Rare Earth Free e-Drives Featuring Low Cost Manufacturing

Collaborative Project
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V5.1	26.09.2019	Slightly review and final release for quality assessment
V6.0	30.09.2019	Final version after quality assessment
V6.1	03.10.2019	Final version to submit

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Abbreviations

AC: Alternative Current
APM: Auxiliary Power Module
BMS: Battery Management System
BOM: Bill Of Material
BP: Battery Pack
CAN: Controller Area Network
CC: Cooling Circuit
CFD: Computational Fluid Dynamics
CNC: Computer Numerical Control
DC/DC: DC converter
DC: Direct Current
ECU I: Electronic Control Unit 1
ECU II: Electronic Control Unit 2
EMI: ElectroMagnetic Interference
EV: Electric Vehicles
CNC: Computer Numerical Control
HMI: Human Machine Interface
HV: High Voltage
IC: Information Cluster
IMD: Insulation Monitoring Device
LV: Low Voltage
N/A: Not Applicable
OBC: On Board Charger
OED: Original Electrical Device
PB: Power Braking
PS: Power Steering
SOC: State Of Charge
SOH: State Of Health
TBD: To Be Defined
WP: Work Package
WP1: Water Pump 1
WP2: Water Pump 2

1 Executive Summary

The present report provides an overview on the activities inherent the Technical Medium Power Powertrain Integration (75kW) for the ReFreeDrive Project, Task 5.5.

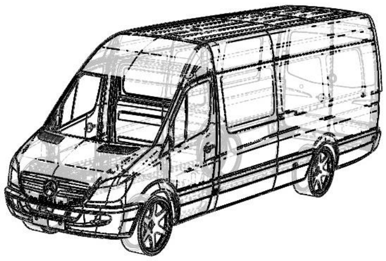


Figure 1 - 3D view of the Mercedes Sprinter

The purpose of this document is to describe the activities of vehicle integration that have been performed in order to allow the Medium Powertrain integration and the demonstration of the new ReFreeDrive motors on the Mercedes Sprinter (Figure 1).

The activities of this report have been divided in 3 different macro areas and therefore divided in sub groups each one related to sub components of the vehicle.

1- **Component Selection.** This section describes the activities related to the analysis of the requirements for each specific sub group of component, the discussion with different suppliers until the final decision has been taken.
2- **Component Integration.** This section describes the detailed design of different sub components such us the Battery Pack (BP) or the activity of integration of purchased parts inside the vehicle.
3- **Powertrain Integration.** This section has a specific focus on the activities performed at a system level and involves the communication and the integration of different components in order to obtain a complete working vehicle.

No barriers and risks to be highlighted to affect the development of the project strategy. A minor number of tasks that was theoretically due within the 5.5 are still under investigation and have been postponed to WP7. They have been marked with To Be Defined (TBD). The reason is that these activities are strictly related to installation in the vehicle and the testing of the components under manufacturing. It would be therefore useless and misleading to work on further investigations at this level.

In D5.5 there have been no deviations in content or time from the deliverable objectives set out in the ReFreeDrive Grant Agreement.

2 Components selection

2.1 Energy and power requirements

In a normal vehicle electrification, we would have started from the vehicle performance requirements in order to find the suitable solution for the best user experience. In this case our goal was to find the best solution that would allow the demonstration of the e-motors designed in the ReFreeDrive project and then adapt them to the requirements of the Mercedes Sprinter.

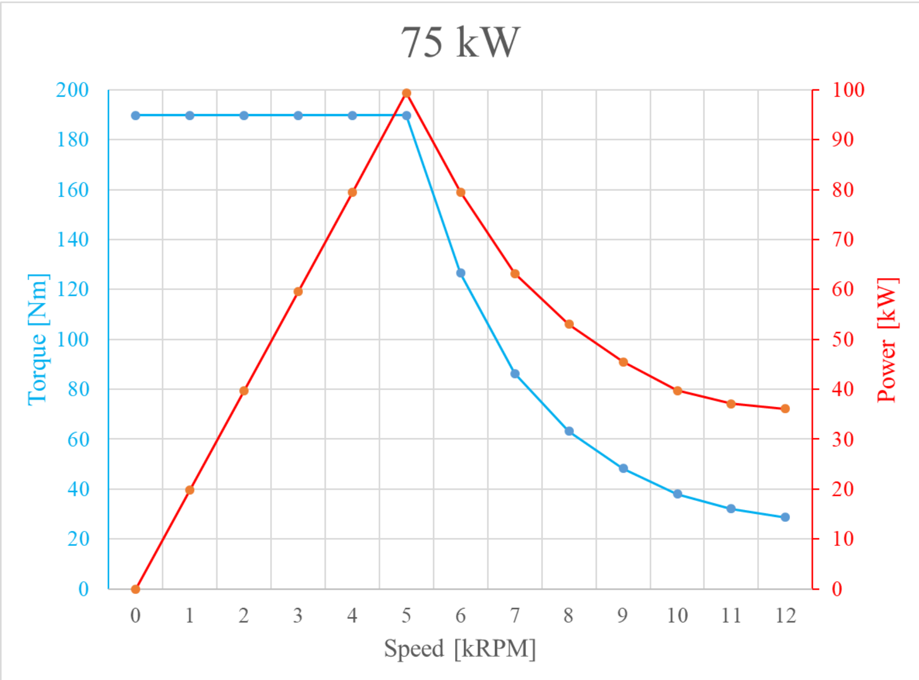
We therefore started our study from the requirements that the motor under development has. See below a chart that describes the motor technical specifications (Table 1 and 2).

Technical specifications

Table 1 - Power and electrical requirements

Parameter	Value	Unit	Comments
Nominal Voltage	350	V	Battery DC voltage
Working Voltage Range	250-420	V	Battery DC voltage
Nominal Power	>30	kW	S1 (>45min)
Peak Power	>75	kW	S2 (>60s)
Nominal Speed	>4000	rpm	To be verified at motor design stage
Maximum Speed	10000-13000	rpm	To be verified at motor design stage
Nominal Torque	>65	Nm	S1 (>45min)
Maximum Torque	>140	Nm	S2 (>60s)
Weight	≤60	Kg	
Dimensions	≤350x350x350		
Cooling Type	Water/Glycole		
Flow rate	1-10	l/min	
Coolant Pressure Drop	≤150	mbar	
Isolation Level	H	H	
Ambient Temperature Range	-20 / 50	°C	
IP Level	>IP55		

Table 2 - Electric motor output data



Speed	Power	Torque
RPM	kW	Nm
5.000	100	190
12.000	36	28.8

Regeneration mode: max 30kW for 10-20 seconds. (high inertia)

From a vehicle dynamic perspective, we have focused our attention on 3 main parameters:

1- **Max speed** = 120 km/h
2- **Range** = 80-100 km
3- **Max Slope** = 20%

Based on that data and on the motor under test we have performed our study that involved the selection and the design of a specific battery pack, the selection of different components to allow the integration of the powertrain and the design of a communication system that allows the correct integration of the different vehicle functions.

The capacity of the battery has been imposed in the range between 20-25 kWh.

2.2 Battery Pack

2.2.1 Type of cell

The type of cell to be used on the battery was selected starting from the desired currents and crossing those results with the availability of the market. Table 3 represents the current thresholds that we have imposed to the system.

Table 3 - Current output and input data

	Service	Current	Time
DISCHARGE	peak	275 A	2 s
	continuous	75 A	-
CHARGE	continuous	60 A	-
REGENERATION	peak 1	275 A	1 s
	peak 2	200 A	3 s

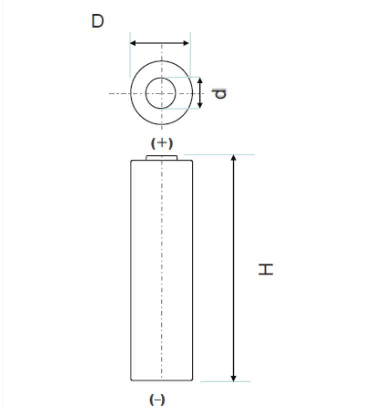
In order to contain the battery total price we have set the capacity to 20kWh – 25kWh and to satisfy the project purpose we studied and compared many kinds of cells. We have found a fair compromise between energy and power density choosing Nickel-Cobalt 18650 cells, which allows us to achieve the performances shown in Table 3.

The first option was a Panasonic NCR 18650 GA (Figure 2)

Specifications

Rated capacity(1)		3300mAh
Capacity(2)	Minimum	3350mAh
	Typical	3450mAh
Nominal voltage		3.6V
Charging	Method	CC-CV
	Voltage	4.20V
	Current	Std. 1475mA
	Time	Std. 270 min.
Weight (max.)		48.0g
Temperature	Charge	10 to +45° C
	Discharge	-20 to +60° C
	Storage	-20 to +50° C
Energy density(3)	Volumetric	693 Wh/l
	Gravimetric	224 Wh/kg

Dimensions



With tube	H	Max. 65.30mm
	D	Max. 18.50mm
	d	Max. 9.0mm

Figure 2 - Panasonic NCR 18650 GA information

The second option was a Panasonic NCR 18650 PF (Figure 3):

Specifications

Rated capacity(1)	Min. 2700mAh
Capacity(2)	Min. 2750mAh Typ. 2900mAh
Nominal voltage	3.6V
Charging	CC-CV, Std. 1375mA, 4.20V, 4.0 hrs
Weight (max.)	48.0 g
Temperature	Charge*: 0 to +45°C Discharge: -20 to +60°C Storage: -20 to +50°C
Energy density(3)	Volumetric: 577 Wh/l Gravimetric: 207 Wh/kg

(1) At 20°C (2) At 25° C (3) Energy density based on bare cell dimensions

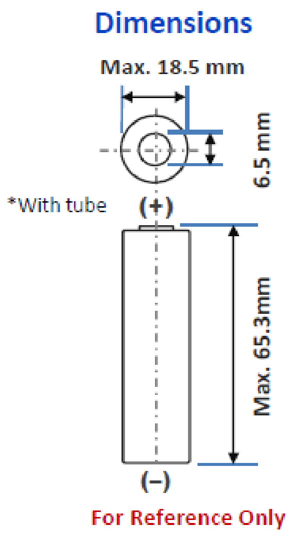


Figure 3 - Panasonic NCR 18650 PF information

With the support of a calculation software that we have implemented internally, different scenarios that involved a different distribution of the cells inside the battery and the charging and discharging phases were evaluated. Below (Figure 4) an example of our calculation.

Cell		
Type	NCR18650PF	
Voltage	3,60	V
1C	2,90	Ah
maker	panasonic	mOhm
Ø	18,00	mm
height	65,00	mm
weight	48,00	g
A_max	10,00	A
C_rate Max	3,45	C
Surface	3.675,663	mm^2
Volume	16540,49	mm^3
energy	10,44	Wh
e specific	217,50	Wh/kg
e density	631,18	Wh/cm^3
n cell(V)	110,00	"->n moduli
n cell(Ah)	17,00	
n cell TOT	1870,00	
peso	89,76	Kg
ene_cell96V	0,00	kWh
Tensione	396,00	V
Capacità	49,30	Ah
Size Battery	19,52	kWh

Figure 4 - Panasonic NCR 18650 PF calculation

In another model we have calculated the charging time and the energy dissipated by each solution (Table 4).

Table 4 – Cell selection comparison

		PF	GA	unit
C_rate	Standard	0,66	0,82	A
	Quick	3,29	3,10	
10-89%	Standard	3,00	3,00	h
	Quick	0,60	0,79	
89-97%	Standard	0,55	0,55	
	Quick	0,11	0,14	
t TOT	Standard	**3,55**	**3,55**	
	Quick	**0,71**	**0,94**	

The final results were in favour of the Panasonic PF because of their better performance (Figure 5) in high peak of discharge and charge and because of their availability on the market.

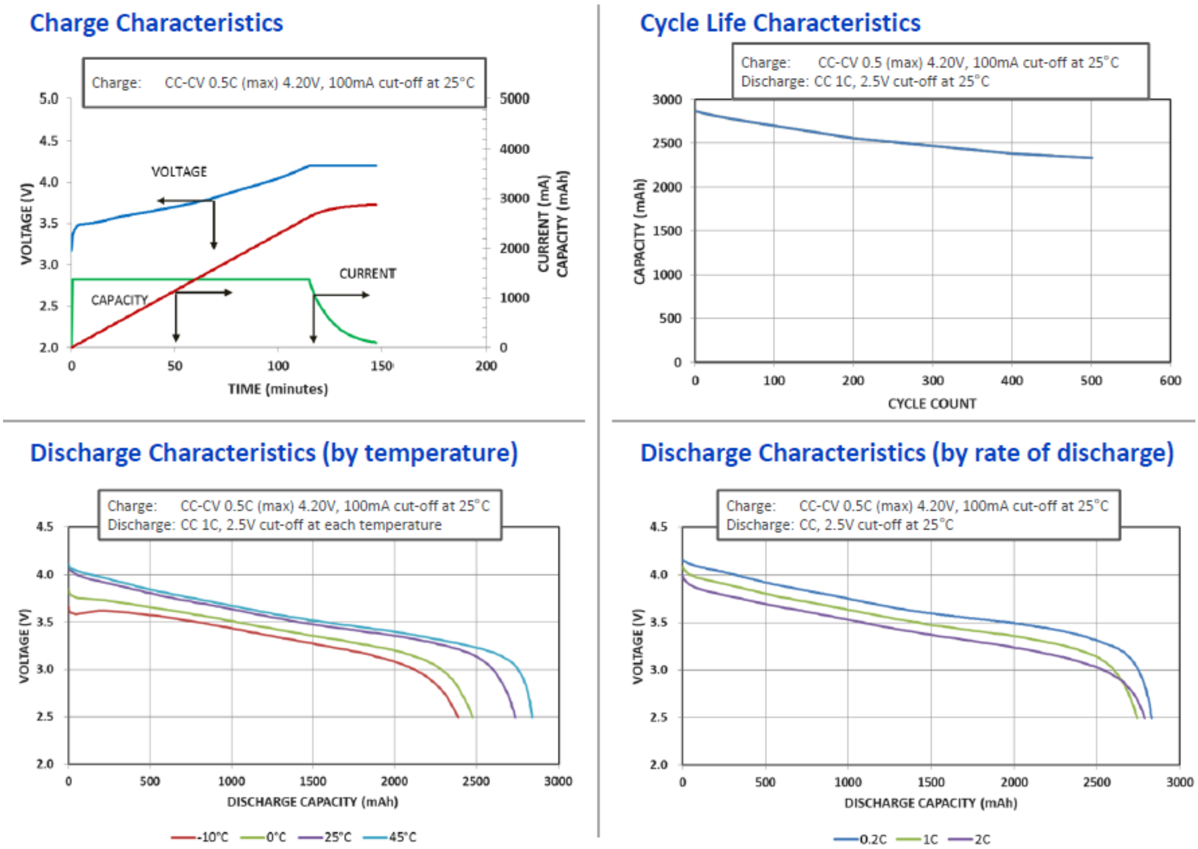


Figure 5 - Panasonic NCR 18650 PF data analysis

2.2.2 Electrical Lay out

The battery is composed of 7 modules (1 Master – 6 Slaves) connected in series. In each module there are 24 groups of cells in parallel, every group is made by 15 cells in series. For this reason the module electrical layout is called 15S-24P. The master module contains inside the case the power contactors, the fuses and the master Battery Management System (BMS Master). The slave modules contain each one its slave battery system manager board (BMS Slave).

Single module

- Module Voltage: 54 V
- Module Capacity: 69.6 Ah
- Module Energy: 3.76 kWh

Battery pack

- Battery Voltage: 378 V
- Battery Capacity: 69.6 Ah
- Battery Energy: 26,3 kWh
- Max Voltage: 441 V
- C-rate max: 4 – 278.4 A

Find below a block diagram (Figure 6) of the electrical layout of the battery pack:

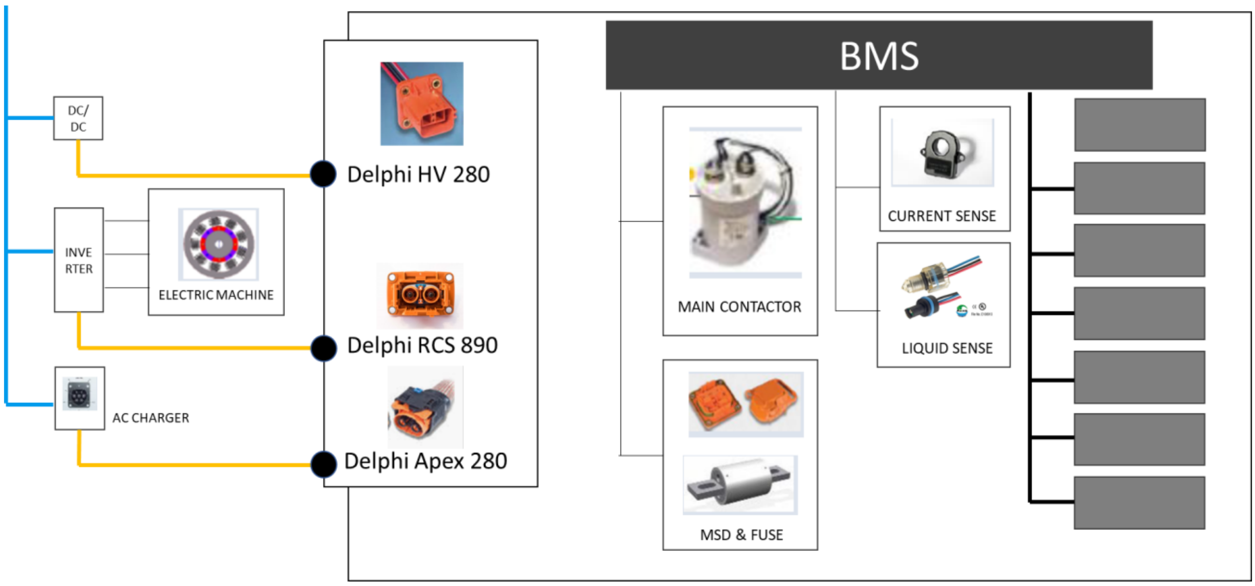


Figure 6 - Battery pack electrical layout

Find below a block diagram (Figure 7) of the pin out of the battery pack:

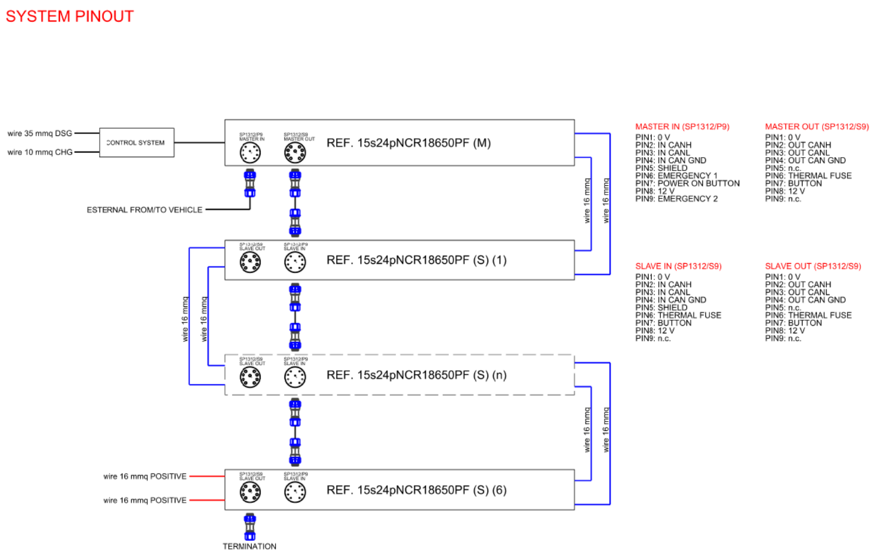


Figure 7 – Block diagram of the pin out of the battery pack

2.2.3 Cooling System

From the data that emerged on automotive applications similar to the one we are working on, it turns out that the cold plate system can fully satisfy the cooling requirements of the battery in question (Figure 8).

