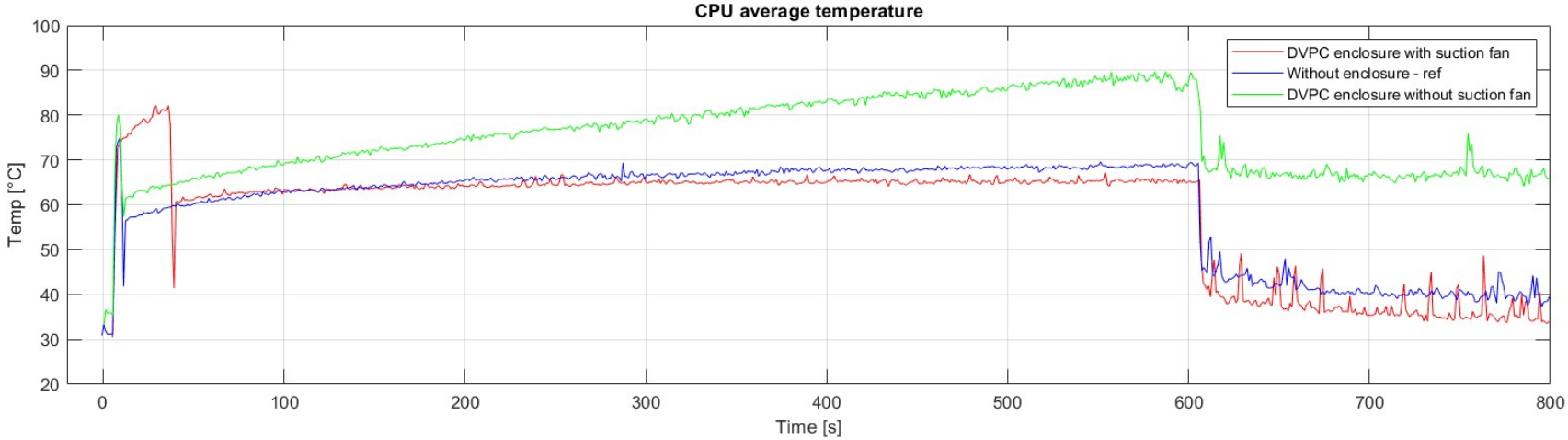
Suction fan: Fan at the DVPC inlet

DVPC cooling test - Result

Inference from temperature readings:

- **CPU temperature** when inside the DVPC enclosure with suction fan turned on is much lower than the reference indicating effective air cooling.
- Temperature of the PC rises continuously when placed inside the enclosure without suction fan and fails to settle down quickly after the test.

