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CONCEPT OF A E/E ARCHITECTURE FOR A 48V ELECTRIC RESEARCH VEHICLE

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This thesis was written during ERASMUS exchange period at Hochschule Esslingen. Thesis is part of HELMAR-project, which aim is to build autonomous & electric research vehicle for Hochschule Esslingen. This thesis focuses on project vision and E/E architecture concept.

Aim of this thesis was to create clear vision for project group and design E/E architecture diagram. As a part of E/E architecture, drive battery & electronic control units was selected. Lastly cooling circuit was designed for the concept vehicle.

E/E architecture diagram consist only main components, due to early phase of the project. In the drive battery selection, six different battery chemistries were compared to each other and most suitable chemistry & product got selected for the project vehicle. The selection of electronic control units focused on dSpace products, due to Hochschule Esslingen earlier, positive experiences of the products. Ongoing component selection process, prevented calculating needed cooling power, thus cooling circuit diagram is theoretical.

As a result, clear and uniform vision was created for project members and E/E architecture diagram with main components got designed. Furthermore, thoroughly Lithium-Ion battery chemistry comparison was made, electronic control units got selected for different stages of the project and two alternative cooling circuit diagrams was created for the concept vehicle.

KEYWORDS:

autonomous vehicles, battery chemistry, cooling circuit, E/E architecture, electric vehicles, electronic control unit

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Johan Vikström

E/E-ARKKITEHTUURIKONSEPTI 48V SÄHKÖISEEN TUTKIMUSAJONEUVOON

Tämä opinnäytetyö kirjoitettiin ERASMUS vaihdossa Hochschule Esslingenissä. Opinnäytetyö on osa HELMAR-projektia, jonka tavoitteena on rakentaa autonominen sekä sähkötoiminen tutkimusajoneuvo Hochschule Esslingenille. Tämä työ keskittyy projektin visioon ja E/E arkkitehtuuri konseptiin.

Tarkoituksena oli luoda selkeä visio projektiryhmälle sekä suunnitella E/E arkkitehtuuri kaavio. Osana E/E arkkitehtuuri kaaviota valittiin ajoakusto & elektroniset ohjainlaitteet. Lopuksi suunniteltiin jäähdytysjärjestelmä konseptiajoneuvolle.

E/E arkkitehtuuri kaavio käsittelee vain pääkomponentteja, johtuen projektin aikaisesta vaiheesta. Ajoakuston valinnassa vertailtiin kuutta eri litiumioni akkukemiaa, joiden pohjalta konseptiajoneuvolle valittiin ajoakusto. Ohjainlaitteiden valinnassa keskityttiin pelkästään dSpace-yhtiö tuotteisiin, koska Hochschule Esslingen oli erittäin tyytyväinen kyseisen yhtiön tuotteisiin. Jäähdytysjärjestelmän kaavio on teoreettinen eikä tarvittavaa jäähdytystehoa pystytty laskemaan, johtuen keskeneräisestä komponenttien valinnasta.

Työn tuloksena saatiin selkeä ja yhtenäinen visio projektin jäsenille sekä pääkomponentit sisältävä E/E arkkitehtuuri kaavio. Tämän lisäksi toteutettiin kattava vertailu eri litiumioni akkukemioiden välillä, valittiin elektroniset ohjainlaitteet projektin eri vaiheisiin sekä luotiin kaksi vaihtoehtoista jäähdytysjärjestelmää konseptiajoneuvolle.

ASIASANAT:

akkukemia, autonominen ajoneuvo, E/E arkkitehtuuri, elektroninen ohjainlaite, jäähdytysjärjestelmä, sähköajoneuvot