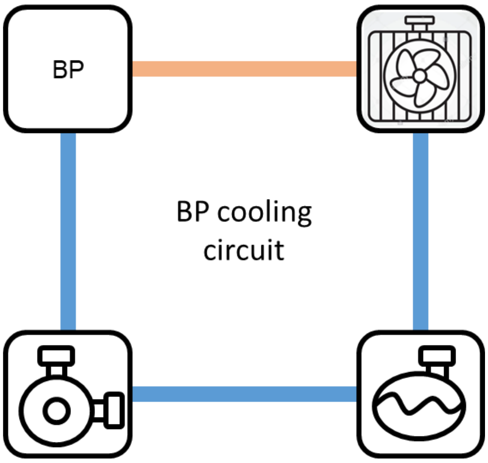


Figure 8 – Battery pack cooling circuit

To ensure less complexity in the prototype production phase it is considered appropriate to eliminate the thermoconductive paste and replace it with a heat conducting mat to be applied as indicated below. The tests on the micro-cell will still be carried out both with conductive paste and with a mat (Figure 9).

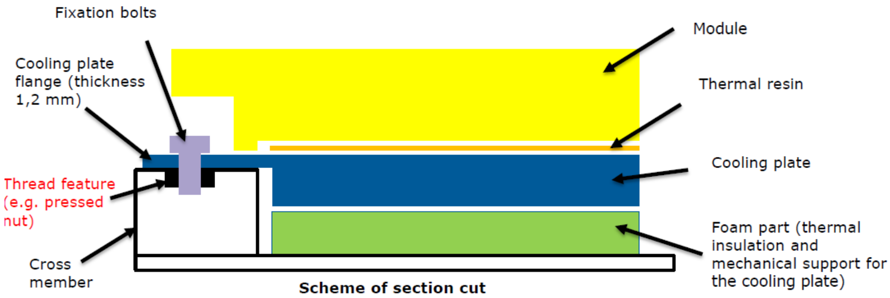


Figure 9 – Cold plate section assembly

The cold plate is made by an aluminium plate with internal pipes to allow the coolant liquid flow, as shown in the figure below (Figure 10).

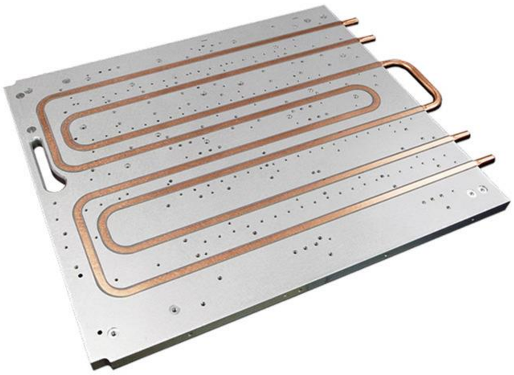


Figure 10 - Example of cold plate

An electric pump is necessary for water recirculation pump. A good candidate for this component is the Toyota Prius component (0400032528) (Figure 11).

<u>PinIn-PinOut</u>

Pin 1	+12V
Pin 2	GND

Figure 11 - Water pump selected

2.2.4 Power Connectors and other components

Based on the power requirements defined in the Table 1 we have performed the selection of the power connectors between 3 different suppliers:

- **Aptiv** (ex delphi automotive PLC)

  A global technology company that develops safer, greener and more connected solutions enabling the future of mobility. Their connector design results in handling operation voltages that range from 400V up to 1000V and carrying currents as high as 250A, in compliance with three standards used throughout the world including SAE J1772 in North America and Japan, IEC62196 Type II in Europe and GB/T 20234 in China.

- **Amphenol**

  It is one of the largest manufacturers of interconnect products in the world. The Company designs, manufactures and markets electrical, electronic and fiber optic connectors, coaxial and flat-ribbon cable, and interconnect systems. HVSL Series is designed to meet AK standards for various Electric Vehicle (EV) applications, including power and signal interconnect solutions. Different versions are available, from 1 position to 4 positions and a rated current from 23A to 350A.

- **TE Connectivity**

  It designs and manufactures a broad portfolio of connectors designed to transmit data, power and signal reliably in the most difficult environments, under the most extreme use. TE connectors are manufactured to reduce the size of the application and energy consumption, while allowing for better performance. TE provides quality electrical and electronic interconnection products for automotive, on- and off-highway, and hybrid and electric vehicles to electrically and mechanically join wires and cables, printed circuit boards, integrated circuit packages, and batteries. Their automotive connectors are built to withstand tough conditions and suit the needs of varying industries.

Table 5 - Battery pack connectors

Inverter power connector			
Aptiv – RCS 800		Amphenol – HVSL1000	
	210 A at 85°C 1000 V 35 mmq T3 V2		250 A at 70°C 1000 V 35 mmq
MSD – Manual Service Disconnect			
Amphenol – MSD		TE – MSD	
	Fuse: 315 A MSDM3502 MSDF350F		Fuse: 350 A 1-1587987-1 1-2103172-1
Battery signal connector			
WEIPU – SP1312/P9 & SP1310/S9		-	
	9 pins 3 A 125 V Ø7 x 9	-	-
DC converter Power connector			
Aptiv – APEX HV280		Amphenol – HVSL 282	
	35 A at 70°C 1000 V 4 mmq T3 V1		32 A at 70°C 800 V 4 mmq
Charger Power connector			
Amphenol – HVSL 362		Amphenol – PowerLock	
	60 A at 70°C 800 V 10 mmq	No image	PL082X-121-10M6 and mating part 10mmq

The connectors selected by us are those present in the first column of the Table 5. In choosing, we sought the best compromise between cost, performance and availability / delivery times. The battery signal and charge power connectors were suggested to us by the respectively suppliers.

2.2.5 BMS and CAN communication

A BMS is an electronic regulator that monitors and controls the charging and discharging of rechargeable batteries.

Battery management systems of various types are used in most devices that use rechargeable batteries.

Battery management systems may be as simple as electronics to measure voltage and stop charging when the desired voltage is reached. At that point, they might shut down the power flow; in the event of irregular or dangerous conditions they might issue an alarm. A more complex BMS monitors many factors that affect battery life and performance as well as ensuring safe operation. They may monitor one-cell or multi-cell battery systems. Multi-cell systems may monitor and control conditions of individual cells. Some systems connect to computers for advanced monitoring, logging, email alerts and more.

Factors monitored and controlled by battery management systems include:

- Battery and cell health.
- Battery or cell voltage.
- Charging and discharge rates.
- Coolant temperature and flow for air or liquid cooling.
- Main power voltage.
- Temperatures of the batteries or cells.

For our battery management system (Figure 12) we have required the following functions:

- BP current reading.
- BP temperature reading.
- BP voltage reading.
- Cell balancing and equalization.
- Charging control.
- Communication with the vehicle.
- Control power-up, power-down and pre-charge.
- Data logger.
- Discharging control.
- Each series of cells voltage reading.
- Faults management.
- Modules temperature reading.
- Modules voltage reading.
- State-Of-Charge (SOC) determination.
- State-Of-Health (SOH) determination.

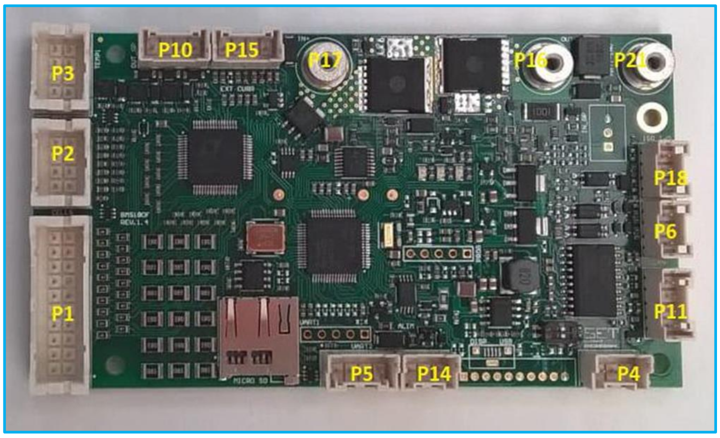


Figure 12 - Master BMS

Controller Area Network system

2 Controller Area Networks (CAN) will be wired in the vehicle, as shown in the Figure 13.

The first CAN-bus has the following nodes:

- On Board Charger (OBC)
- BMS
- DC converter (DC/DC)
- Electronic Control Unit I (ECU I)
- Electronic Control Unit II (ECU II)
- Inverter-Motor
- Insulation Monitoring Device (IMD)

While the nodes of the second network are:

- ECU II
- Information Cluster (IC)
- Human Machine Interface (HMI)
- Original vehicle CAN-bus

The 2 networks share information between them.

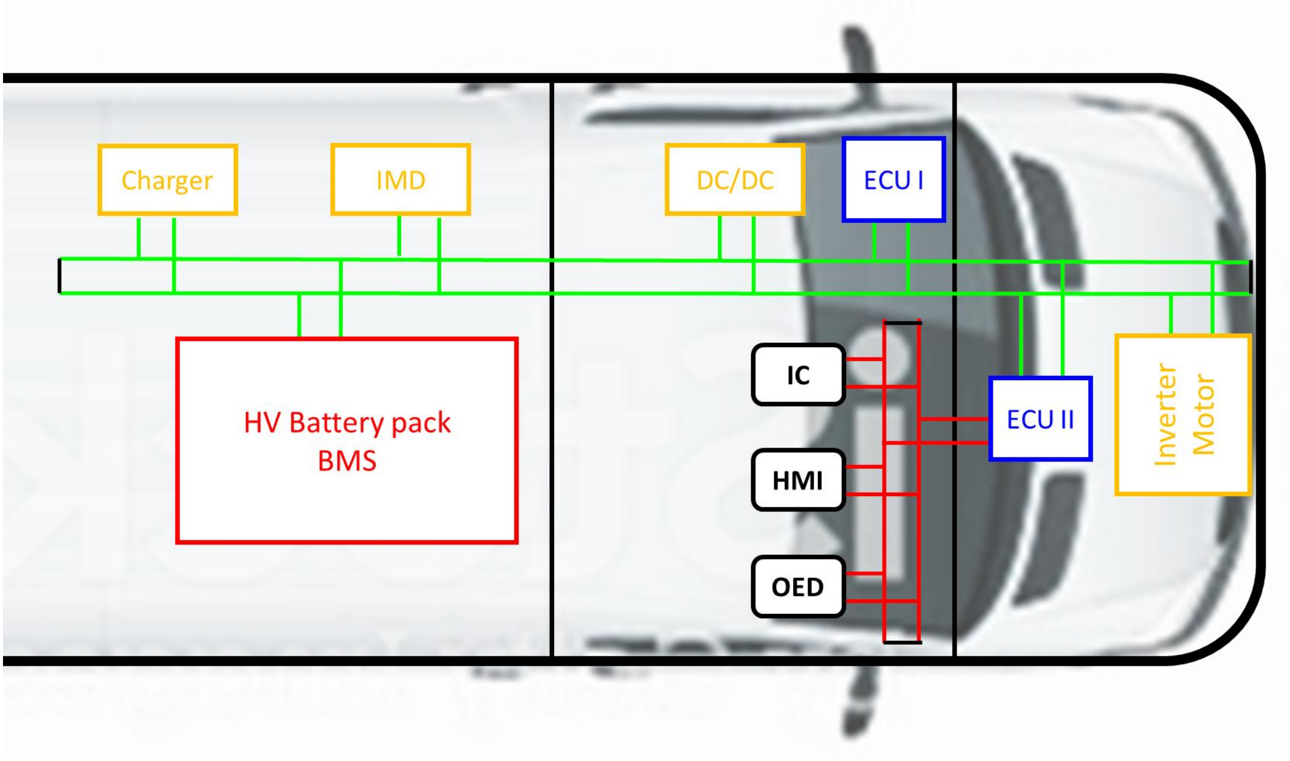


Figure 13 - Communication layout and components

ECU I – Electronic Control Unit 1

The first electronic control unit, which will be positioned inside the engine compartment, performs the following functions:

- collects and manages all information between High Voltage (HV) components;
- check the status of all systems;
- management of the different CAN protocols.

ECU II – Electronic Control Unit 2

The second ECU, which will be positioned inside the passenger compartment, performs the following functions:

- filters and manages and messages to and from the instrumentation (HMI, IC, Electronic Ignition Switch);
- battery pack and inverter/motor thermal management (on/off valves, pumps and fans);
- setting and debugging of systems by remote control.

2.2.6 Charging System

The suitable charging system has been selected between three different suppliers taking into account our design constraints:

1- Possibility to have a single-phase input.
2- Charging time between 1 and 2 hours.
3- Compliance with most recent design and safety standards.

The charging system could have been liquid cooled or not and the dimension was not a constraint given the space available in the loading van of the Sprinter. The following Table 6 shows the main characteristics of the battery chargers analysed by each supplier considered:

Table 6 - Evaluated chargers

	**EDN – EVO22KL** Power: 22 kW Efficiency: >90% Type of cooling: liquid Input AC: tri-phase SAE J1772 & EN 61851 Compliance Yes
	**XEPICS – XP-maxi** Power: 22 kW Efficiency: >90% Type of cooling: liquid Input AC: tri/single-phase SAE J1772 & EN 61851 Compliance Yes
	**Zivan – NG9** Power: 9 kW Efficiency: >87% Type of cooling: air Input AC: tri-phase SAE J1772 & EN 61851 Compliance No

The Xepics solution has been selected because it better answers our needs.

2.2.7 Direct Current converter

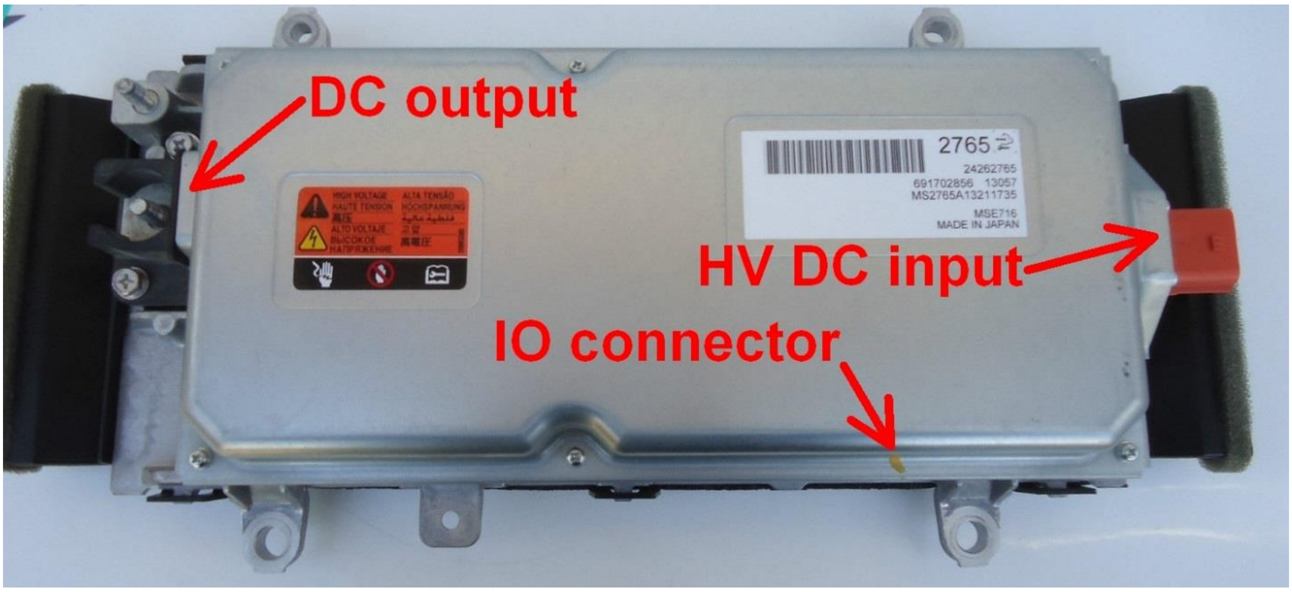


Figure 14 - DC/DC converter

DC/DC functional Overview

The DC/DC converter (Figure 14) is a high voltage to low voltage DC/DC converter and goes by several names including “APM (Auxiliary Power Module)” and “14V Power Module”.

It is manufactured by TDK and is CAN controlled, and air cooled. It requires an external fan to provide the necessary air cooling for operation. The DC/DC converter is air-cooled. The converter is not waterproof. It needs both hardwired enable inputs and CAN control to function.

The Ignition and Accessory inputs need to be connected to +12V and CAN communication established before it will turn on. The CAN data necessary to command the converter is a single CAN message at ID 0x1D4. This message commands both an enable and the voltage command. Placing a value of 0xA0 in byte 0 will turn the DC/DC on and a value of 0x00 will turn it off. If CAN communication is lost to the DC/DC after it has been initially commanded to turn on, it will remain on but drop to 13.5Vdc. It will then remain on until the ignition and accessory inputs are disconnected from 12V.

The DC voltage is measured on the output. The value is obtained by dividing by 12.7. For example, if the value is 0xAC then the voltage would be 0xAC=172 / 12.7 =13.5VDC

The DC/DC efficiency as a function of output current is shown by the curve in the Figure 15.

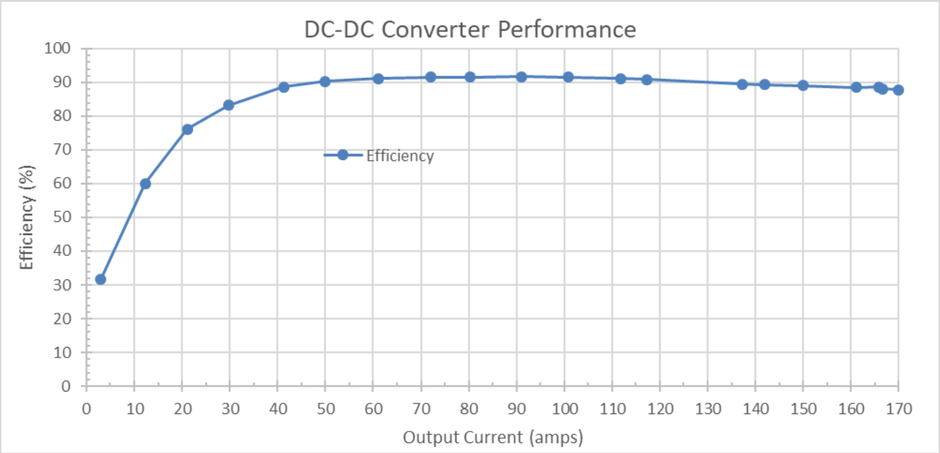


Figure 15 - DC/DC converter performance curve

The Table 7 lists the connectors and cable sections to wire the DC/DC.

Table 7 - DC/DC connectors

	Type	**MSE716**	**Cable**
HV input connector (Delphi part number)	cable	13861584	4 mm2
	panel	13743443	
Low voltage output studs		M8 studs x2	Multiple
Low voltage IO connector	Cover-shield	AIT2PB-10P-2AK	10 x 0.1 mm2
	Pin-contacts	SAIT-A02T-M064	

PinIn-PinOut

Pin 1	Termination resistor	Pin 6	Termination resistor
Pin 2	CAN Low	Pin 7	CAN Low (same as pin 2)
Pin 3	CAN High	Pin 8	CAN High (same as pin 3)
Pin 4	NC	Pin 9	NC
Pin 5	Ignition	Pin 10	Accessory

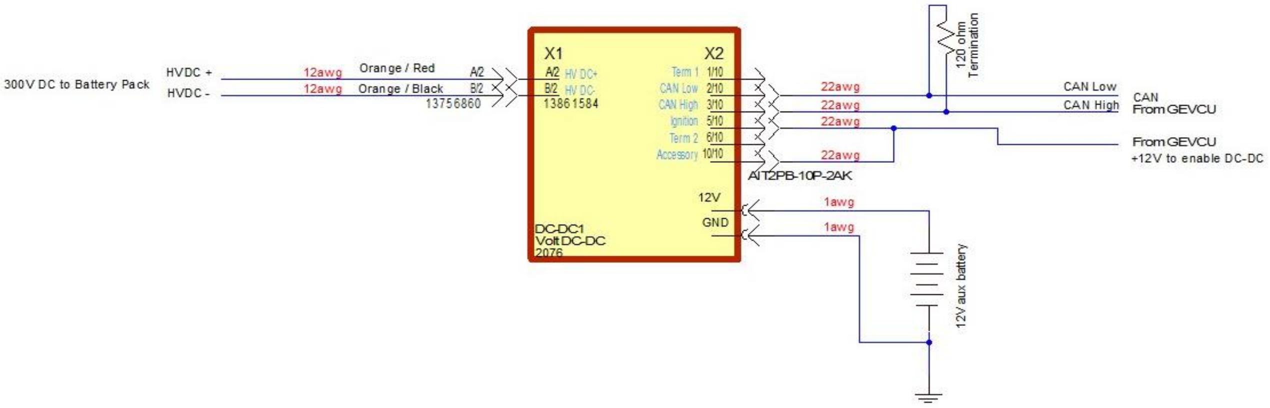


Figure 16 - Wiring diagram

The pinout and the wiring diagram (Figure 16) complete the information necessary for the integration of the component.