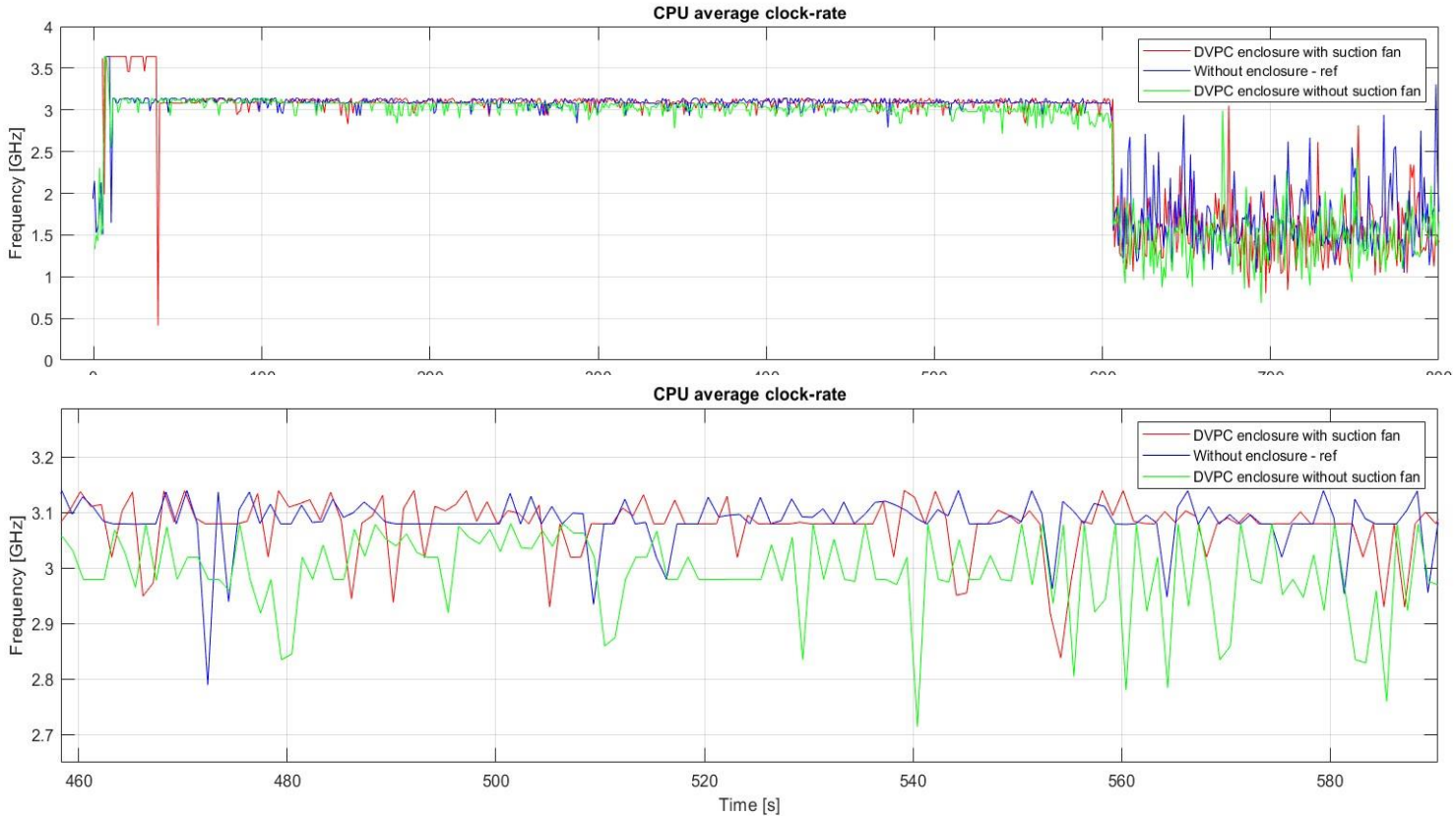




Ambient air temperature: 23°C

DVPC cooling test – Result

Trends from the **CPU clock rate** shows similar trend as the CPU temperature with showing less oscillation and higher values of clock rates when suction fan is on.