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LIST OF ABBREVIATIONS

°C	Degree Celsius, Celsius Temperature (Bosch Automotive Handbook 2018, 26)
A/C	Air conditioner (Bosch Automotive Electrics and Automotive Electronics 2014, 528)
App	Application; a computer program that is designed for a particular purpose (Cambridge Dictionary)
AC	Alternating Current (Bosch Automotive Electrics and Automotive Electronics 2014, 528)
AD-ECU	Autonomous driving- ECU (Browne David 2017)
ASIC	Application specific integrated circuit (Bosch Automotive Electrics and Automotive Electronics 2014, 528)
B, Bit	Binary digit (Bosch Automotive Electrics and Automotive Electronics 2014, 528)
BMS	Battery Management System (Bosch Automotive Handbook 2018, 1767)
C-rate	Specifies the speed a battery is charged or discharged (Battery University, 2017-a)
CAN	Controller Area Network (Bosch Automotive Electrics and Automotive Electronics 2014, 528)
CISC	Complex Instruction Set Computing (Bosch Automotive Handbook 2018, 1421)
CPU	Central Processing Unit (Bosch Automotive Handbook 2018, 1422)
DC	Direct Current (Bosch Automotive Electrics and Automotive Electronics 2014, 528)
DoD	Depth of Discharge (Battery University 2019)

E/E architecture	Electrical and Electronic architecture (Bosch)
ECU	Electronic Control Unit (Bosch Automotive Electrics and Automotive Electronics 2014, 528)
EEPROM	Electrically Erasable Programmable Read Only Memory (Bosch Automotive Electrics and Automotive Electronics 2014, 528)
EPROM	Erasable Programmable Read Only Memory (Bosch Automotive Handbook 2018, 1422)
ERASMUS	European Region Action Scheme for the Mobility of University Students (UCAS)
Flash	Electrically Erasable Programmable Read Only Memory, erased with using Electrical flash pulses (Jänne 2019-a)
g	Gravitational force equivalent (Wikipedia 2021-a)
GB	Gigabit (Bosch Automotive Handbook 2018, 25)
HELMAR	Hochschule Esslingen light individualized mobility in applied research, Name of the research vehicle and the project (Hochschule Esslingen)
HMI	Human-Machine Interface (Inductive automation, 2018)
I/O	Input/Output (Bosch Automotive Electrics and Automotive Electronics 2014, 529)
kWh	Kilowatt-hour (Bosch Automotive Handbook 2018, 29)
LCO	Lithium Cobalt Oxide (Battery University 2020-b)
LFP	Lithium Iron (Ferro) Phosphate (Battery University 2020-b)
Lidar	Light Detection and Ranging (Bosch Automotive Handbook 2018, 1773)
Li-Ion	Lithium Ion (Battery University 2018)
LIN	Local Interconnect Network (Bosch Automotive Handbook 2018, 1773)
LMO	Lithium Manganese Oxide (Battery University 2020-b)
LTO	Lithium Titanate (Battery University 2020-b)

M-ECU	Main-ECU
MIT	Massachusetts Institute of Technology (Mit.edu)
NCA	Lithium Nickel Cobalt Aluminum Oxide (Battery University 2020-b)
NiMH	Nickel-metal-hydride (Battery University 2020-a)
NMC	Lithium Nickel Manganese Cobalt Oxide (Battery University 2020-b)
OEM	Original Equipment Manufacturer (Bosch Automotive Handbook 2018, 1774)
PROM	Programmable Read Only Memory (Bosch Automotive Handbook 2018, 1422)
PTC	Positive Temperature Coefficient (Bosch Automotive Handbook 2018, 1775)
RAM	Random Access Memory (Bosch Automotive Handbook 2018, 1423)
RISC	Reduced Instruction Set Computing (Bosch Automotive Handbook 2018, 1422)
ROM	Read Only Memory (Bosch Automotive Handbook 2018, 1422)
TB	Terabit (Bosch Automotive Handbook 2018, 25)
TUAS	Turku University of Applied Sciences (Tuas 2020)
USB	Universal Serial Bus (Cambridge Dictionary)
V	Volt, Derived SI-unit (Bosch Automotive Handbook 2018, 26)
V2I	Vehicle to Infrastructure (3M)
V2V	Vehicle to Vehicle (Bosch Automotive Handbook 2018, 1777)
W	Watt, Derived SI-unit (Bosch Automotive Handbook 2018, 26)
WLAN	Wireless Local Area Network (Bosch Automotive Electrics and Automotive Electronics 2014, 530)

PREFACE

I would like to thank

International Relations Coordinator Anniina Jaranne and Leader of Education, Lic. Sc. (Tech.) Markku Ikonen from Turku University of Applied Sciences & Professor, Dr. Jürgen Haag and B.Eng. Kevin Keul from Hochschule Esslingen and ERASMUS exchange program who made this exchange semester possible for me.