2.3 Gearbox

2.3.1 Gearbox requirements

The gearbox has a very important role on the integration of the vehicle and therefore on the validation of this powertrain solution.

Starting from the power and the torque of the motor under design we have used a calculation model (Table 8) to find the perfect Gear Ratio that could guarantee a suitable top speed, comparable with other commercial vehicles on the market and a suitable torque at the wheels that could allow the vehicle to overcome a slopes along the way.

Table 8 - Calculation model for gearbox

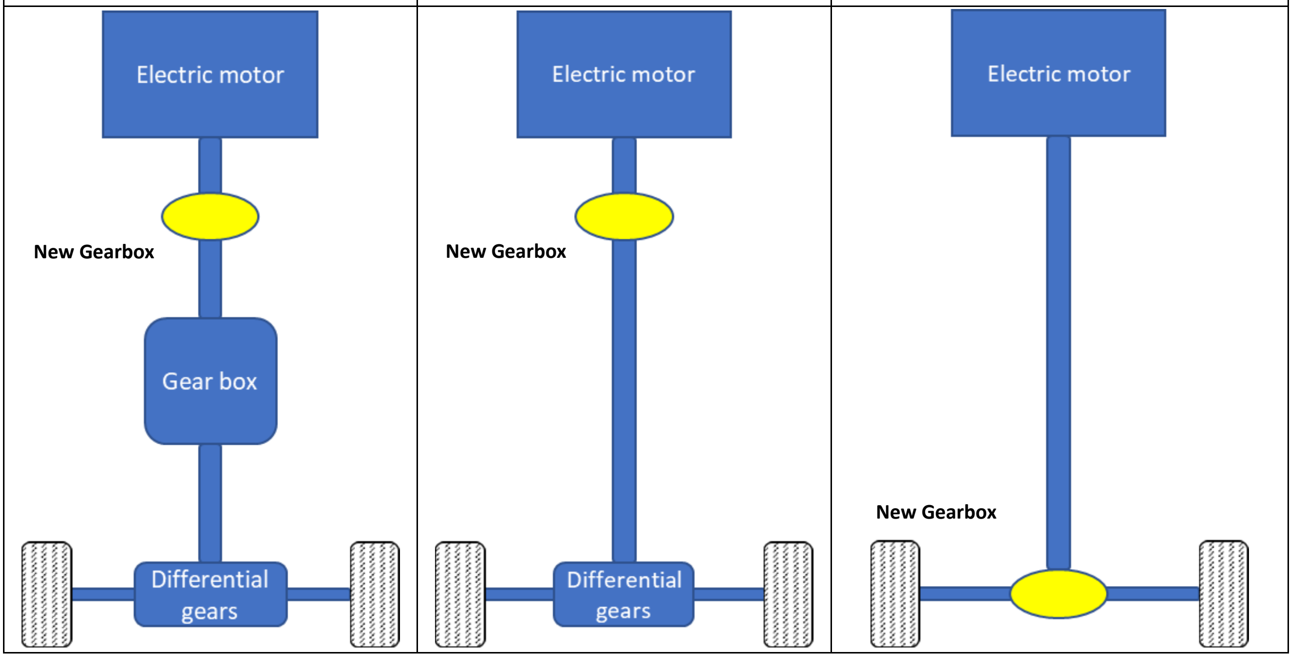
Gear ratio	optimal 3.84						
V. max	optimal 106.91 km/h						
Max slope	optimal 20 %						
Calculation model				ρ	Air density	1,2	kg/m^3
Max loaded mass	3.500,00	kg		μ_r	Drag coefficient	0,015	
Max speed		TBD		C_a	Aerodynamic coefficient	0,4	
Average Speed		TBD		S	Front section of the vehicle	2	m^2
Max speed on slope		TBD					
Differential ratio	3,923						
Total transmission ratio	**13,73**						
Wheel radius	0,356	m					
N	34.324,50	N					

The optimal gearbox could be placed at different stages of the cinematic transmission and should withstand a maximum rotation speed of 12.000 rpm at the input shaft. So, we also evaluated the possibility of using the actual gearbox of the Mercedes Sprinter in the cinematic chain (Table 9).

Max speed motor:	12.000 rpm	
Max torque motor:	190 Nm	
Max power motor:	100 kW	
Gearbox ratios:	I.	5.014
	II.	2.831
	III.	1.789
	IV.	1.256
	V.	1.00
	VI.	0.828
Differential gears:	3.923	

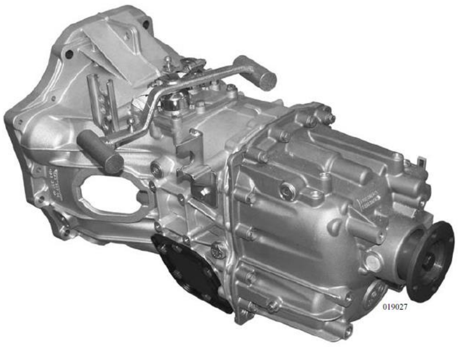
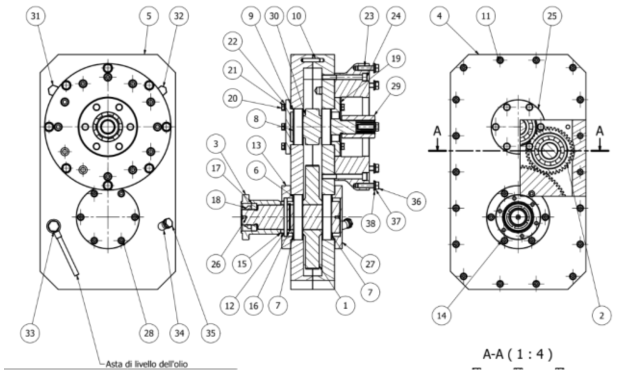
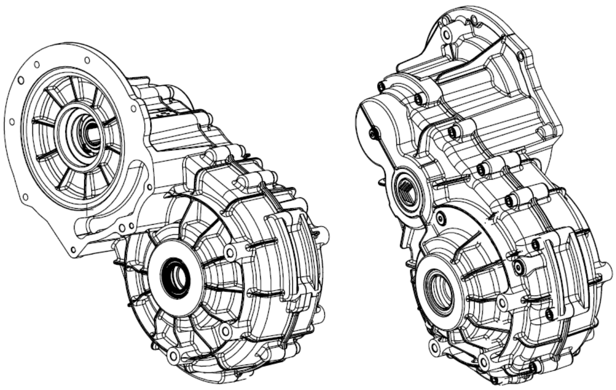
Table 9 - Different gearbox installations

Configuration A	Configuration B	Configuration C



- Gear ratio needed for configuration A and B: 3 – 6.5
- Gear ratio needed for configuration C: 12 – 21

Table 10 - Gearbox supplier selection

	Gearbox – supplier **ZF** Gear ratio → 3.15 Max input power → >120 kW Max input torque → >440 Nm Max rpm input → TBD (7-8.000 rpm) V. max → 130.3 km/h Max slope → 15.8%
	Gearbox – supplier **eyesvehicles** Gear ratio → 3.5 Max input power → 100 kW Max input torque → 190 Nm Max rpm input → 13.000 rpm V. max → 117.3 km/h Max slope → 17.7%
	Gearbox – supplier **Bonfiglioli** Gear ratio → 14.88 Max input power → 375 kW Max input torque → 300 Nm Max rpm input → 12.000 rpm V. max → 108.2 km/h Max slope → 19.2%

After a detailed comparison between the different solutions, Table 10, we have decided to proceed with the supplier **eyesvehicles** because the input rotational speed of this product is in line with our expectations and the gear ratio can be adjusted to our needs. The gearbox will be installed according to the Configuration B; therefore the creation of a special transmission shaft will be required.

2.4 HMI

The Human Machine Interface is the communication bridge between the driver and the car itself. For this application we decided to implement a dedicated interface with the purpose of providing a better and safer driving experience.

The HMI system is made of 2 main "parts":

1- Hardware. The screen and all the electronic parts needed to assure the publication of the information and the communication between human driver and the ECU of the car.
2- Software. A Bluetooth and CAN communication has been implemented.

2.4.1 Hardware

The Joying 10.1 Inch Double Din Android 8.1.0 Car (Figure 17) has been selected because it's powerful and has a nice 10.1" touch screen that makes it easy to see all the relevant parameters. This units works with an integrated Android for CAR software that can be connected with other APP already developed in the market.

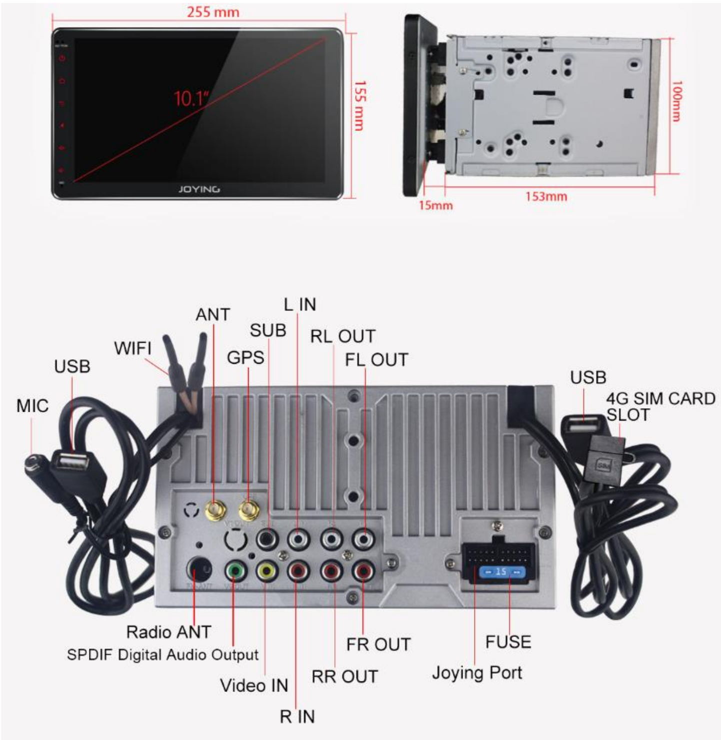


Figure 17 – Joying 10.1 Inch Double Din Android 8.1.0 Car Tech information

The unit (Figure 18) is equipped with a Bluetooth low energy communication and can be easily installed in the location of the car where usually the Radio System finds place.

Figure 18 - Joying 10.1 Inch Double Din Android 8.1.0 Car side view in operation

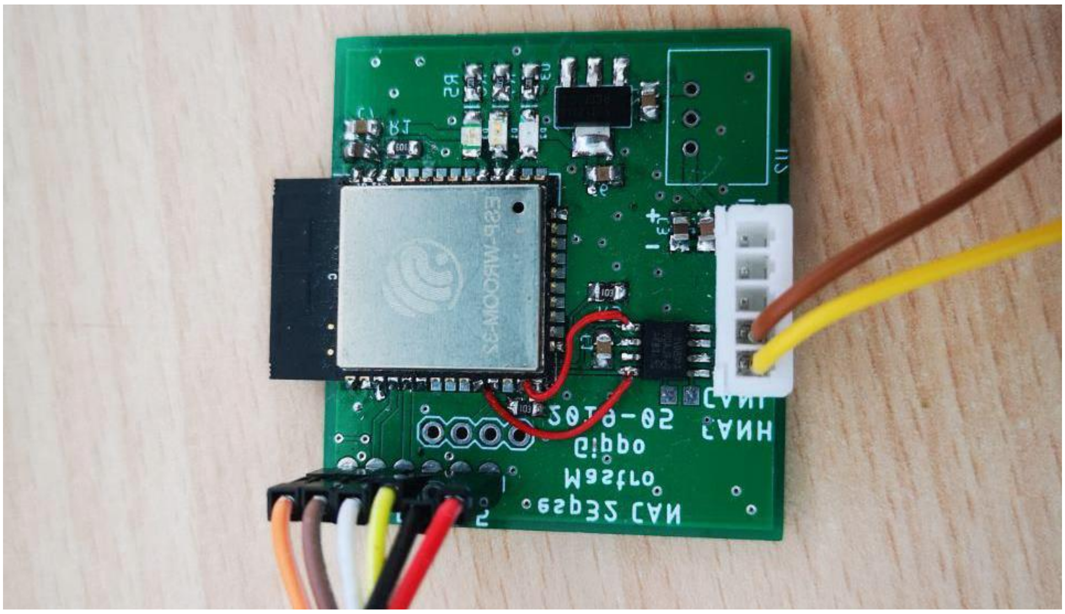


Figure 19 - Custom board based on the NXP LPC1768

Figure 20 - ESP32 chip with Bluetooth communication

The vehicle interface is a custom device (Figure 19) that translates the CAN messages to the custom protocol required by the Torque app. In the first prototype it was based on an ESP32 chip with Bluetooth communication (Figure 20). However, while this worked greatly when paired to our test smartphone, when testing with the Joying head unit we had Bluetooth compatibility problems. We replaced this interface with another custom board based on the NXP LPC1768 IC that is currently under prototyping.

2.4.2 Software

The head-unit runs android so instead of spending a big effort to develop a custom app from scratch, we choose to base the interface on the Torque app.

This app is designed to read data from combustion vehicles so it already has many useful features that can be reused.

There are graphing and logging functions, and a dashcam function drawing gauges over the recorded video.

The most important feature is the interface flexibility, as it's possible to create custom screens and add widgets associated to various values reported by the vehicle interface. Having access to every single CAN message from the system, we can prepare different pages for the various components; as shown in Table 11 and Figure 21:

Table 11 - HMI outputs

General page	Battery pack - State of charge
	Available range
	System temperatures
	Charging status
	Visualization of custom alarms
Specific battery subsystem page	Cell balance status
	Voltages
	Currents
	Modules temperatures
	Detailed charging information
Inverter / Motor parameters page	RPM
	Torque (estimated)
	Power (estimated)
	Phase voltage
	Phase current
Cooling system page	Components temperatures
	Coolant temperatures
	Pumps status
	Tank liquid level

Figure 21 - Control APP developed by Privé on the Torque background

3 Components integration

3.1 Battery Pack

3.1.1 Mechanical Layout

After the considerations on the cooling system made above and to guarantee a reduction in the manufacturing cost, it is considered appropriate to eliminate the external structure that would contain the module.

Given the height of the cells (65mm) the two upper and lower cell holders could be obtained from a 30 mm thick plastic plate and should constitute the same cell protection shell, as well as the structure that will ensure safety and solidity in transport and assembly. This would allow us to eliminate one component at the base of the cost problems that emerged during our study (Figure 22) and to obtain the same results in terms of reliability and mechanical performances. The modules (Figure 23) will then be stacked and positioned inside an external protective aluminium box that will be properly anchored to the sprinter chassis.

See below a representative application of the above.

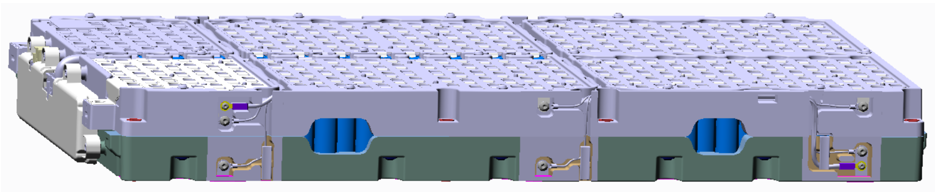


Figure 22 - side view of the battery pack module, first layout

Module structure has been made with PVC material and divided in 4 plates manufactured through Computer Numerical Control (CNC) machines. The 4 plates will be assembled with screws and then once together connected with the lower structure in aluminium that will be used as a mechanical support during the assembly.

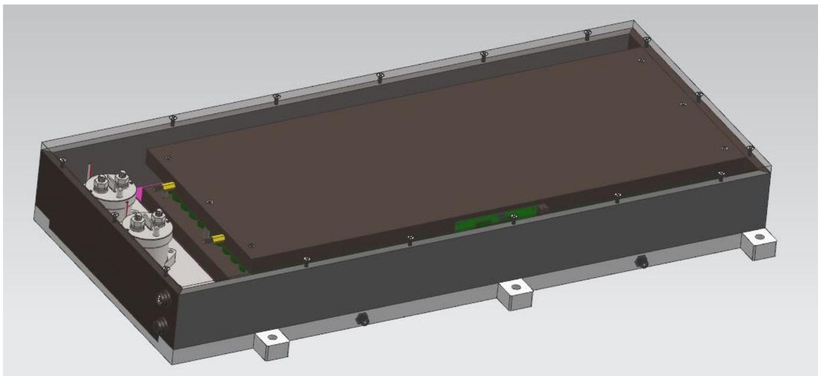


Figure 23 - view of the battery pack module, second layout

The external housing of the BP (Figure 24) has been made with 5 metal parts and 1 plastic cover.

1 – A lower plates that has the purpose to sustain the battery pack during the mounting process.

2 – Front and rear plates with the purpose of supporting the modules inside the pack. They have been designed in order to be tightened with metal bars that are used to hang the modules.

3 – Left and right cover. They are removable and they will be used to place the connectors.

4 – Plastic cover. Place on top of the battery will protect the inner part of it.

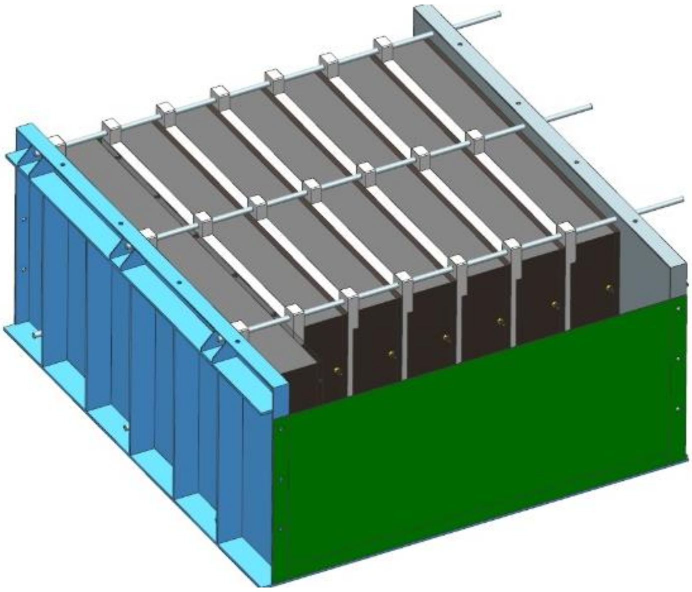


Figure 24 - View of the battery pack

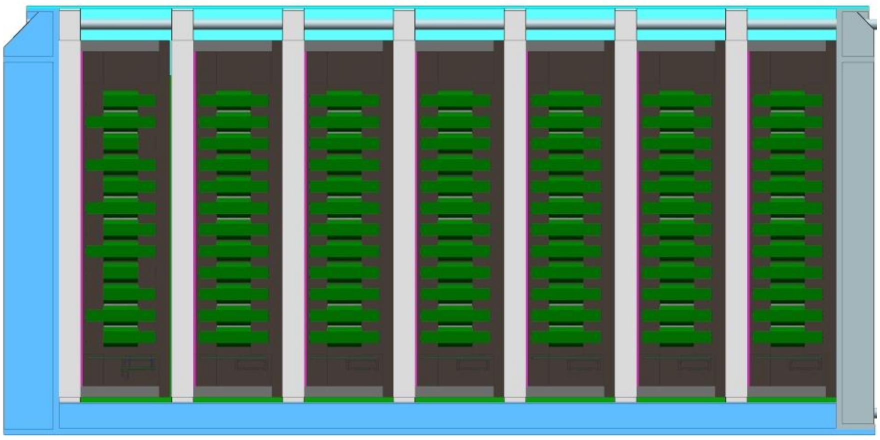


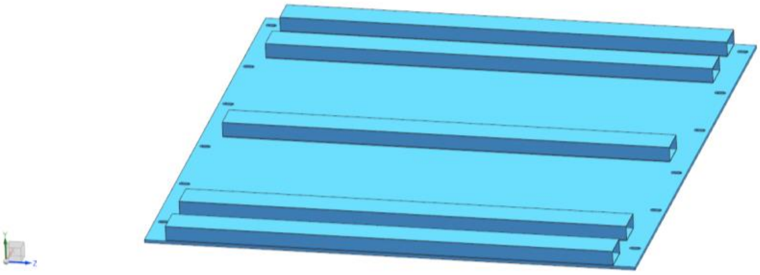
Figure 25 - View of the battery pack in section

In this side view of the battery pack (Figure 25) you can see the different components after the final assembly.