In-car testing

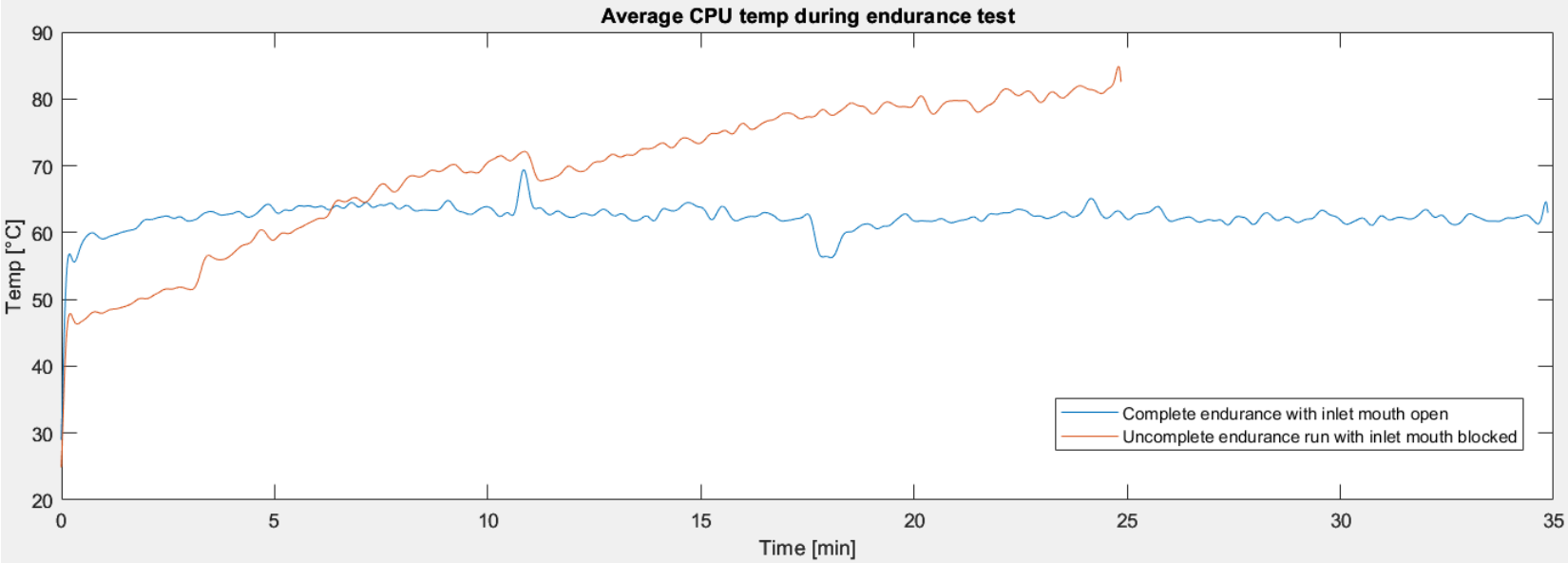
DVPC cooling test – Endurance test results

Aim: Verify if the cooling system designed is effective during vehicle test.

Method: CPU temperature data from foxglove (a data visualization and observability tool) was used to analyze the temperature effects with and without inlet mouth exposed.

Inference: After initial temperature rise, the temperature when inlet is exposed reaches steady state.

Conclusion: DVPC is effectively cooled by air cooling and with help of the new heat sink.



Competitions

Competitions

Roles and responsibilities at competitions:

- **Design event**: Responsible for Low Voltage and Electric Motors in both FS east and FS Germany (FSG) design events. This required understanding and preparing design documentations for all the different components in low voltage hardware and electric motor design and testing.

- **Cost and manufacturing event**: Responsible for electronics in cost and manufacturing event along with Lowe Blank in both competitions and also for real case study in FSG. This requires to make sure the BOM (Bill of Materials) for all electronics parts are added along with supporting material (images). Real case requires to come up with a poster presentation of the topic that was announced a couple of weeks before competition.

- **Food responsible**: "Food is memories.“ A lot of good memories in preparing food during competitions. Competition is hectic and responsibilities were well distributed within the team for food preparation. Alumni were super helpful.

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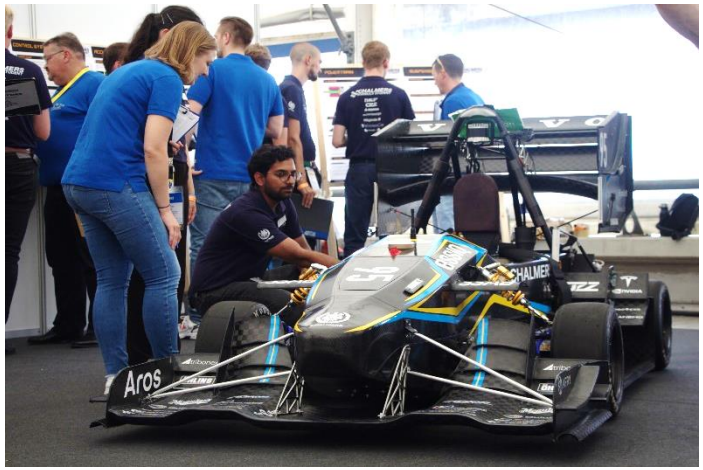
Design event – Low Voltage

NTE: The design judge in Nordic Test Event had question related almost every topic in LV: Harness, CAN, Telemetry, embedded software, Microcontroller selection and collaborations with other subgroups etc. This is when we realized that it requires the people representing LV to have knowledge about all aspects of LV system and need basic idea about autonomous and other subgroups as well.