I want to express my gratitude to Meri Vikström, Oona Turkki and Tytti Uusitupa, who have supported me on this long and challenging journey.

Askel ainainen

Pysähtyy paikalleen

Luokseen laulaa

Seireeni syvyyden

Kanssaan kylmään

Tuonelaan tummaan

Lepoon lopulliseen.

1 INTRODUCTION

Electric and Hybrid vehicle represents new era of transportation and they are becoming more common technology in our daily lives. These are solutions for high environmental emissions caused by transportation. Next enormous revolution in automotive sector will be autonomous vehicles, which will increase road safety and relieve driver from his duty.

This thesis is part of Hochschule Esslingen HELMAR -project. HELMAR stands for ***H**ochschule **E**sslingen **l**ight individualized **m**obility in **a**pplied **r**esearch*. Aim of the project is to construct fully electric autonomous research vehicle. Figure 1 Presents pick-up idea of the HELMAR -project.

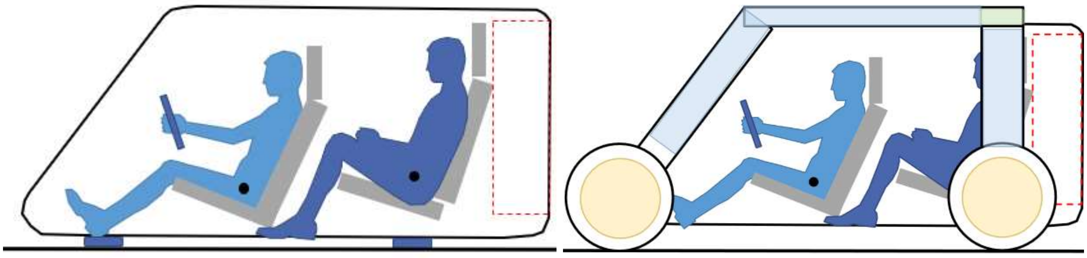


Figure 1. Pick-up concept of the HELMAR (Hochschule Esslingen 2020).

This thesis will focus on the vision for the HELMAR and Electrical & Electronic architecture concept. This topic is important for two reasons. The first reason is to unify different the project groups to work towards the same goal and the second is creating diagram of main components needed for the HELMAR. Objectives include selection of drive battery and main control units as well as creating cooling system as a part of a E/E architecture. This thesis will give thorough recommendations of objectives mentioned for the project group.

Commissioner

Commissioner of this thesis is Hochschule (University of) Esslingen, which roots dates to 1868. The Hochschule Esslingen is merged from two different schools named Fachhochschule für Technik Esslingen and Fachhochschule für sozialwesen Esslingen in 2006. In 2021 the Hochschule Esslingen is celebrating it is 15 years of fusion. (Hochschule Esslingen-b).

The Hochschule Esslingen is a home university of 6 000 students and has 230 professors. The Hochschule has three campuses, 2 in Esslingen and one campus in Göppingen, 30km from Esslingen. The Hochschule works closer cooperation with different companies in area. (Hochschule Esslingen-a).

In 2020 Turku University of applied sciences and the Hochschule Esslingen became partner universities, which made ERASMUS exchange possible between the universities. Got honored to be the first student from TUAS to study in the Hochschule Esslingen. This thesis is included to the ERAMUS exchange program.

2 RESEARCH VEHICLE HELMAR

The HELMAR is a research vehicle, which is being built by students in the Hochschule Esslingen. The Project started in the summer semester 2019 and plan is to make the HELMAR fully electric, autonomous vehicle with separate chassis and passenger compartment. Few design concepts as seen in picture 1, one thesis and decision of using 48/12 -volt electrical circuit was made. These were starting points for the winter semester 2020/2021.

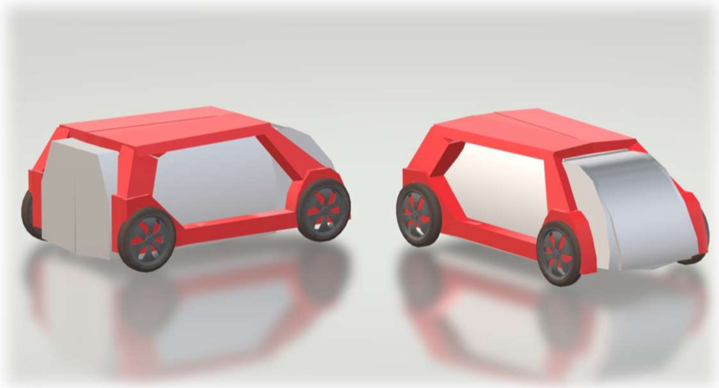
Picture 1. Early design concept of the HELMAR (Hochschule Esslingen 2019).