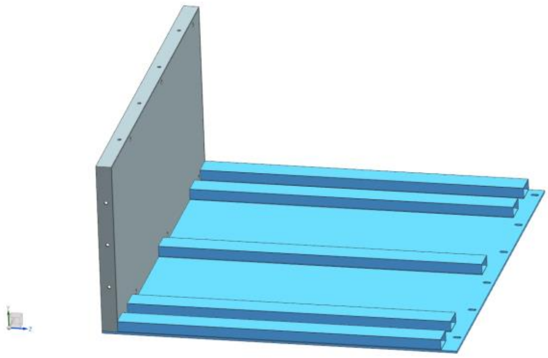
In the following Table 12, you can find the description of all the metal parts that form the battery housing and their assembly sequence.

Table 12 - Description of the BP assembly sequence

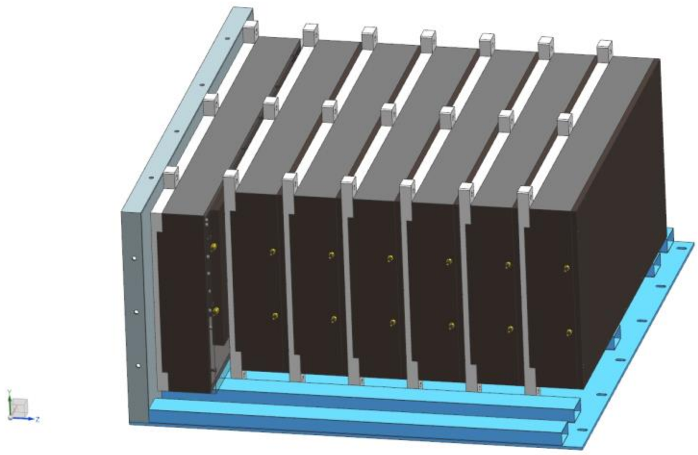
Nr	Part	Material	Description	Weight
1	Lower plate	S275 jr or equivalent	Steel base consisting of a 5 mm plate with holes and welded tubes	31kg



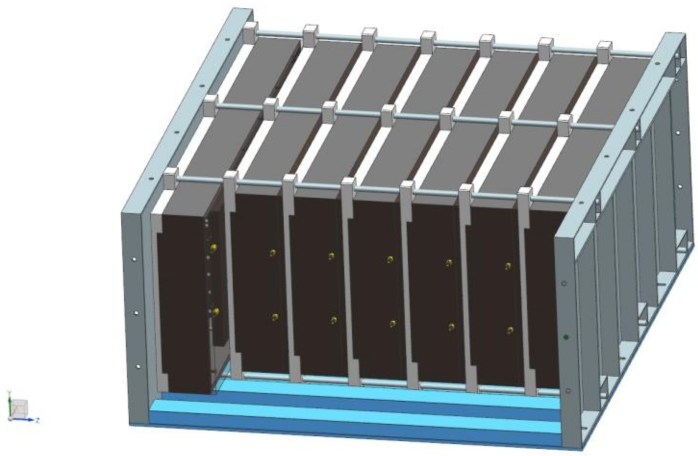
Nr	Part	Material	Description	Weight
2	Lx plate	S275 jr or equivalent	Side structure consisting of welded plates and holes	19kg



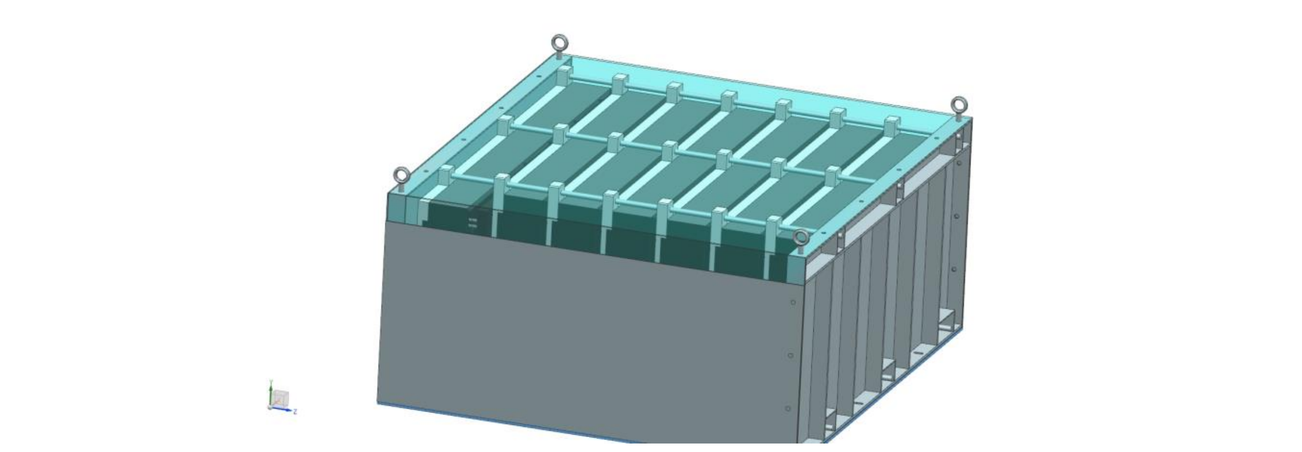
Nr	Part	Material	Description	Weight
3	Master module	N/A	N/A	44kg approx.
4	Slave module	N/A	N/A	36kg approx.



Nr	Part	Material	Description	Weight
5	Rx plate	S275 jr o equivalent	Side structure consisting of welded plates and holes	19kg
6	Steel tie rods	N/A	Diameter 10 mm	N/A



Nr	Part	Material	Description	Weight
7	Front cover	S235 jr or equivalent	N/A	N/A
8	Rear cover	S235 jr or equivalent	N/A	N/A
9	Top cover	Plastic	N/A	N/A



A Finite Element Method (FEM) analysis (Figures 26,27 and 28) has been performed in order to guarantee the solidity of the structure under specific loading conditions:

- 600kg are applied along the negative Y axis with supports at the top of the Rx and Lx covers to simulate the load on the battery. The maximum deformation of the structure is less than 1mm.

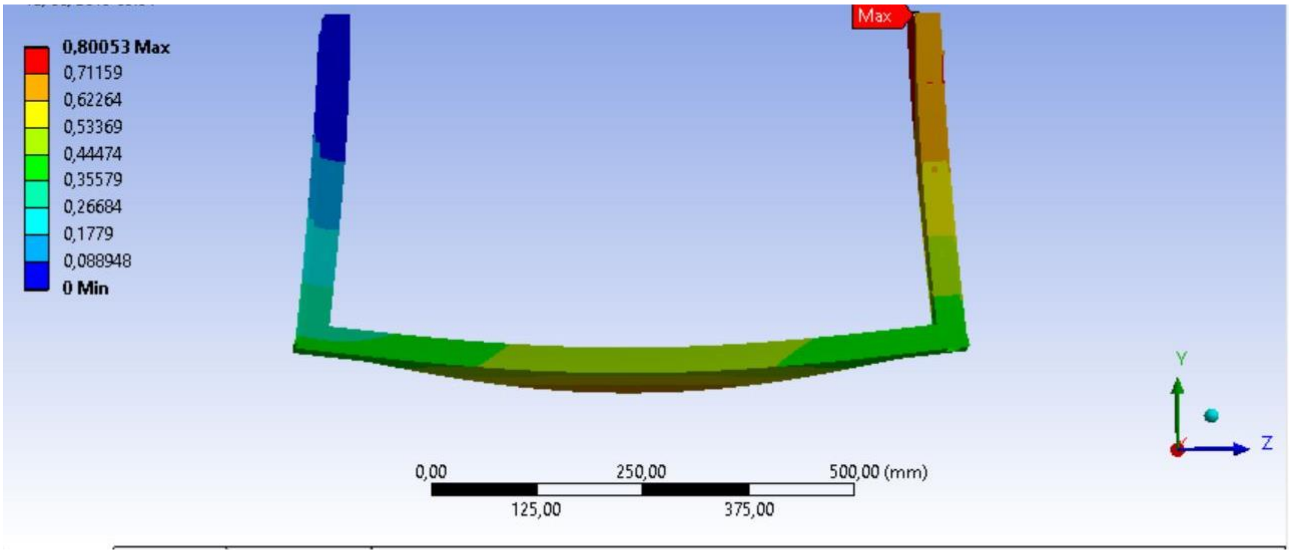


Figure 26 - View of the deformations

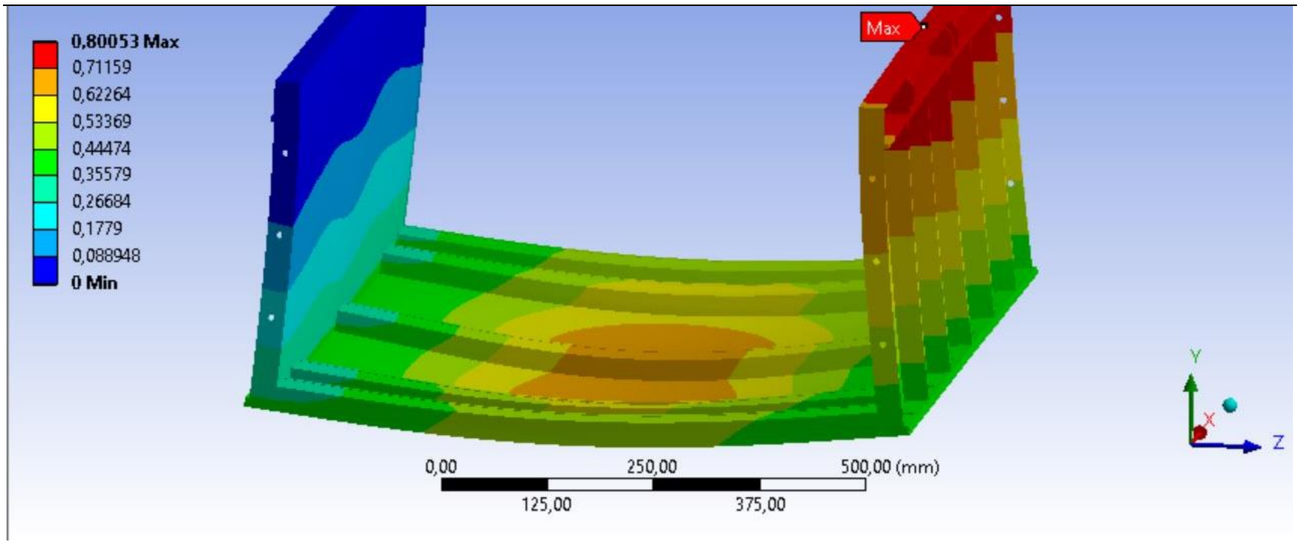


Figure 27 - View of the deformations

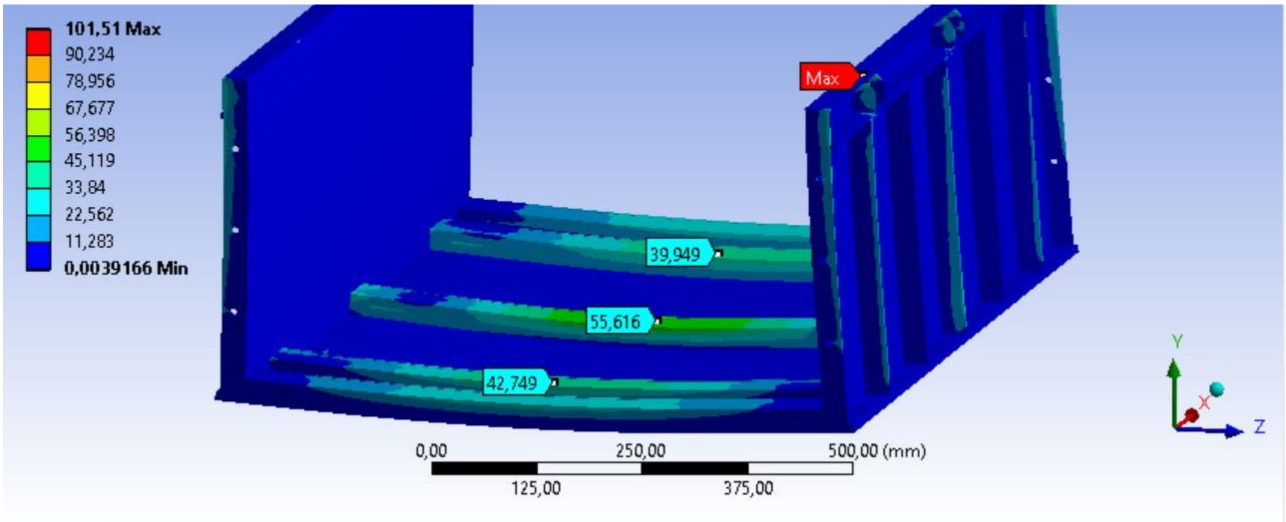


Figure 28 - View of Von Mises stresses

The results showed that the structure can withstand the forces that we have considered in the worst-case scenario.

3.1.2 Electrical Routing

All the battery connectors, input and output have been installed on the side left cover in order to allow easy operations in case of any need.

A manual service disconnect has been placed between the 4th and the 5th module in order to allow safe operations on the battery pack. The manual service disconnect can be open manually and it take out the power from the plus output of the battery pack.

Because of the layout of the modules that we have chosen the plus output of the battery and the minus have been located in opposite sides, that required a specific study on the cables path to assure the safety of the battery pack. In the Figure 29, you can see the power output locations.

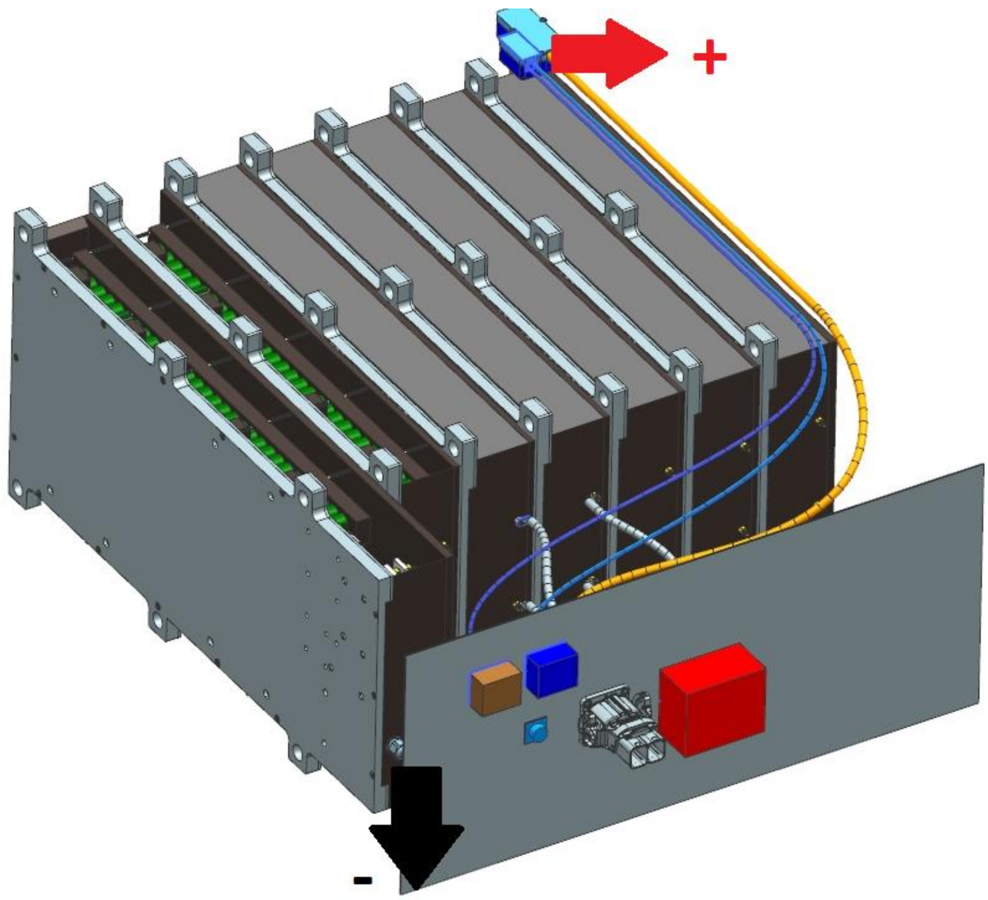


Figure 29 - View of the battery pack with connectors and plus and minus terminals

In the Figure 30, you can see the different connectors located on the side cover of the battery pack.

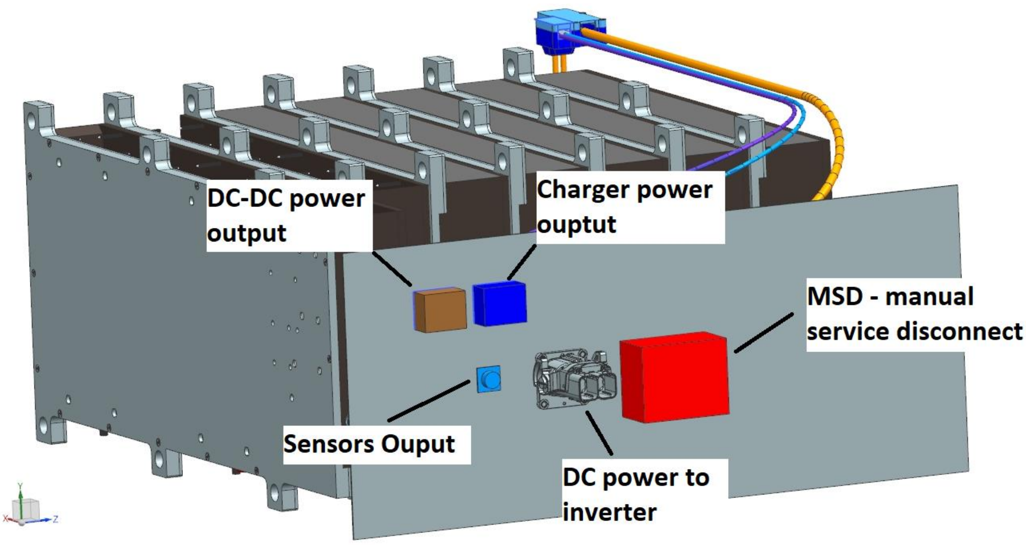


Figure 30 - View of the battery pack with connectors

All the modules have been connected in series and their connection has been done with a screw/bolt system (Figure 31). To decrease the dimension of the cables and allow an easier mounting process each power output has been divided in two parts.