FS East: The judge for Low Voltage asked us to explain our entire low voltage system and only interrupted us in places where he had questions. Otherwise, it was myself and Manfred talking for the whole time period. We went through each and every slide that we had prepared.

FSG: There were two design judges in FSG for low voltage who wanted a quick overview of the system and swiftly jumped to specific questions they had. One judge was focused on harness, CAN and sensors while the other was more into software implementation and working procedure.



Design event – Motors

NTE: The design judge in Nordic Test Event had more theoretical questions related to Electromagnetics of stator and rotor. He also asked about the design choices with reasoning and assembly procedure for the E-machine. The judge also asked about how this current design can be improved and new design ideas. Realized more pictures of motor design and E-mag simulations were required and stronger motivations for design choices.

FS East: The judge in FS east was more focused about design process, how the machine design was approached. The other main focus was prototyping and lab test results and test data that proves the machine has achieved it's intended specifications. This data was missing in the preparation.

FSG: The judge wanted to know what were the changes made in the motor for this year and was disappointed that it was carry over. Also asked about encoder and its choice.

Summarizing design event: Notice that for each event the judges expected different things so advisable to prepare for all possible topics because you don't know who is going to show up!!

"We don't judge your car; we judge your knowledge about the car"
~ Theresa Krug (FSG LV judge)

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Cost and Manufacturing event

NTE: Did not have a mock cost event.

FS East: There was three segments to the cost event.

- First one was Finding parts in the BOM, where we had to show the parts that judges mention in our BOM file. The focus was more on DBOM and cost explanation.
- Second segment was on the spot topic on which we had to speak for 5 minutes after a 5-minute preparation time.
- Third was the real case poster presentation. We realized some parts were missing in the BOM and also preparation for the real case study was not enough.

FSG: The cost judges in FSG were more focused with DBOM and cost explanation as well. But there were a couple of electronics parts that we were asked to find in the BOM. Some out of the context team management questions were asked. The second segment of cost event in FSE was not there in FSG. The real case presentation went well this time as we were well prepared.

Conclusions

Pre-Study

- Reading previous reports worked well and gives a good idea about the subgroup and specific work roles.
- Proper distribution of roles and responsibilities in MPT-LV would be better before design phase begins.
- More involvement from manager would help in ensuring if the necessary learning from pre-study is achieved.

Design

- MPT group discussion sessions and CAD sessions really worked well in communicating our troubles and knowing the progress of the other members in the subgroup. Don't forget to help each other, We are a team!!

Manufacturing

- Wiring harness manufacturing worked really well; it was quicker because of detailed harness design.

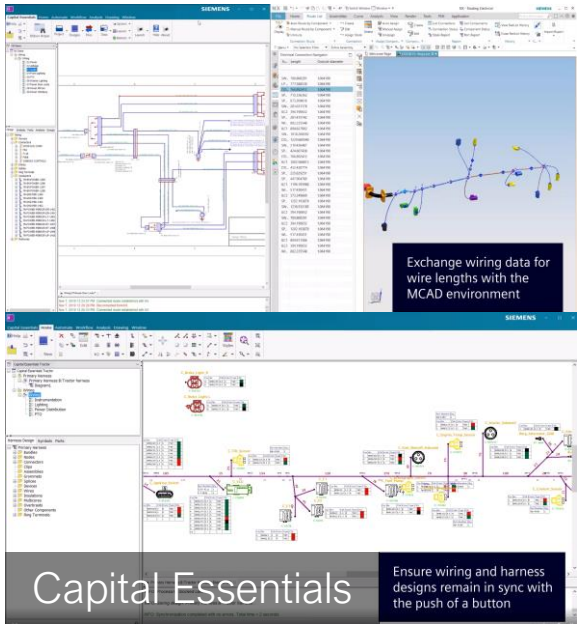
Testing and verification

- Testing of LV components need to be prioritized to ensure they are verified and validated before it is assembled in the car, it takes time to find hardware issues once assembled in the car.
- LV test bench worked well and helped faster debugging of LV system.