The Hochschule Esslingen demands rapid progress on the HELMAR -project, which could be hard to achieve. Middle of the winter semester 2020/2021 2-stage approach was introduced to shorten manufacturing time. 2-stage approach is explained in detail down below.

The first stage idea is to use commercially available parts, components that could be plugged in & played and parts, that the Hochschule Esslingen has already. Level of autonomous is lowered and some driving tasks is given back to the driver. Component placing is not considered too widely in the first stage, because aim of the first stage is to fabricate moving vehicle with finished exterior. After testing the HELMARs driving capabilities and other systems, is time to move on into the second stage. (Haag 2020).

The second stage is mostly for fabricating custom parts, mounting parts for the best possible location, and making the chassis & the passenger compartment independent from each other. As important is to finish interior for spotlight. Aim is to polish the HELMAR for showrooms and make sure everything functions properly.

The HELMAR -project is in early phase and enormous decisions is expected to take place in this semester. After many different design concepts, early in the winter semester the HELMARs design concept was decided. Selected concept is shown in picture 2.



Picture 2. Selected design concept of the HELMAR (Hochschule Esslingen 2020).

3 VISION OF HELMAR

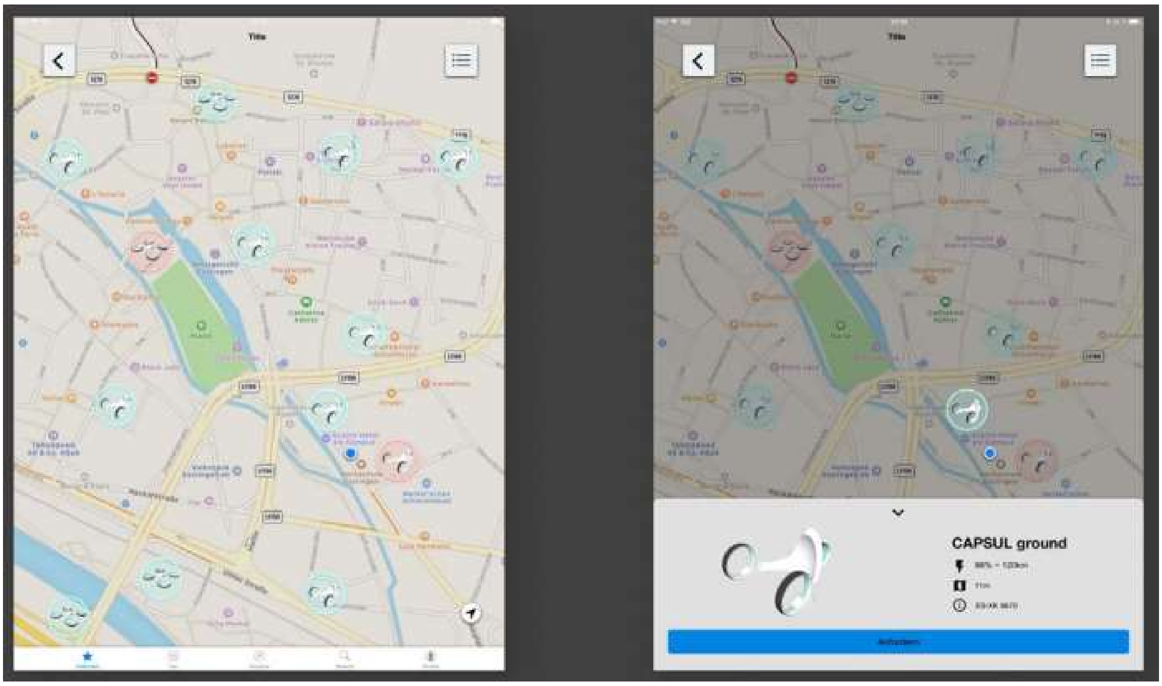
The next chapter represents thesis writer’s visions and thoughts on the future of the automotive industry and where this project should aim. These visions are personal and might not be fully in line with vision of the project group. This vision works around the Hochschule Esslingen’s idea of the HELMAR with the separate passenger compartments, which are privately owned.