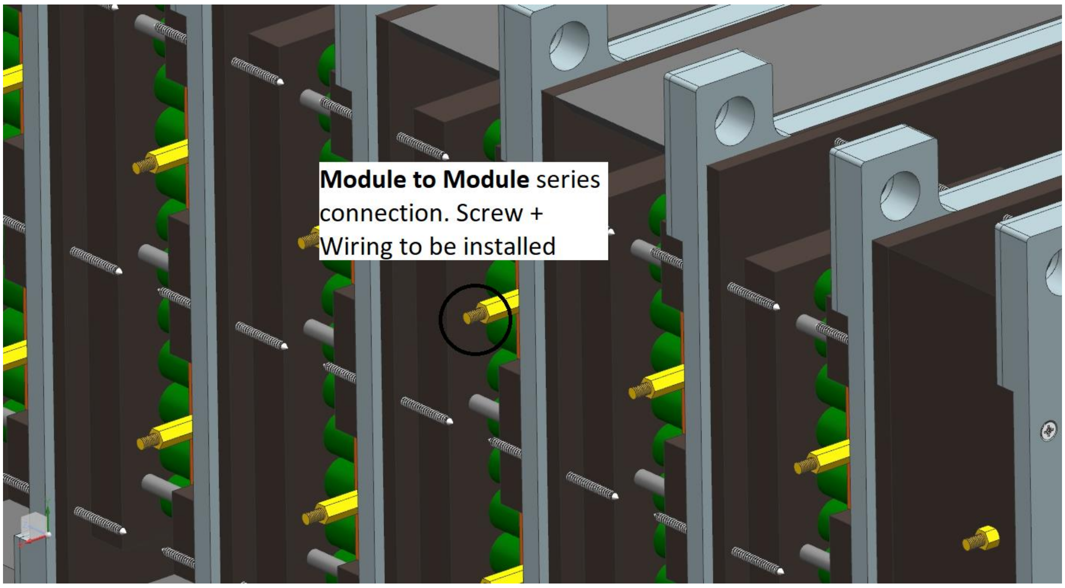


Figure 31 - View of the module to module connections

The 2 cables coming out from the module power output has been joined in one single copper plate inside the derivation box and then divided in 3 cables to different output:

1- DC power output to the inverter
2- DC/DC low power output
3- Charger power input

In the Figure 32, you can see the lay out of the derivation box

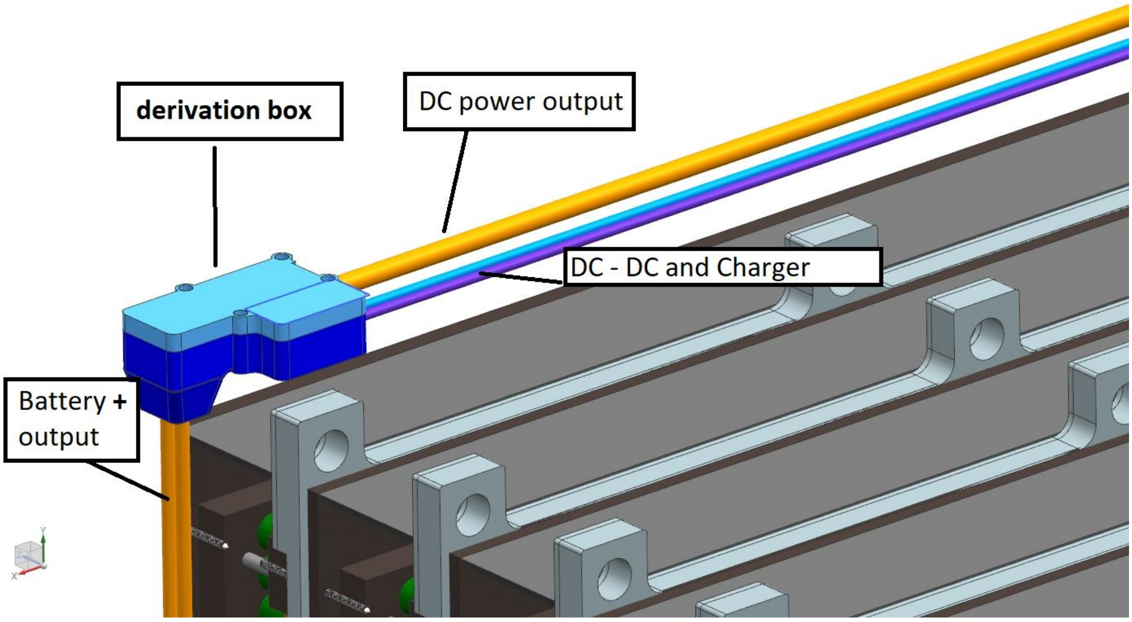


Figure 32 - View of the battery pack derivation box

This component will be manufactured with rapid 3D printing in 2 halves connected with screws. The copper bar inside will be obtained with laser cut.

3.1.3 Liquid Cooling Design and Installation

For the cooling of the main components (inverter, motor, charger and battery pack), we have designed 2 cooling systems, one of which specific for the BP (Figure 33).

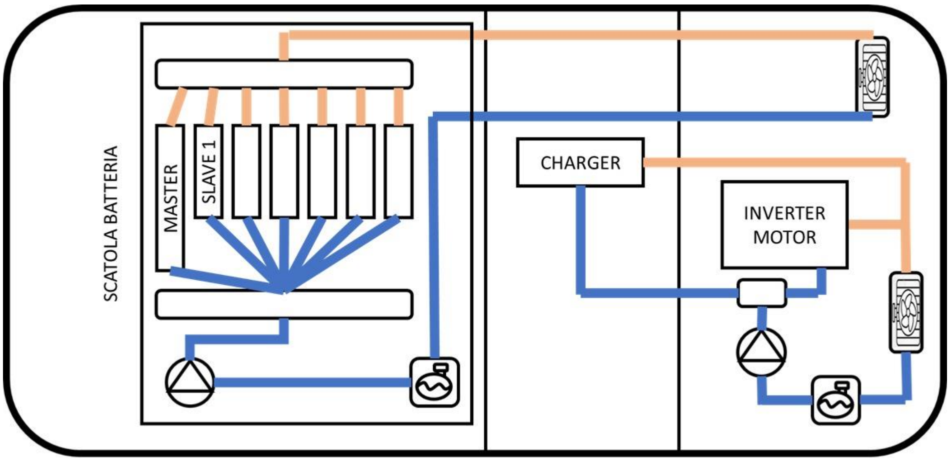


Figure 33 - Liquid cooling installation

The Cooling Circuit (CC) is in parallel with the different cold plates and after a Computational Fluid Dynamics (CFD) analysis we have selected the correct flow rate of the cooling liquid [17.5 l/min]. See the Figure 34 below.

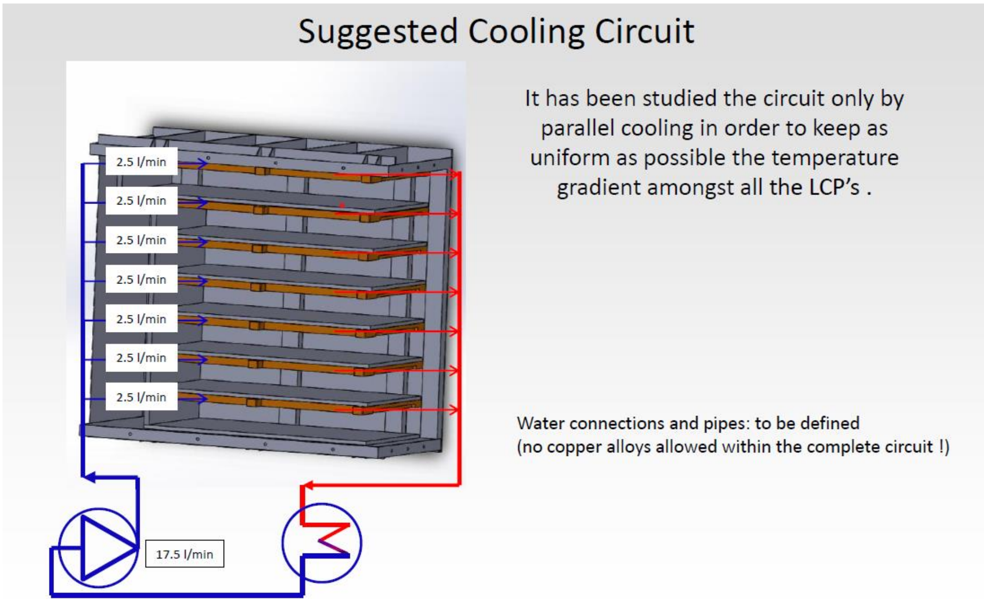


Figure 34 - Liquid cooling flow rate inside the battery pack

With this flow rate we have verified that the temperature on cells won't go over the safety level prescribed but the manufacturer. See in the Figure 35 below, the temperature pattern highlighted with the CFD analysis.

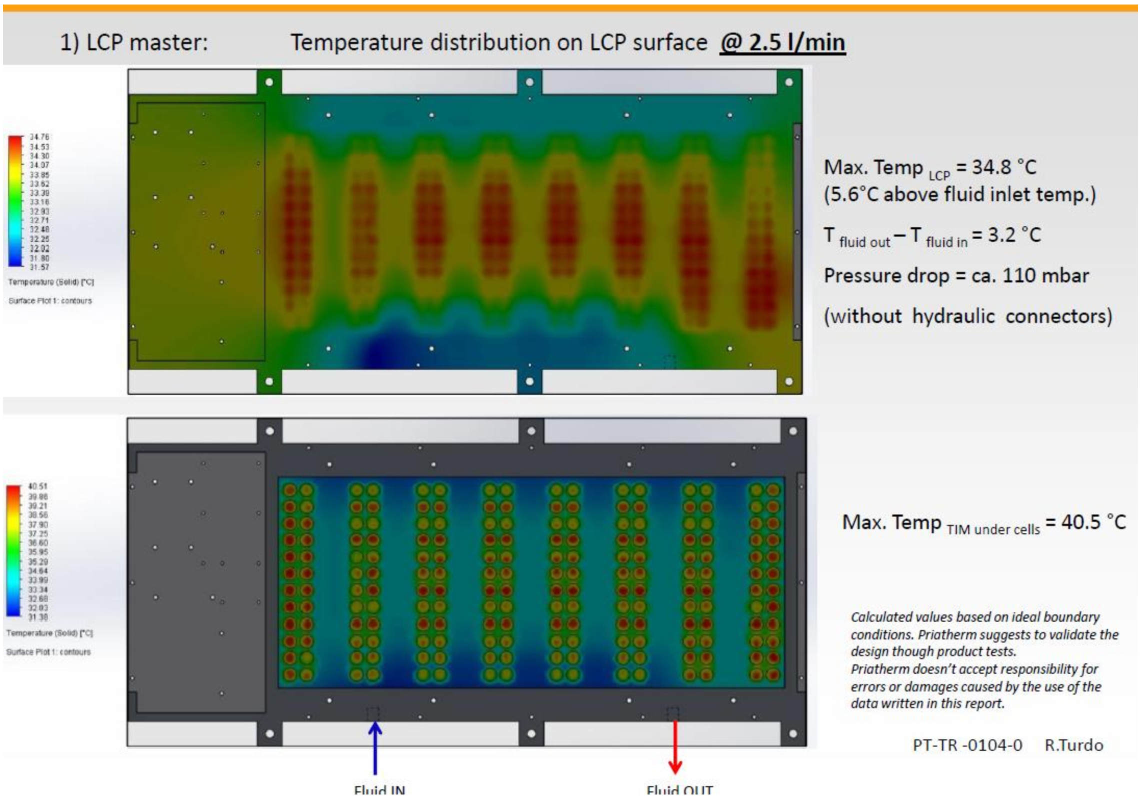


Figure 35 - Liquid cooling temperature inside the battery master cooling plate

The next step has been the design of the cooling plates to be produced with the CNC manufacturing process. The Figure 36 below shoes the final 3D.

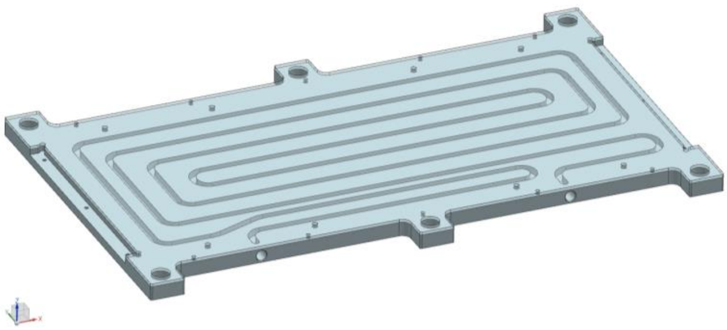


Figure 36 - View of the battery slave cooling plate

In order to guarantee the best heat transfer between the cold plate and the cells we have interposed a thermal pad of 2mm thickness with the characteristics descripted in the Table 13.

Table 13 - Thermal pad information and view

Index	Testing Standard	WT5902-45-40
Appearance	Visual	Grey
Thermal Conductivity (W/m*K)	ASTM D5470	4.4
Thickness (mm)	ASTM D374	1.0~5.0
Hardness (Shore OO)	ASTM D2240	40
Density (g/cc)	ASTM D792	3.3
Breakdown Voltage Strength (KV/mm)	ASTM D149	5.0
Volume Resistivity (Ω.cm)	ASTM D257	1.0×10^{11}
Temperature Range (°C)	--	-50°~200°
Flame Retardancy	UL94	V-0

The silicon elastomer will assure both a good heat transfer and a dielectric insulation.

3.1.4 Charging System

The charger selected is XPPOWERPLUS (Figure 37) produced by Xepics Italia s.r.l.

To integrate this component in the vehicle we have defined:

- Space and position in the vehicle,
- Electrical connections,
- Mechanical connections.

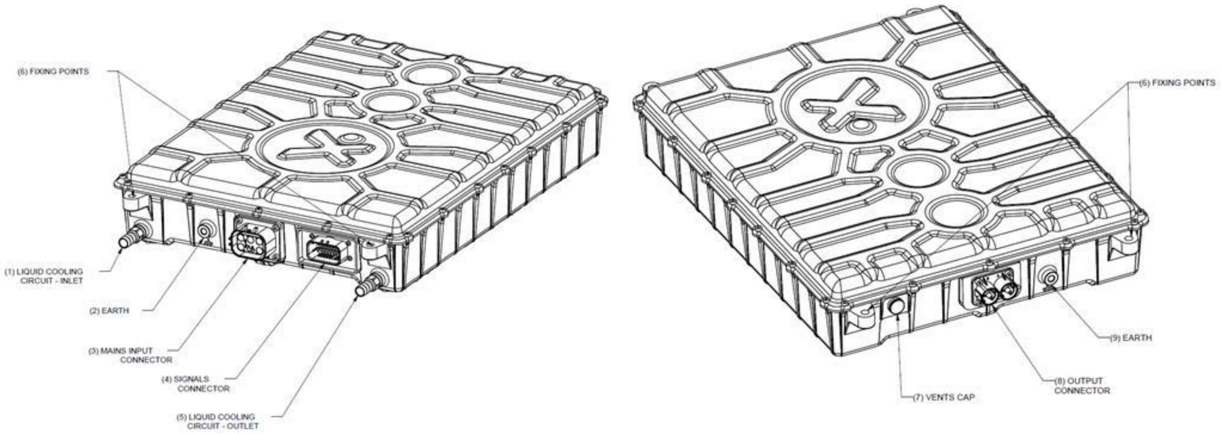


Figure 37 - Charger views

Position in the vehicle

Usually in electric vehicles, the charger is a component that is not easy to access but being our demonstration vehicle, we have decided to install it in the vehicle's load compartment; for the following reasons:

- Minimization the length of the cables and therefore reduction of the section,
- Need for easy access to change the settings,
- Faster intervention in the event of a fault.

Electrical connections

a- Fuses and protections

The XPpower+ has an internal fuse protection for each main phase line (L1, L2, L3). The maximum input current per phase is 32Arms and the fuse protection is set to 40A. The internal fuses act as a protection to avoid a severe damage to the OBC, wiring and connectors, due to an overcurrent event.

The DC output of the charger is not internally fuse protected, then a fuse shall be installed outside (in the distribution box). The fuse shall be of 40A and shall be a fast-acting type. Cables shall be shielded, and the shield shall be correctly adjusted during the cable assembly in order to avoid loss of insulation with positive and negative terminals and to assure a good electrical connection with the OBC’s housing.

b- Earth connections

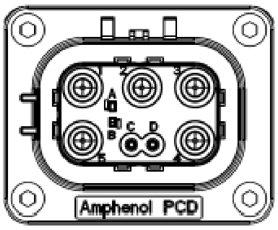
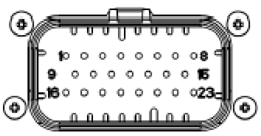
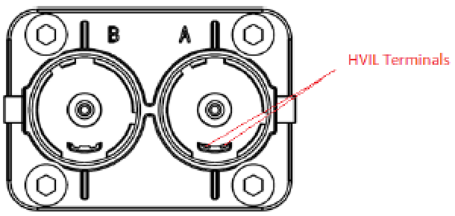
Earth connections are essential in order to guarantee the ElectroMagnetic Interference (EMI) performances of the device and to comply with the safety features. The Earth wire, screwed with an M8 screw to the OBC housing, shall be connected to vehicle's frame, in the same point in which the negative pole of service battery is connected, realizing the shortest possible connection. All the necessary measures to guarantee a good quality of the connection over time shall be taken. For the earth to frame connection a cross-section of, at least, 16mm2 is recommended.

The OBC has a second earth point connection near the output connector. It's a good rule to connect also this point to the vehicle's frame, avoiding realizing a large Earth area loop with the previous installed Earth point (connect to the vehicle's frame, if it is possible, at the same fixing point).

c- Electrical connectors

The following Table 14 shows the list of electrical connectors on the charger:

Table 14 - Power and signal charger connectors

Power connector AC side	
 **Figure 1** - *Mains Input Connector Front View*	**Manufacturer:** Amphenol **Housing Part Number:** HVSL365025A **Power Terminals (1,2,3,4,5) Part Number:** C310026000 **Interlock terminals (A, B) Part Number:** C310003616S **Signals Terminals (C, D) Part Number:** LVRC20SC01S **Mating part:** HVSL365065A-104I
Signal and CAN connector	
 **Figure 2** - *Signals Connector Front View*	**Manufacturer:** TE **Part Number:** *1-776228-1* **Mating part:** 770668-1
Power connector DC side	
 	**Manufacturer:** Amphenol **Part Number:** PL082X-121-10M6 **Mating part:** PL182X-121-10

Mechanical Integration

a- Fixing points

The charger shall be fixed to the vehicle frame using all the four connection points. Furthermore, the connection between the charger and the frame shall be made using vibration damper/shock absorber, as shown in the Figure 38 below:

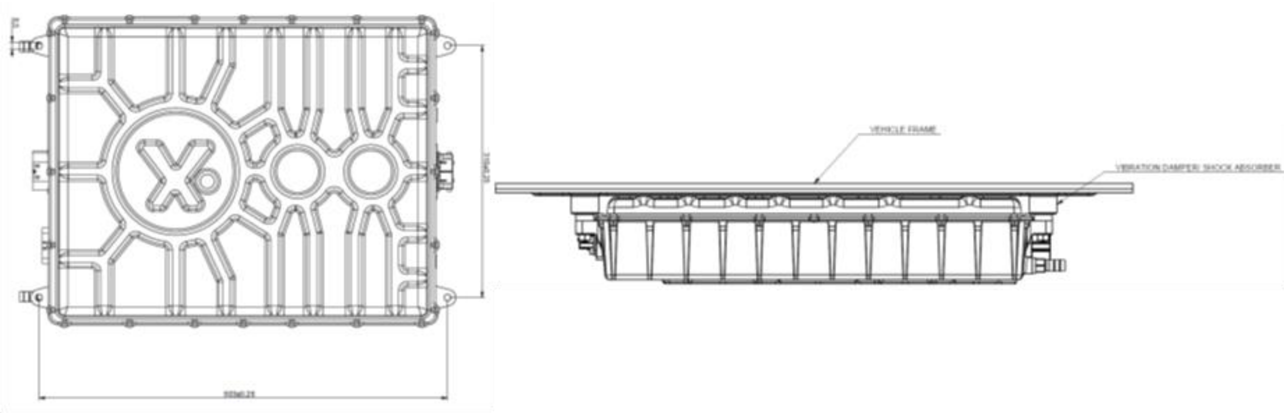


Figure 38 - Installation points of the charger

b- Liquid cooling circuit connections

XPpower+ shall be liquid cooled to operate properly. The device has 2 hose fittings, one for inlet and one for outlet connection to the liquid CC (Figure 39). The internal diameter of the hose shall be 12mm and, depending on the hose type, a hose clamping should be needed. The maximum liquid temperature shall be lower than 65°C and higher than -40°C. The liquid cooling circuit shall use GLYSANTIN® G40® as coolant. The flow rate shall be at least 6l/min; pressure drop is lower than 0,2bar and the maximum pressure shall be lower than 3bar. The amount of coolant in the device is about 0,2 liters.