Recommendations for CFS25

Wiring harness

- Harness design process that we developed in CFS24 was quite lengthy in transferring data between two software tools. This could be made more efficient by using the **Siemens Capital Essential** [9], a harness design tool that can be integrated with Siemens NX CAD. We need to work on getting siemens sponsorship in getting this software.
- Add a **separate Grounding insert** in an accessible position for grounding LVMS and other LV components in the rear compartment during manufacturing of monocoque. We forgot to add it in CFS23 & CFS24 and had to use mainhoop fastener.
- An **additional LV test bench** can be prepared during manufacturing to carry separately to the competitions for displaying it to the design judges. This can help improve design points and will be appreciated by the judges. This can be kept in mind while going to Wiretronic and taking more people along and prepare cables for this additional test bench. Also need to keep in mind to have spare PCB's, additional connectors and enclosures for this.
- The wiring harness mat design was well appreciated at all competitions so continue to improve on the hard work that CFS24 has spent in implementing this industry method.



Harness weight: Do not forget to measure harness weight upon completion of manufacturing. This data will be helpful to compare harness weight contribution.

Recommendations for CFS25

- **TSMP:** Enclosure can be made more compact by repositioning the measuring points. Some ideas for this can be found in Appendix D. This will be based on changes in the monocoque. The TSMP enclosure-front plate interface can be redesigned to be similar to DVPC enclosure-lid interface with O-ring.

- **ASSI/brake/TSAL light:** Instead of having the lights PCB on the outside and needing to waterproof them, an alternate is have the lights logic PCB integrated to the nodes and have only the LED lights on the outside of the car. Some pictures of similar ideas implemented by other teams are attached in Appendix D.

- **Front node:** Design concept of front node enclosure needs to change to make a more waterproof enclosure and lessen/avoid usage of silicone. Discussions can be held with PCB designers to find if there is an alternate choice for superseal connectors attached to the PCB which can help change the enclosure design.

- **Dash screen:** Re-designing the screen enclosure is recommended to make it waterproof and lessen/avoid usage of silicone.

- **EMC testing**: Recommend trying to performing EMC testing in order to depict the interference noises produced by HV system at various frequencies and how it affects LV.

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Recommendations for CFS25

- **Motors:** If new electric machines are purchased, study needs to be performed to justify the new motor specifications are superior to the existing ones. **Motor Bench test** needs to be performed to collect data of the machine parameters (measured value of back-emf, torque constant and load testing etc…). Also **Electromagnetic simulations** and **FEM analysis** for both stator and rotor to understand the pros and cons of the design and these could be questioned during the design events.

Overall recommendations:

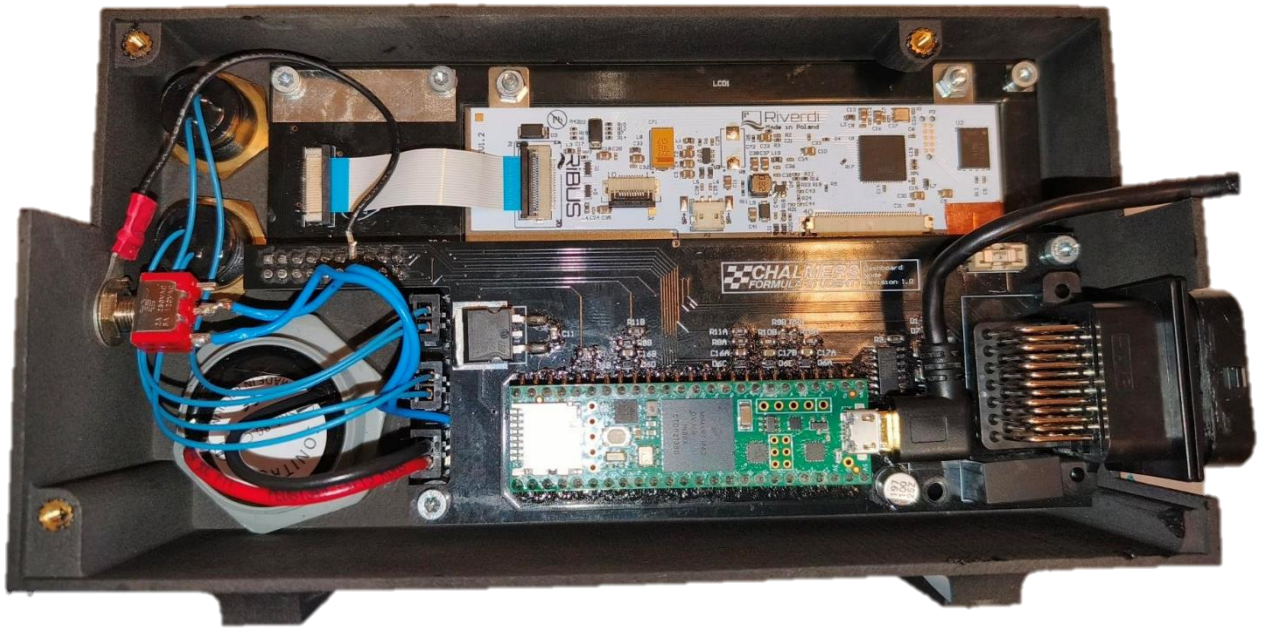
- **MPT pre-study**: During Pre-study, people focusing on mechanical design of LV should try and gain a basic understanding of the LV system. This includes understanding the basic functionalities of the nodes, sensors and sensor architecture, CAN lines, overview of telemetry system and its components and the CFS24 wiring harness in general.
- **Harness group**: Would suggest forming a harness group with LV electrical and LV MPT people quite early during the pre-study, to ensure the everyone working in harness start design phase with an equal understanding of the system.
- **Design event preparation**: Suggest individual subgroups to have weekly presentations of the design event report during the manufacturing phase. A standard template could be created to ensure all design questions are addressed by everyone.
- **Cost event preparation:** More mock cost sessions are recommended. CFS24 did 2 mock sessions.
- **Sponsorship:** Upgrade Wiretronic to a higher level they are giving us way more than a silver sponsorship.

References

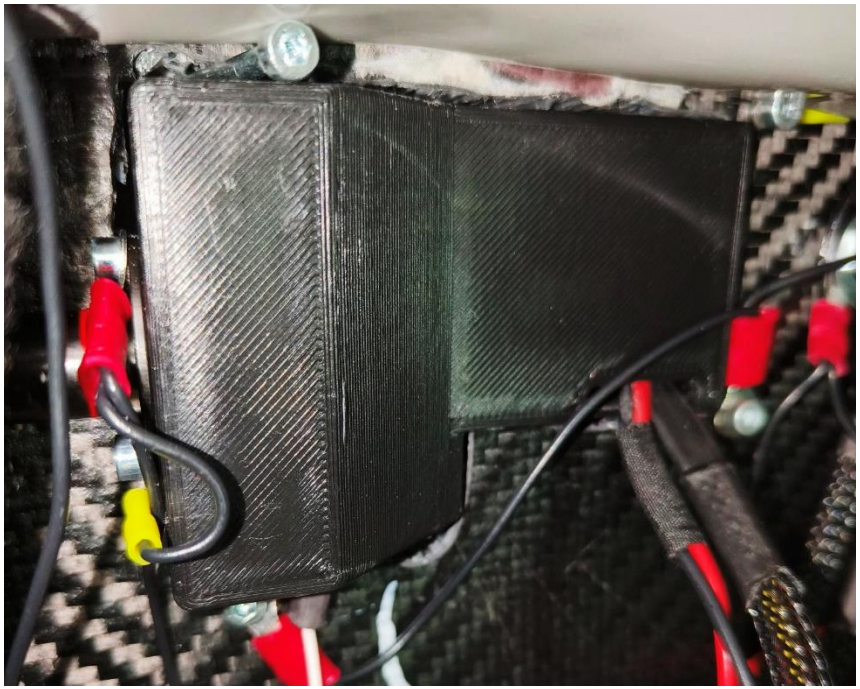
1. Charlie Nilsson, Final report CFS23
2. Prajwal Bharadwaj, Final report CFS23
3. Structural Equivalency Sheet CFS24
4. Ayman Alzein, Final report CFS24
5. DVPC suction fan data sheet
6. Videos for Harness design in Siemens NX electrical routing tool
7. NX Training – Basic and Electrical Routing
8. Sealing Elements - Technical Handbook O-rings
9. Wiring and harness design with Capital Essentials