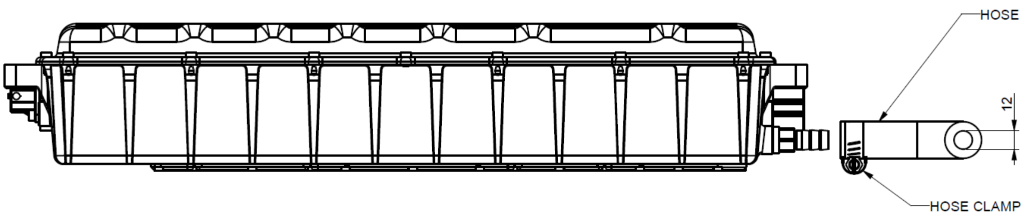


Figure 39 -View of the charger cooling input and output

3.1.5 BOM

In the following Bill of Material (BOM), you can see a summary of the different components that we are going to buy off the shelf. In the Figure 40 you can see even the size of the cables that we are going to use.

Component	Function	Color	Volt	Ampere	Mounting	M/F	Pins	Terminals	Cable size	IL	IL cable	Brand	Model	Con. Code	Contacts	other code
Battery	HV In	orange	441	300	panel	M	2P	F	35	si	0,5-0,75	Aptiv	RCS 800	33511764		
					cable	F		M						13974469		
	MSD	orange	441	300	panel	-	1P	-	35	si		Amphenol	Plug	MSDM3502		
					plug	-		-					Socket	MSDF350F		
	CAN	black	-	-	panel	M	9	M		-		Weipu		SP1312/P9		
					cable	F		F						SP1310/S9		
	HV DC	orange	441	6	panel	M	2P	F	4	si		Aptiv	Apex HV280			
					cable	F		M								
	HV Ch	orange	441	25	panel	M	2P	F	10	si		Amphenol	HVSL362			
					cable	F		M	16							
Inverter	HV	orange	441	300	panel		1P		85	NO		-	-	-	-	-
					cable				35				-	-	-	-
	CAN		-		cable	-	-	-		-		TE		776164-1		
Acc pedal	Signal AP	black	-	-	cable	F	6	F	1	-						
Dc/dc	HV	orange	441	6	panel	M	2P	M	4	si		Aptiv	Apex HV280			
					cable	F		F		si						
	LV	-	14	180	studs		2P			-						
	CAN	black	-	-	cable	M	10			-		JST		AIT2PB-10P-2AK	SAIT-A02T-M064	
Charger	HV	orange	441	25	cable	F	2P		16	si		Amphenol	PL082X-121-10M6			
	Input AC	orange	3-phase	30	cable	F	5P	F	4	si		Amphenol	HSVL365025A	C310026000	C310003616S	LVRC20SC01S
	CAN	black	-	-	cable			23	1 - 0,5	-		TE	1-776228-1			

Figure 40 - Connectors BOM

Below you can find the BOM (Table 15) of the macro component inside the battery pack.

Table 15 - Battery pack mechanical BOM

	Part	Material	Description	Weight
M001	Low plate	S275 jr or equivalent	Steel base consisting of a 5 mm plate with holes and welded tubes	31kg
M002	Lx plate	S275 jr or equivalent	Side structure consisting of welded plates and holes	19kg
M003	Master module	N/A	N/A	44kg approx.
M004	Slave module	N/A	N/A	36kg approx.
M005	Rx plate	S275 jr or equivalent	Side structure consisting of welded plates and holes	19kg
M006	Steel tie rods	N/A	Diameter 20 mm	N/A
M007	Front cover	S235 jr or equivalent	N/A	N/A
M008	Rear cover	S235 jr or equivalent	N/A	N/A
M009	Top cover	Plastic	N/A	N/A

3.2 Electric Motor and Inverter

3.2.1 Vehicle installation

The Electric Motor and the inverter have been integrated in the vehicle using different custom designed support. The shaft of the motor has been connected with the input shaft of the gear box with a special flange that you can see in the Figure 42. This flange has a female threads that fits with the male threads on the motor and the gearbox.

In the Figure 41, you can see the gearbox flange and the motor connected. The surface of the flange marked in blue will be connected with the surface of the gearbox with threaded bolts.

In the top of the motor you can see the inverter box connected with the motor enclosure with 4 threaded bolts.

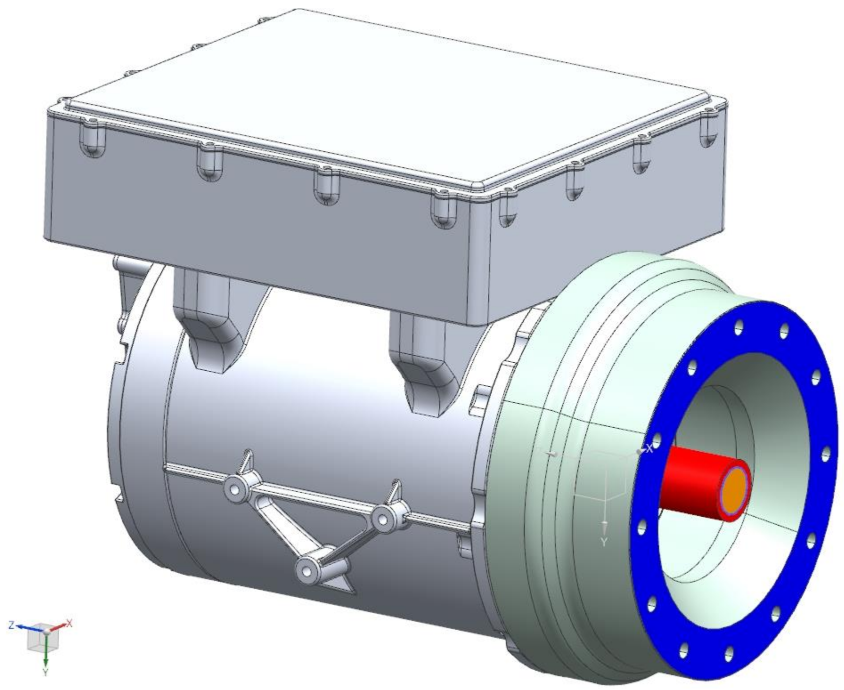


Figure 41 - 3D view of the motor and inverter with the gearbox connecting flange marked in blue

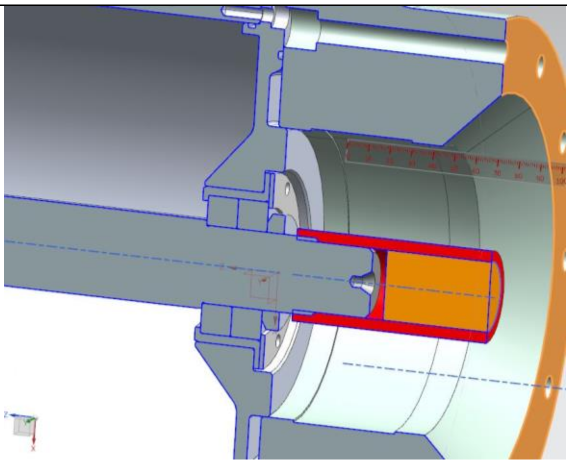


Figure 42 - Detailed view of the motor shaft and the gearbox shaft with their connector marked in red

In order to provide a stable connection between the powertrain system and the vehicle chassis a metal frame has been designed. The frame has been designed with the help of a 3D scansion of the internal part of the vehicle that is visible in the Figures 43-47 in blue.

We have used 4 connecting points with the vehicle and designed 3 flanges that will connect the motor with the frame. In the Figures 43-47, you can see in red the rear flange that connects the motor with the frame. In green the point of connection between the frame and the vehicle chassis.

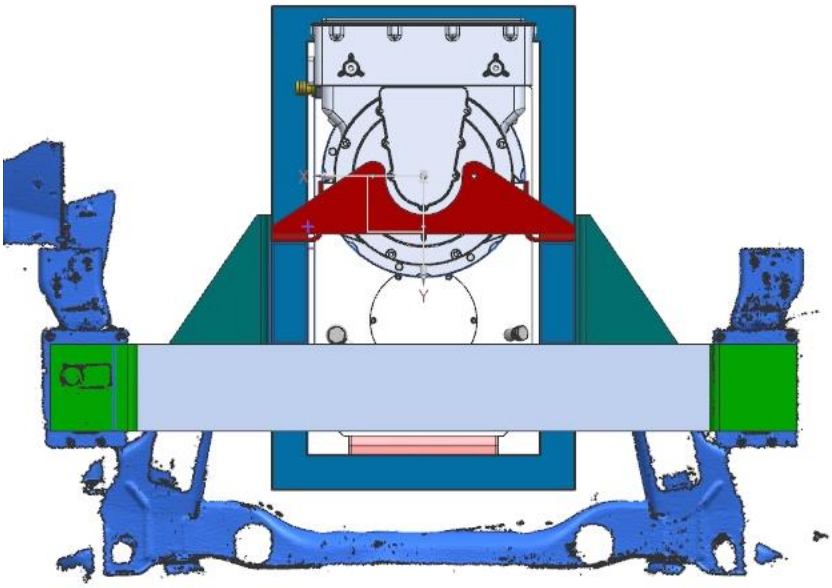


Figure 43 - Front view of the powertrain sub frame with the motor and gearbox assembled

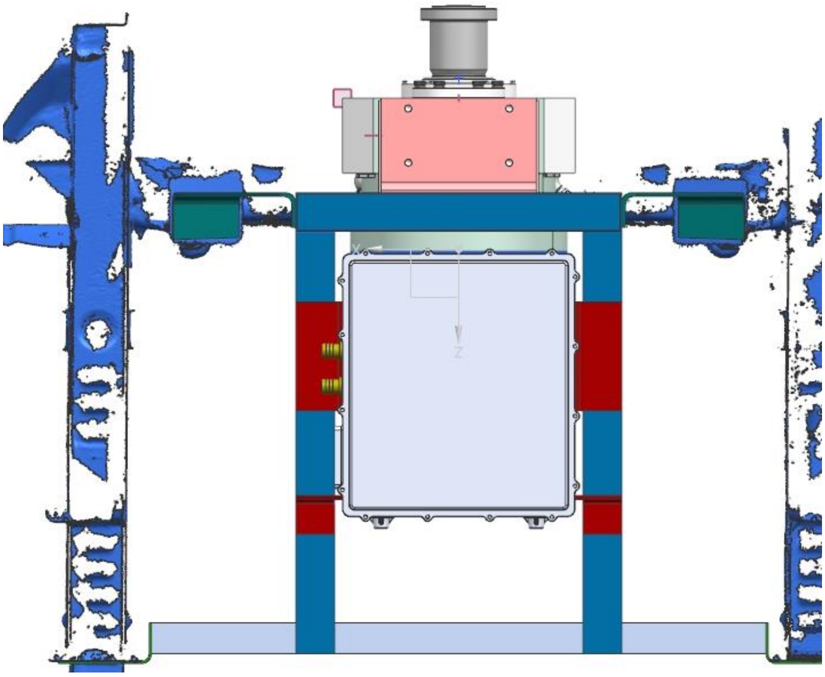


Figure 44 - Top view of the powertrain sub frame with the motor and gearbox assembled. In red the 3 flanges that we have designed in steel to support the motor

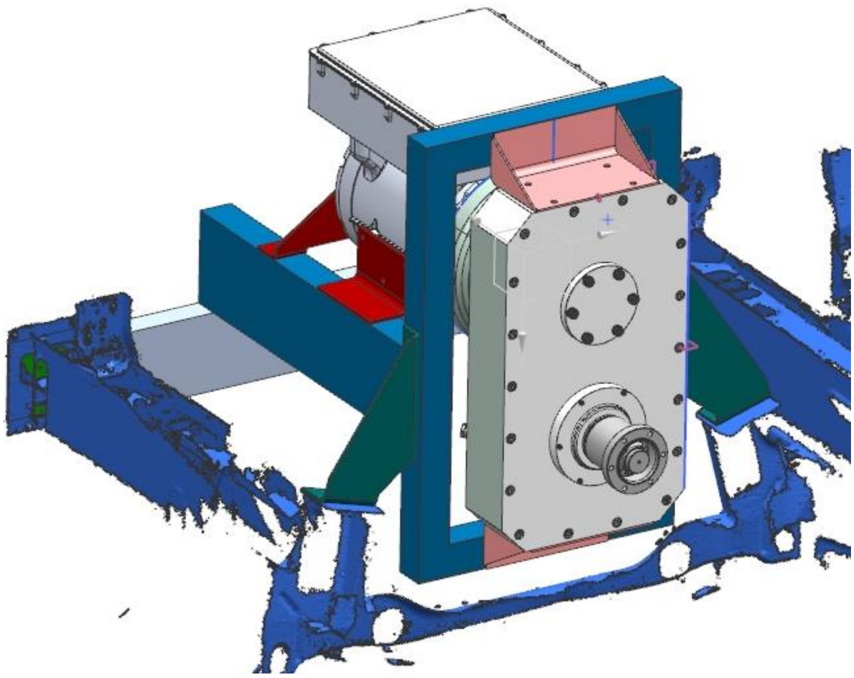


Figure 45 - Rear 3D view of the powertrain sub frame with the motor and gearbox assembled. In dark green the rear connection with the chassis of the vehicle

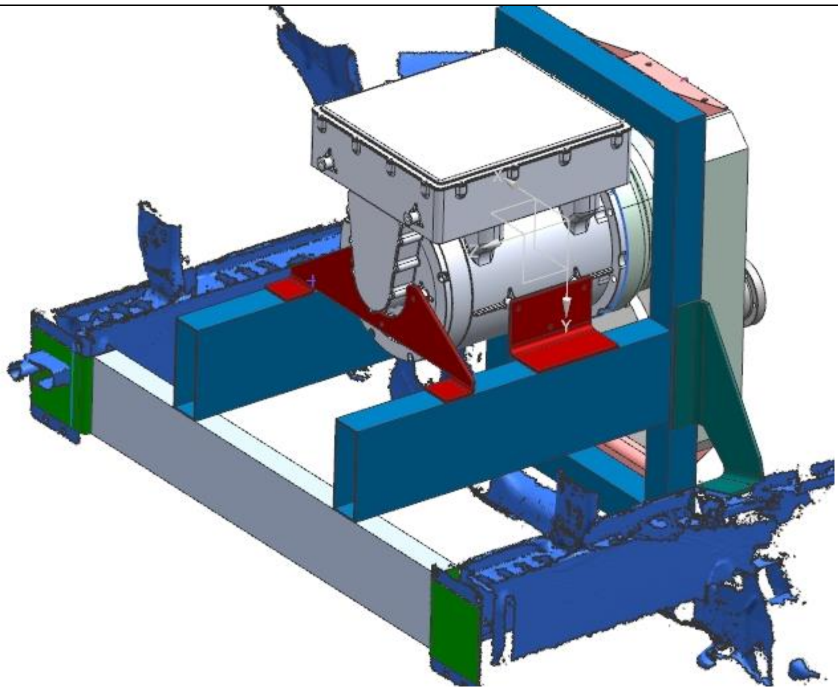


Figure 46 - Front 3D view of the powertrain sub frame with the motor and gearbox assembled

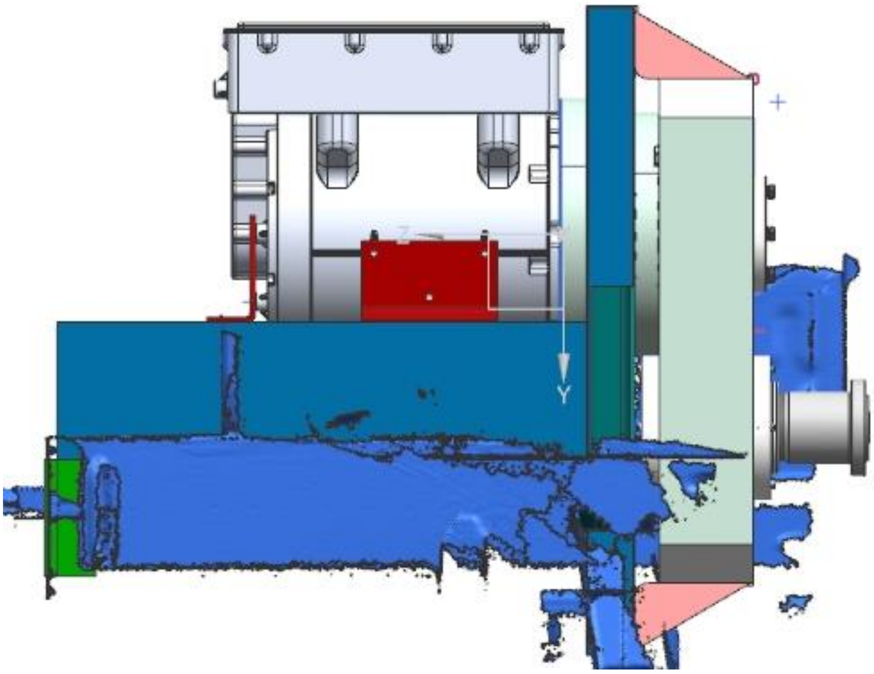


Figure 47 - Side view of the powertrain sub frame

3.3 Gearbox

3.3.1 Vehicle Installation

The gearbox selected (Figure 48) is of waterfall gears typology and it is composed by 3 gears. In the picture below you can see how the input torque comes from the left side and output to the transmission shaft goes to the left. That counterpose lay out has been selected because of the rear traction of the vehicle.

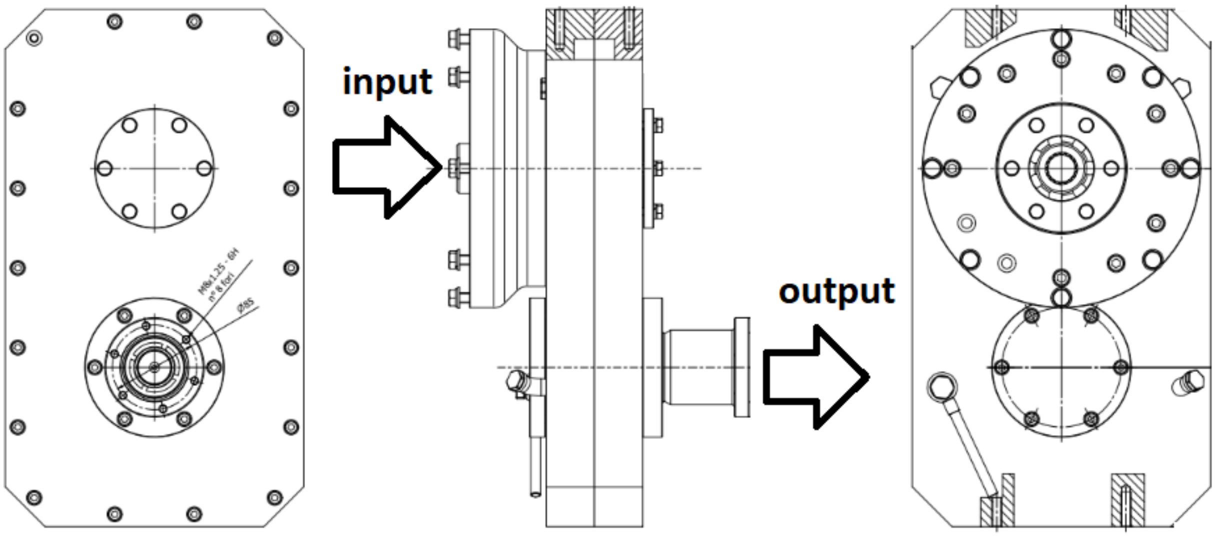


Figure 48 - View of the selected gearbox

The activities performed for the integration of this component has been of three types:

1- Connection of the motor with the gearbox.
2- Connection of the gearbox with the transmission shaft of the Mercedes Sprinter.
3- Connection of the gearbox with the frame of the vehicle.

The first activity has involved the design of a specific component that you can see on the Figure 49. The flange has the function to connect the motor with the outside frame of the gearbox. The shaft of the motor has been connected with the help of a specific component that you can see in the Figures 49 and 50.