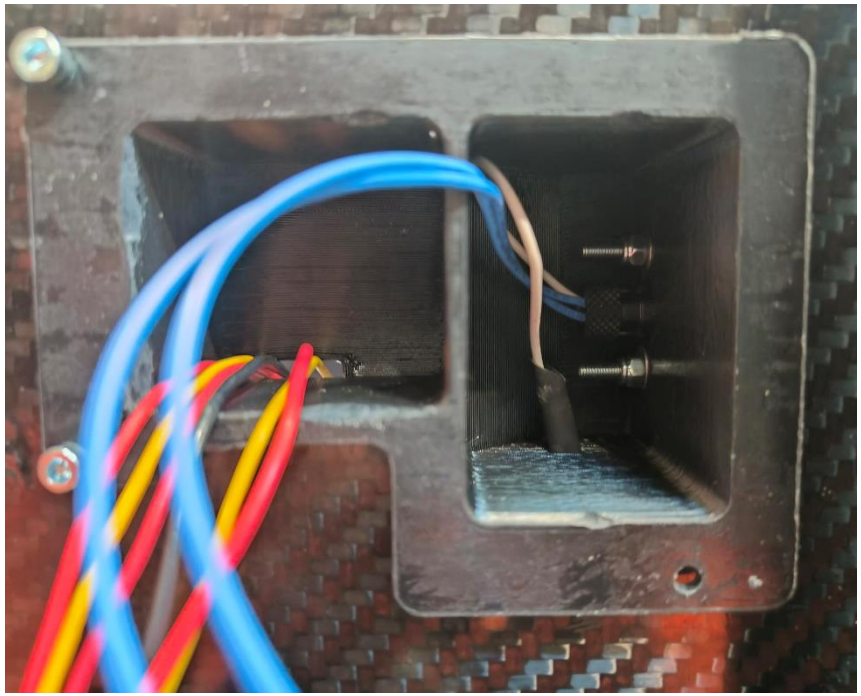
APPENDIX

Appendix A – Inside Dash enclosure for reference

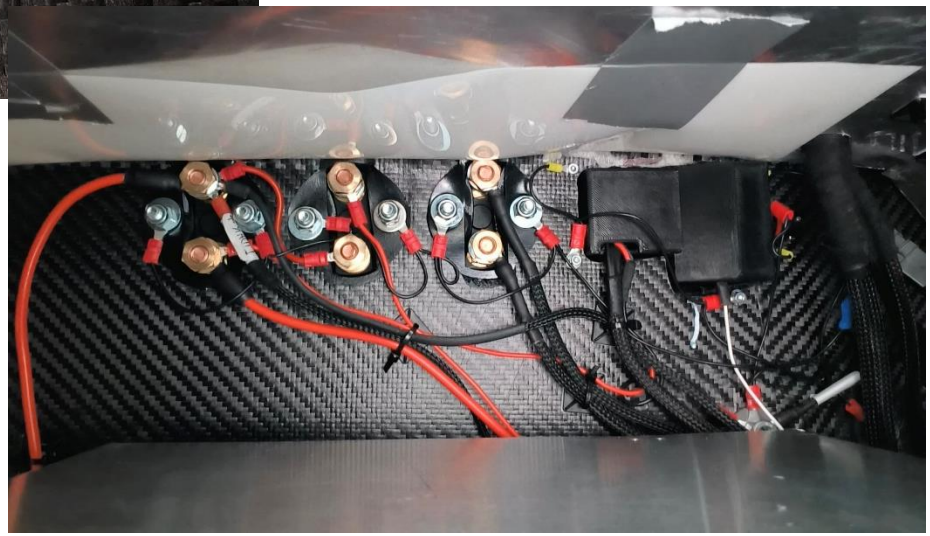


Appendix B – TSMP pictures for reference





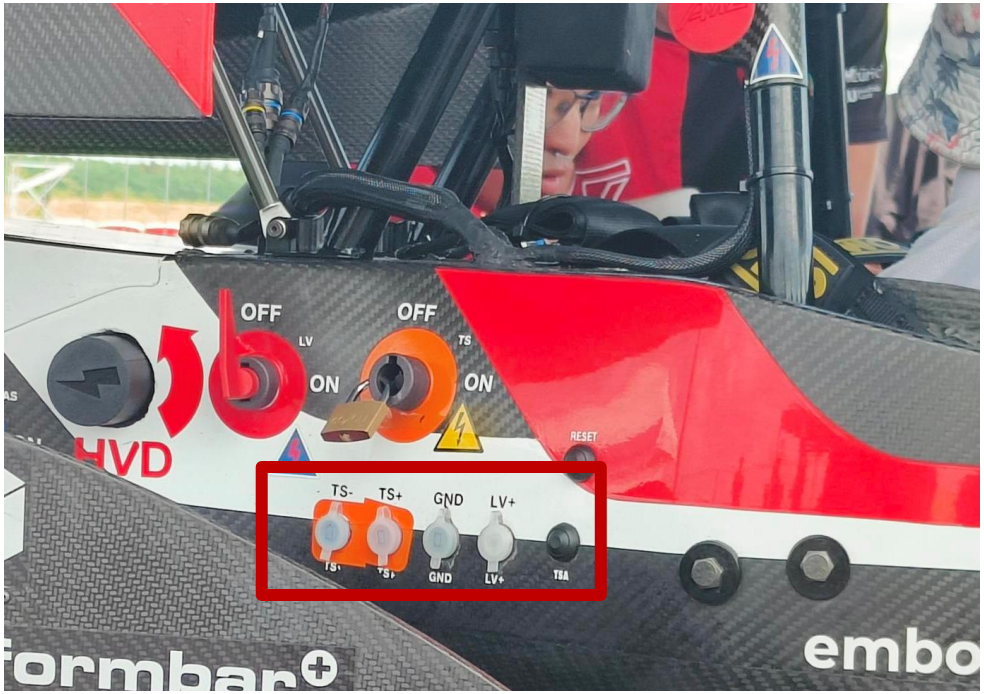
Appendix C – Master Switch pictures for reference



Appendix D – Ideas for CFS25

TSMP and MS positioning

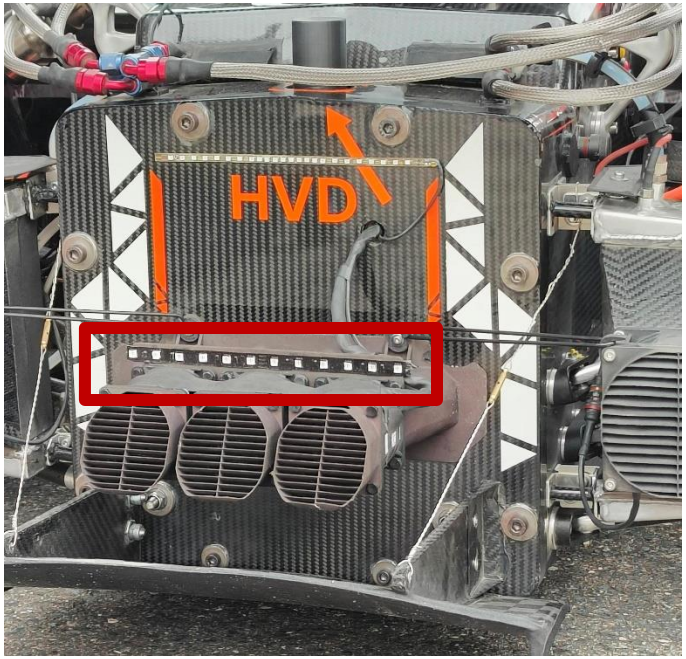
PT Milano - DynamisPRC



ETH Zurich – AMZ racing

Appendix D – Ideas for CFS25

LED lights for ASSI/Brake



TU Dresden -Elbflorace

ETH Zurich – AMZ racing