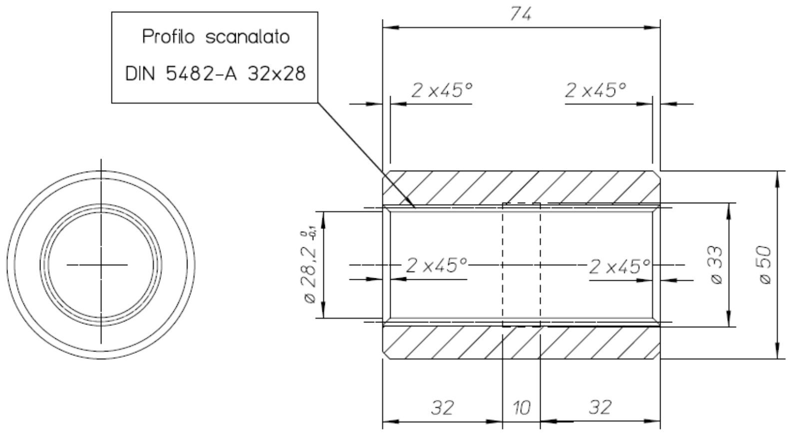
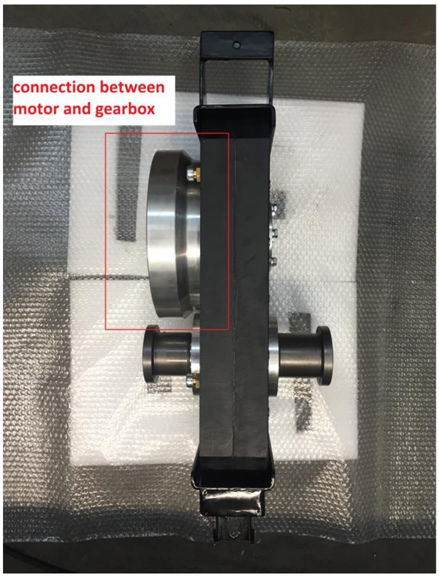


Figure 49 - View of the connecting flange



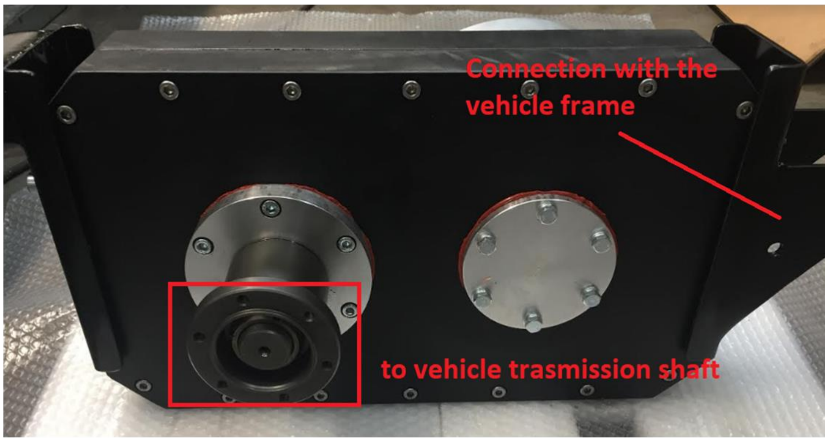


Figure 50 – Eyesvehicle's gearbox views

The connection between the gear box and the transmission shaft has been done with an extension of the Sprinter transmission shaft as described in the Figure 51.

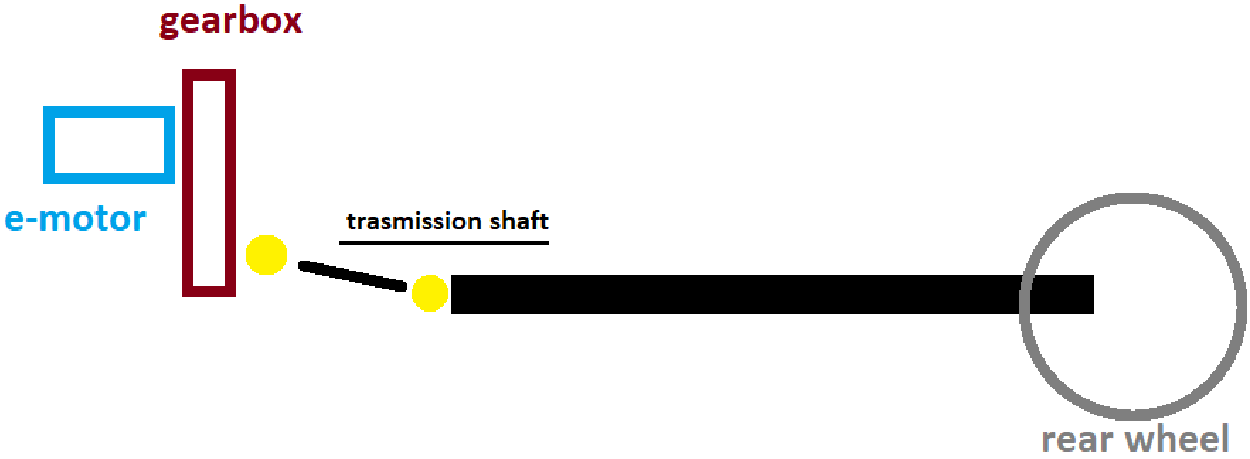


Figure 51 - Simplified scheme of the connection between the gearbox and the transmission shaft

In order to design reliable connection of the gearbox to the vehicle we have firstly scanned the inside of the Mercedes sprinter engine compartment. In the Figure 52, you can see the result of this activity.

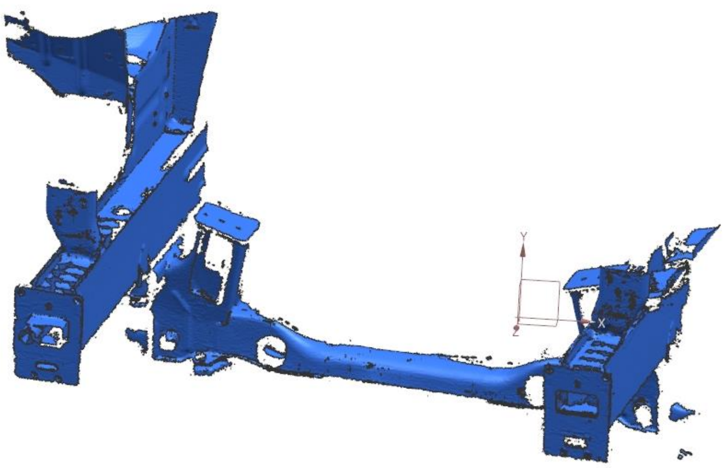


Figure 52 - Mercedes Sprinter engine compartment

The gearbox has been connected with the chassis of the vehicle using a frame custom designed by Privé s.r.l. In Figure 53 and 54, you can see in dark green the point of connection of the frame with the vehicle. In dark blue you can see the sub frame that goes all around the perimeter of the gearbox and in pink you can see the flanges of connection of the gearbox with the sub frame.

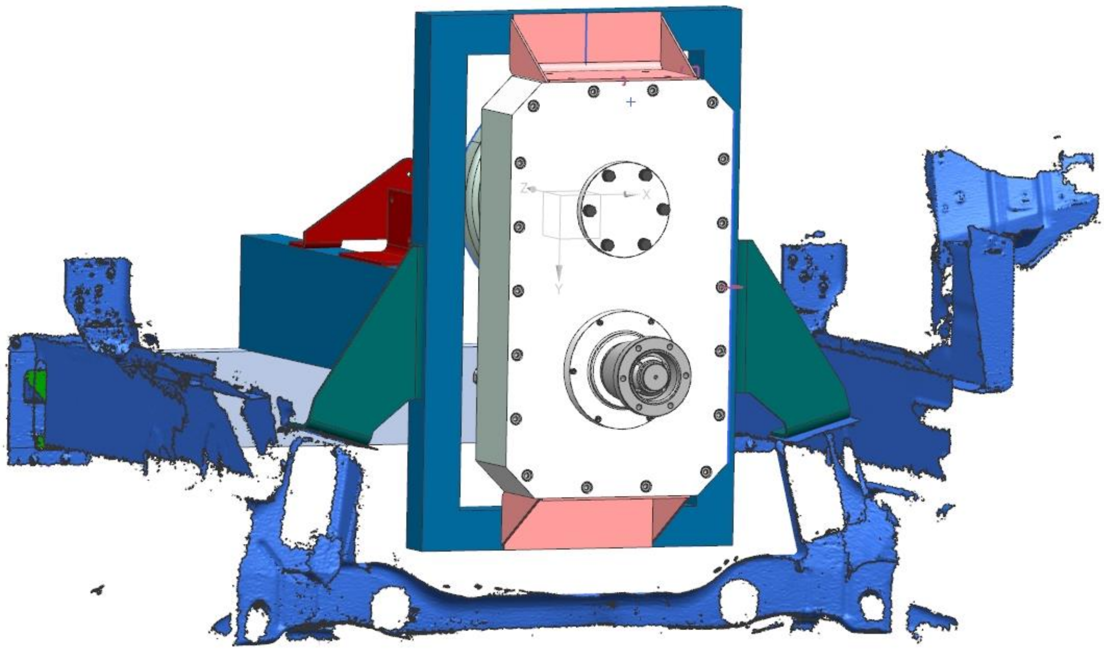


Figure 53 - 3D view of the gearbox mounted on the chassis of the vehicle

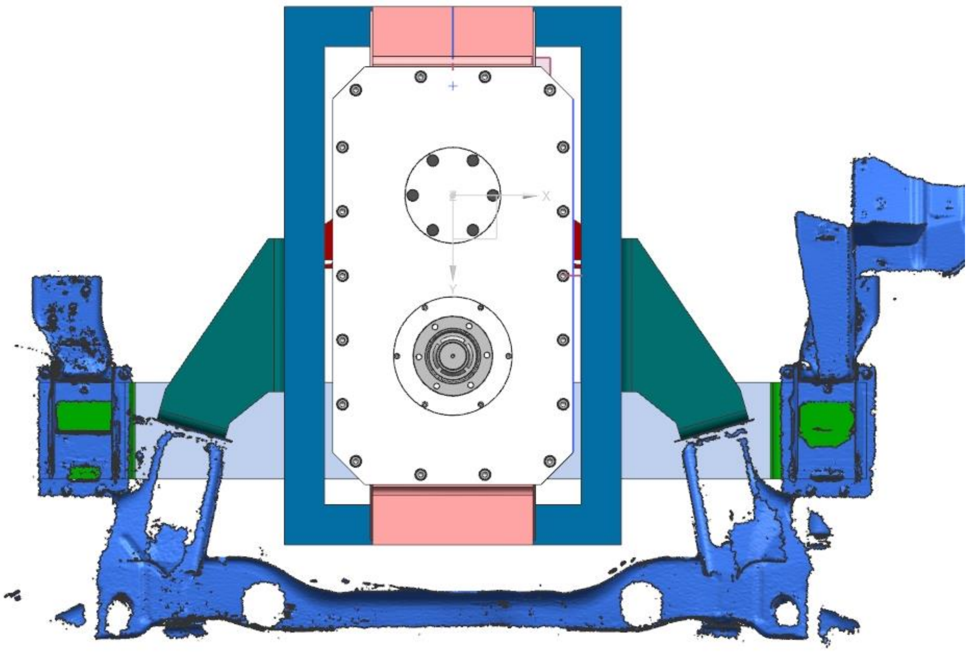


Figure 54 - Orthogonal view of the gearbox mounted on the chassis of the vehicle

3.4 SERVICES

3.4.1 Power steering

The Sprinter power steering is a completely hydraulic system. There is no electronics involved. Comparing tubing size and type, we determined that flow and pressure should be similar despite the differences in vehicle size: negligible comfort problem.

- Renault Kangoo, part number TRW 77014707083 (Figure 55)

Nominal Power: 250 W

Voltage: 12 V

Nominal Current: 0.8-5 A

Speed: 2500 rpm

Nominal Torque: 1.8 Nm

Direction of Rotation: clockwise

Type of Duty: S1

Figure 55 - Power steering pump

PinIn-PinOut

Pin 1	+12V
Pin 2	GND

3.4.2 Power braking

Original vacuum pump for power braking is powered by the distribution belt. That pump should not be reused in a conversion, as that requires mechanical adaptations that would increase complexity and introduce reliability issues.

A good solution is a standard power brake electric pump, powered by 12V (Figure 56).

Testing will determine if a vacuum reservoir will be needed; the available vacuum without power to the pump should be enough for 4-5 full brake depressions.

Figure 56 - Power braking components

PinIn-PinOut

Pin 1	+12V
Pin 2	GND

The connection diagram is shown in the Figure 57 below.

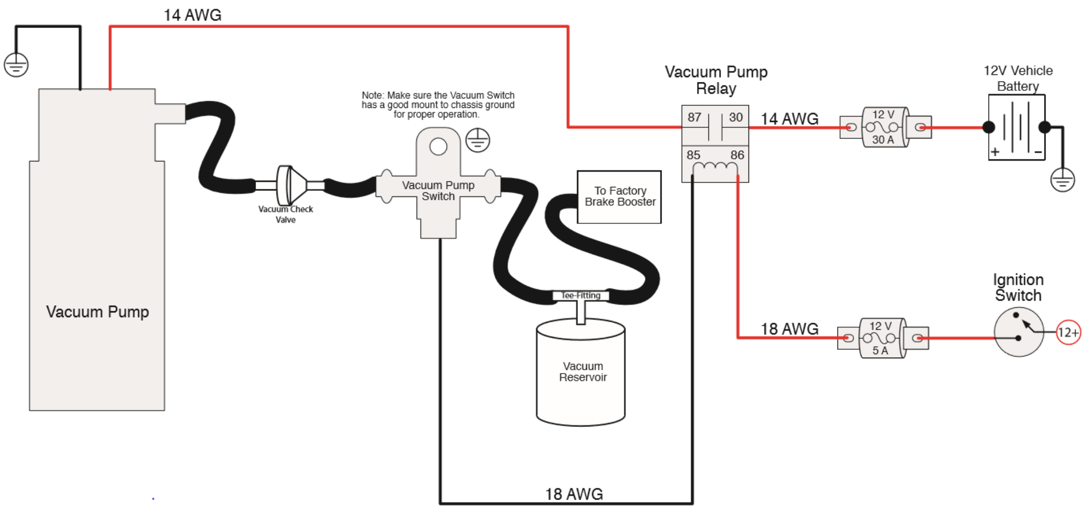


Figure 57 - Power braking system

3.4.3 Acceleration pedal

Figure 58 - Sprinter acceleration pedal

The accelerator pedal (Figure 58) is a standard hall-sensor part with redundant outputs.

“This kind of accelerator pedal is compatible with standard motor inverters without any further modification.”

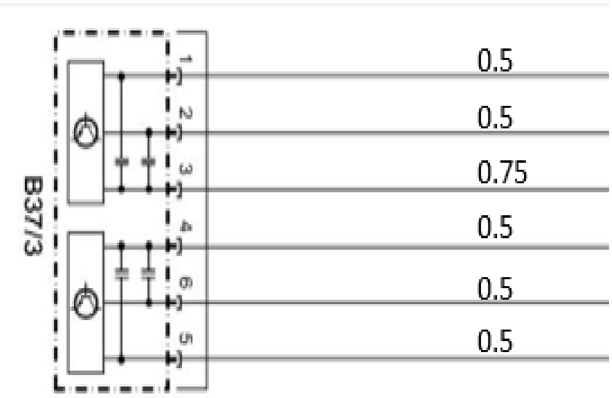


Figure 59 - Throttle pin out

PinIn-PinOut

Pin 1	+5V	
Pin 2	Output	0.44 - 3.58 V 0 - 100 %
Pin 3	GND	
Pin 4	GND	
Pin 5	+5V	
Pin 6	Output	0.19 - 1.74 V 0 - 100 %

The Figure 59 above shows the acceleration pedal pinout.

4 Powertrain integration

4.1 Cooling circuits – Integration

4.1.1 HV Battery pack C.C.

1. Components position

The circuit (Figure 60) will consist of the following components:
Pump, manifold in, battery pack with integrated cold plates, manifold out, radiator and tank.

We can divide the vehicle into three zones:
engine compartment, passenger compartment and load compartment.

The radiator, to dissipate the heat, will be positioned in the engine compartment; on the front of the vehicle. The pump, the tank and the 2 manifolds will be placed inside the battery box; which will be placed in the load compartment.

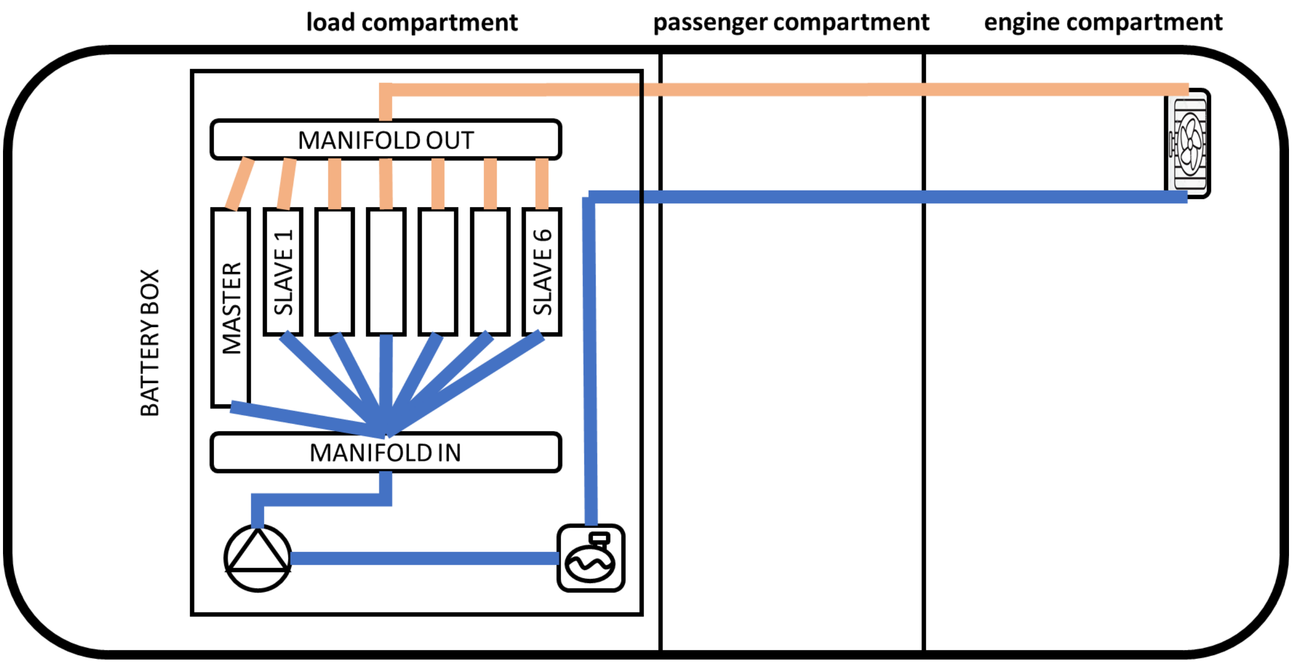
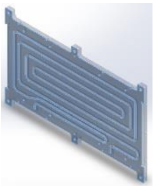


Figure 60 - Location of the components of the battery cooling circuit

2. Components data

The following Table 16 shows the data and hydraulic characteristics of all the components of the CC (-- = TBD)

Table 16 - Characteristics of the selected components

Manifolds (in/out)		
No selected	Requested flow rate: Head losses: Recommended maximum pressure: Internal diameter of inlet / outlet connections:	17.5 l/min -- bar -- bar 20 mm
Cold plate (7 pcs)		
Priatherm 	Requested flow rate: Head losses: Recommended maximum pressure: Internal diameter of inlet / outlet connections: Thermal power to be dissipated:	2.5 l/min 0.11 bar -- bar 11 mm 0.5 kW
Radiator		
No selected	Requested flow rate: Head losses: Recommended maximum pressure: Internal diameter of inlet / outlet connections: Thermal power to be dissipated:	--l/min -- bar -- bar -- mm 3.5 kW
Tank		
No selected (probably custom)	Capacity: Recommended maximum pressure: Internal diameter of inlet / outlet connections:	--l -- bar -- mm
Hose		
No selected	Estimated circuit length: Head losses per meter: Recommended maximum pressure: Internal diameter:	10 m -- bar/m -- bar -- mm

3. Circuit layout

In Figure 61 - BP cooling circuit layoutFigure 61, the scheme of the battery pack cooling circuit:

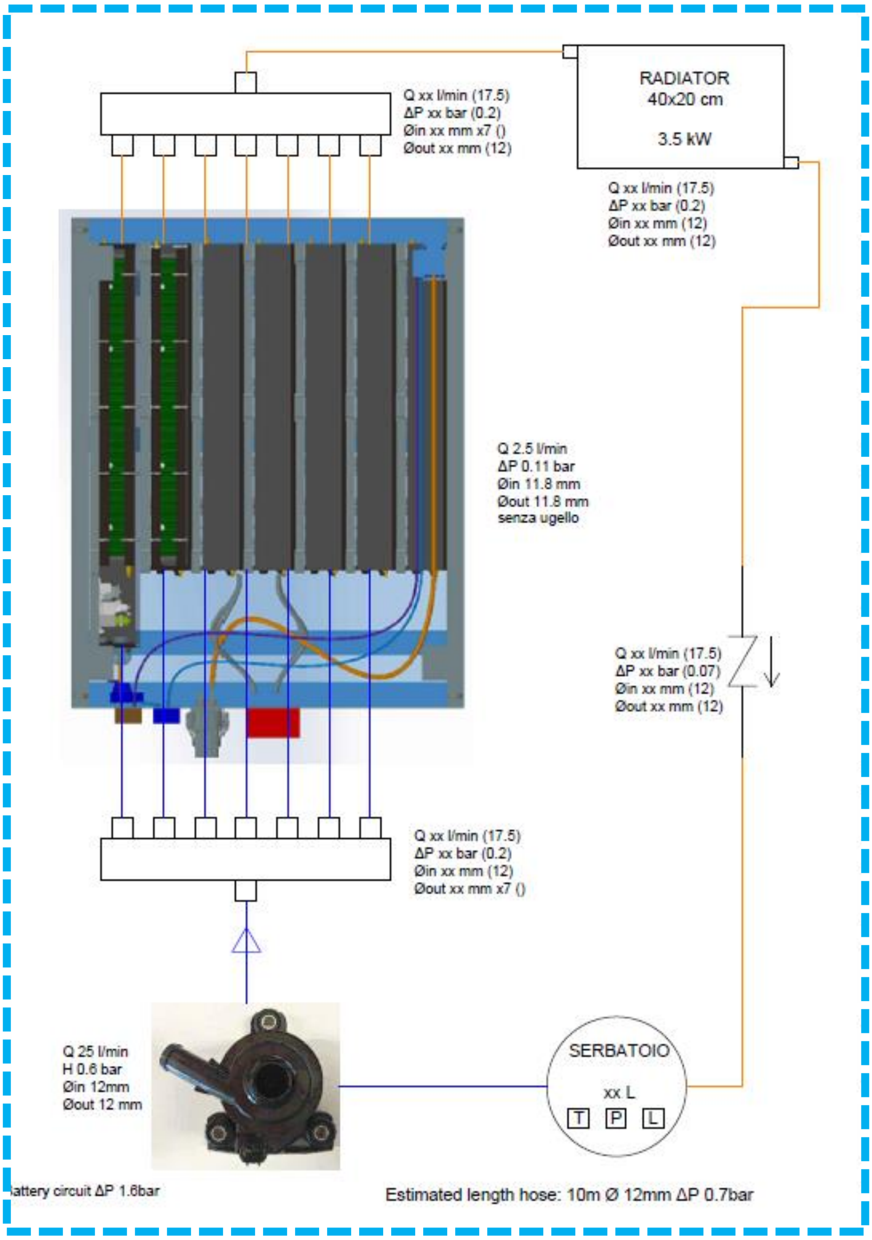


Figure 61 - BP cooling circuit layout

4. Calculation of the pump head

Using a program, we have created a model (Figure 62) of the circuit and we calculated the total head losses.

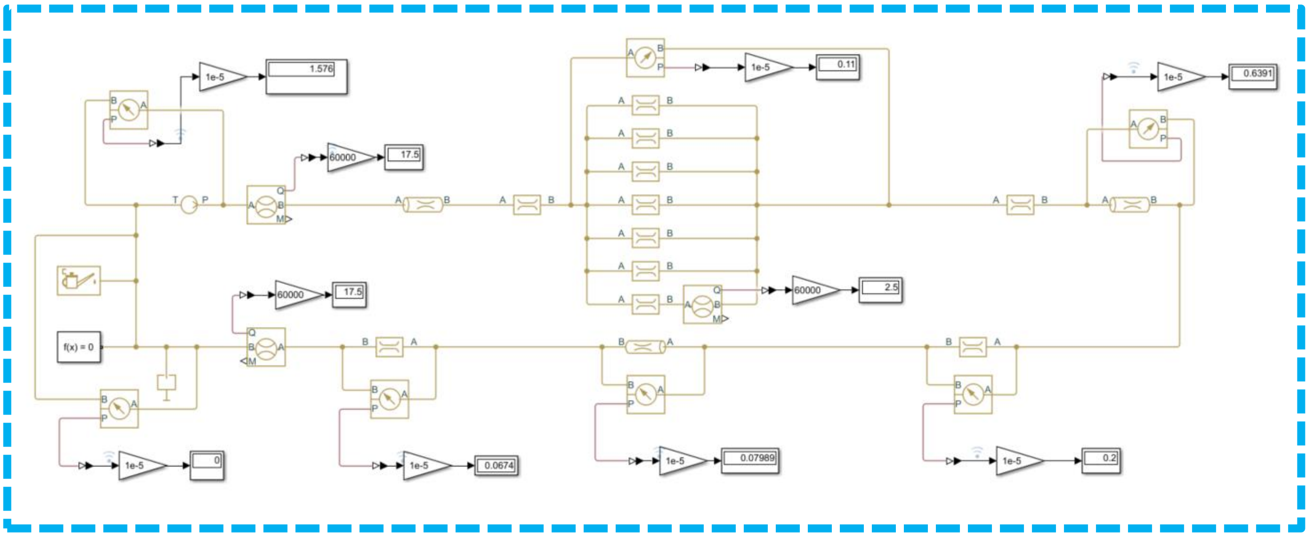


Figure 62 - Circuit modeling

We have estimated that the load losses of the circuit are <u>1.6 bar</u>; with this data, we will select a 12V automotive pump.

5. Cooling control logic

The activation and deactivation of the cooling will be managed by the ECU I, depending on the strategy in the Figure 63. The ECU I receives the maximum and minimum temperature of the HV battery pack from the BMS. Furthermore, on the circuit there are 2 temperature sensors.

T1 – Room temperature.
T2 – Coolant temperature in the tank.
T3 – Max HV BP temperature.

T1>T2>T3	T1>T3>T2	T2>T3>T1	T2>T1>T3	T3>T1>T2	T3>T2>T1
NO	NO	NO	NO	Sì	Sì

SE	T3	<=	18°C	NO

Figure 63 - Cooling control strategy

6. Safety Concept

A level sensor will be inserted in the tank to detect any leaks in the circuit.

The hydraulic connections will be made on the bottom of the battery pack.

4.1.2 Drivetrain C.C.

The drivetrain cooling system will be installed following the below conceptual scheme (Figure 64).

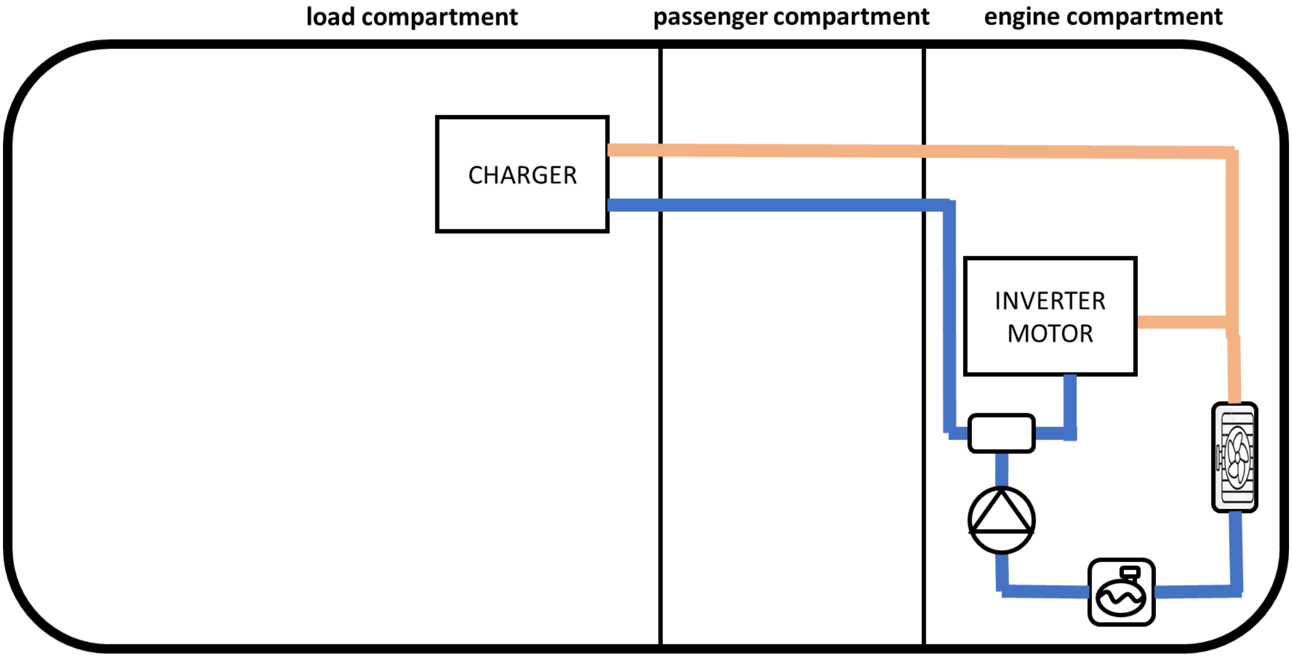


Figure 64 - Drivetrain cooling circuit layout

The radiator will be installed in the front of the vehicle as seen in the sprinter with combustion engine. The different components are under selection and the system will be designed in the next weeks.

4.2 Electrical integration

HV bus

The High Voltage bus (Figure 66) will provide power DC connections between:

- HV Battery – Braking
- HV Battery – DC/DC Converter
- HV Battery – Inverter & Braking Resistance
- HV Battery – OBC

Power AC connections are provided between

- Charging socket – OBC
- Inverter – Electric Motor

For the power connections 5 cables (Figure 65) will be realized:

			WIRE 1		WIRE 2			END1		END2	
CABLE NAME	**TYPE/MODEL**	**WIRES NUMBER**	**ΦINT**	**ΦEXT**	**ΦINT**	**ΦEXT**	**END NUMBER**	**END TYPE**	**PIN**	**END TYPE**	**PIN**
X1	TBD	2	35 MMQ	TBD	35 MMQ	TBD	2	Aptiv – RCS 800 (A1)	TBD	junction	NONE
X2	TBD	2	35 MMQ	TBD	35 MMQ	TBD	2	stud (M TBD)	NONE	stud (M TBD)	NONE
X3	TBD		35 MMQ	TBD	35 MMQ	TBD	2	stud (M TBD)	NONE	stud (M TBD)	NONE
X4	TBD	2	10 MMQ	TBD	10 MMQ	TBD	2	Amphenol HVSL 362 (A2)	TBD	Amphenol PL082X-121-10M6	TBD
X5	TBD	2	2.5 MMQ	TBD	2.5 MMQ	TBD	2	Aptiv – APEX HV280 (A3)	TBD	Delphi MSE 716	TBD

Figure 65 - Wiring cables

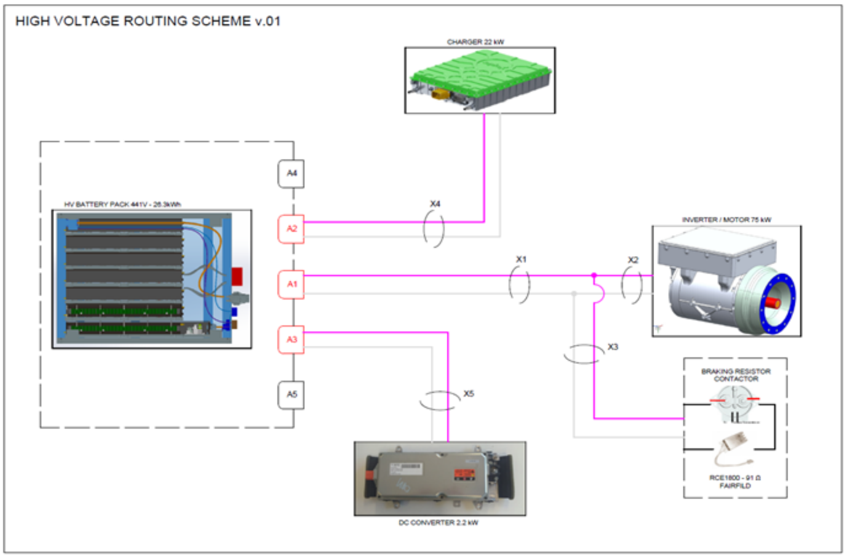


Figure 66 - High voltage routing scheme

LV bus

The Low Voltage (LV) PowerNet (Figure 67) provide supply current to the following devices:

Under key control

- OED (Original Electrical Devices)
- PS (Power Steering)
- PB (Power Braking)
- BMS (Battery Management System)
- HMI (Human Machine Interface)
- IC (Information Cluster)
- IMD (Insulation Monitoring Device)
- ECU 1 (Vehicle Control Unit 1)
- ECU2 (Vehicle Control Unit 2)
- INV (Inverter)
- WP1 (Water Pump 1)
- WP2 (Water Pump 2)
- FAN1
- FAN2

Always On:

- Service Lights

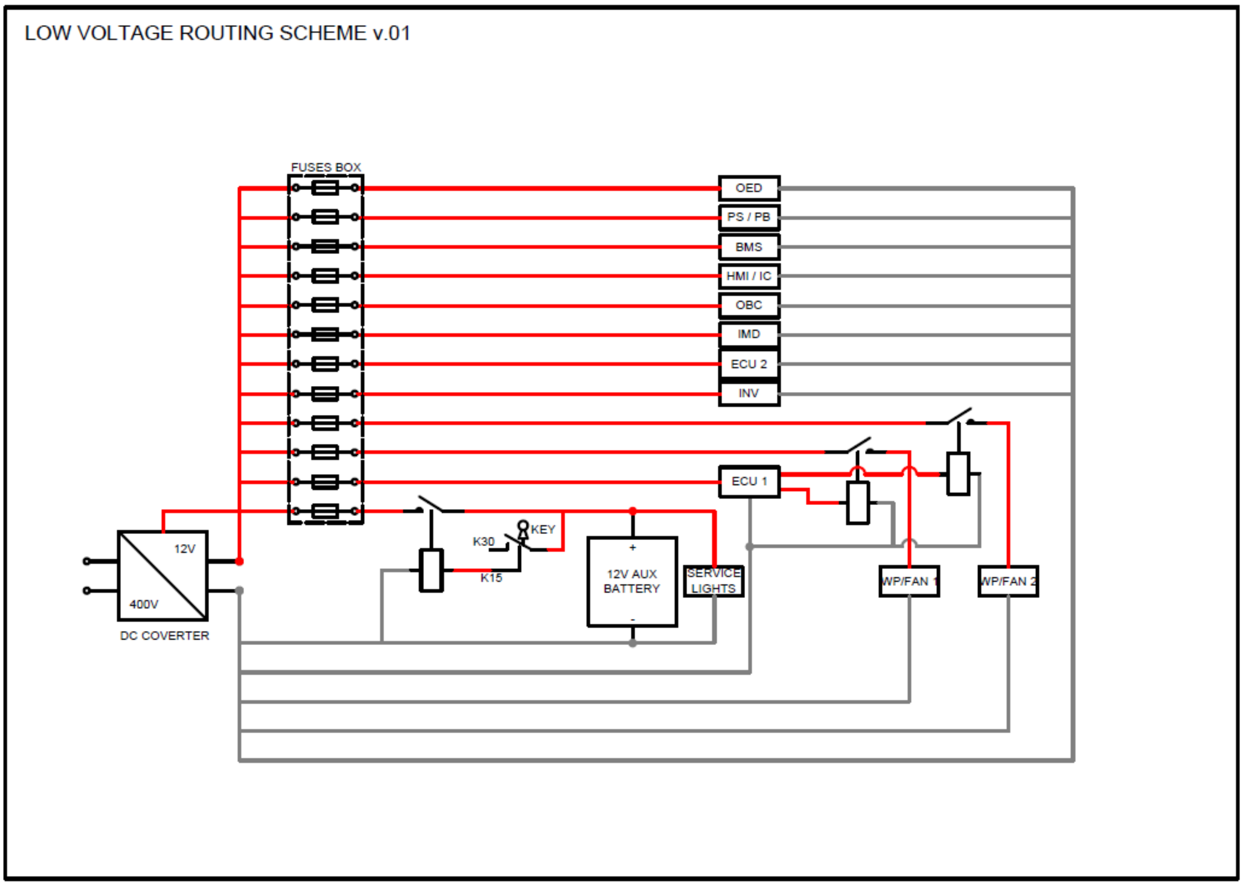


Figure 67 – Low voltage routing scheme

CAN bus

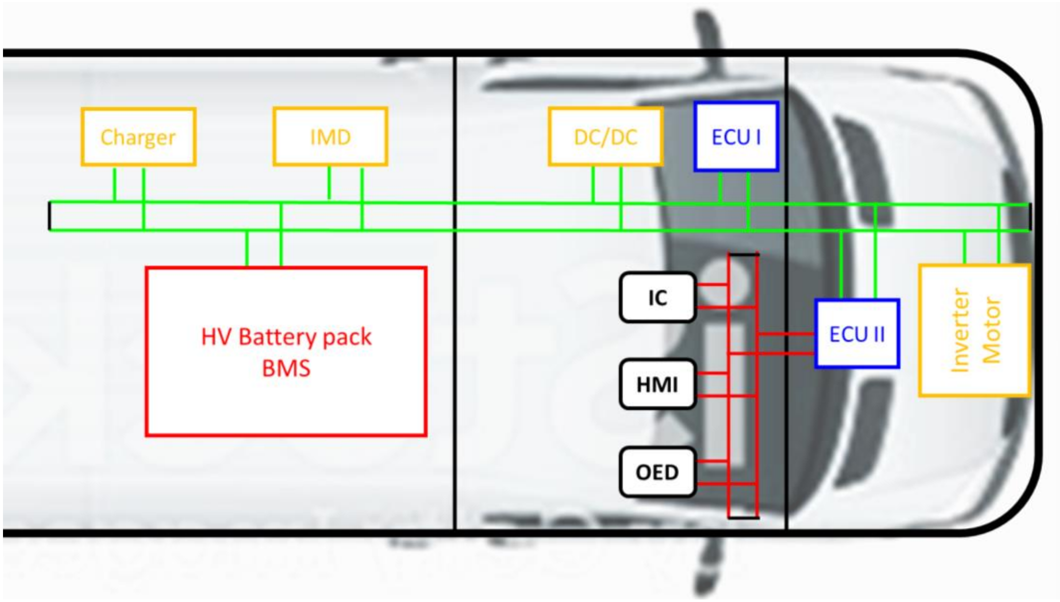


Figure 68 - CAN lines

The CAN lines (Figure 68) provide communication between components as shown in the 2.2.5 paragraph.

The CAN line wiring will be realized with a 2-pole cable connecting all the CAN enabled devices. In each device, we can find the dedicated pin to connect as shown in the following Table 17.

Table 17 - Pins of the CAN connectors

DEVICE	CONNECTOR	PIN CANH	PIN CANL
CAN LINE 1			
OBC	TE 1-776228-1	4	3
BMS	WEIPU SP1310/S9	2	3
IMD	TBD	TBD	TBD
DC/DC	APTIVE 13743443	3	2
ECU1	TBD	TBD	TBD
ECU2	TBD	TBD	TBD
INVERTER	TBD	TBD	TBD
CAN LINE 2			
IC	TBD	TBD	TBD
HMI	USB	TBD	TBD
OED	Amphenol ahdp06	41	54

5 Conclusions

The Deliverable D.5.5 has been fully described in the chapters above. The great majority of the tasks planned has been successfully completed and the attention is now shifted towards the manufacturing and the installation of the component selected or designed.

A minor number of tasks that was theoretically due within the 5.5 are still under investigation and have been postponed to the next deliverable. They have been marked with TBD. The reason is that these activities are strictly related to installation in the vehicle and the testing of the components under manufacturing. It would be therefore useless and misleading to work on further investigations at this level.

The next months will see the company involved in the following macro activities:

- Electrical testing and bench validation of the battery pack
- Mechanical assembly on the battery pack in the vehicle
- Manufacturing of the motor and inverter supports
- Vehicle cooling system component purchasing and installation
- HMI software definition
- HMI hardware installation on the vehicle
- Manufacturing of the high and low voltage routing.