Let us start with a story from future: it is a 7 O’clock in morning, you are dressing up for work and running late again, like usual. You ask your virtual assistant “Is my HELMAR on the way?” Virtual assistant replies “your HELMAR will pick you up in 15 minutes. Traffic is jammed in normal route to work, the HELMAR recommends switching route.”

You are finally ready and go to the passenger compartment, you start reading news on windshield display. The HELMAR arrives and attaches to the passenger compartment and the journey begins. When arrived at the destination, the HELMAR will drop you off in the main entrance, parks your passenger compartment and heads to a charging station.

Early afternoon the HELMAR comes to retrieve your passenger compartment, drive to school to pick up children and take them to home. End of your workday the HELMAR will be waiting for you in the main exit of your workplace, ready to drive you home.

Mobile application is a centric part of this vision as connecting smartphone to the HELMAR gives user possibility to interact with the vehicle regardless of distance. In this vision the app user can order a ride, enter a most visited places and locate the passenger compartment, like in picture 3. The app could have features like voice control and machine learning, for easier use and learning daily rhythms of a user. By knowing users’ daily rhythms, the app becomes more independent and can make smart suggestions, like order the ride to and from work on weekdays without the user even requesting it.



Picture 3. Locating capsule in the HELMAR-App (Hochschule Esslingen 2019).

3.1 Passenger Compartment

In the passenger compartment you would travel as a passenger, no need for controlling the HELMAR. There would not be steering wheel or pedals. Depending on the size, the passenger compartment could have seats for four people or just one seat with desk for working purposes. Windscreen would be a one big head-up display and where entertainment system would connect. Entertainment system would have basic functions, example A/C, Bluetooth radio, adjustable seats, navigation, sound systems and a Computer functions. When including computer to the entertainment systems, it could be used for working purposes or entertainment like movies, games, etc. The passenger compartment could be voice-controlled as well as keyboard & mouse for working purpose.

The passenger compartment would have own 12-volt power system, for powering central locking, interior lights, and entertainment. The HELMAR would recharge 12-volt system from the drive battery, whenever connected to the passenger compartment.

3.2 Travelling / Parking

Like said before the HELMAR would drive passengers in the main entrance of the destination and afterwards park the passenger compartment. Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) technologies would share information with the HELMAR, about where is the nearest empty parking spot, among other things. Parking space size could be reduced, because entering the passenger compartment in parking spot would not be necessary. Shopping malls could have dedicated pick-up zones(Figure 2) next to exit, for packing groceries.

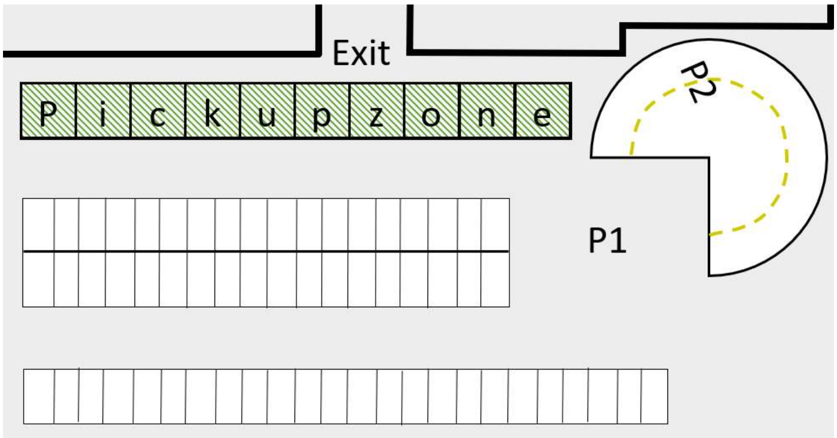


Figure 2. Pick-up zone.

Long time parking in train stations and airports could be avoided, by sending the passenger compartment back to home without passengers. Similar function could be used for picking kids from school, driving kids to hobbies, and picking up groceries from store while adult is inhibited.

Long distance trips would be achievable by changing the transporting HELMAR with low range to fully charged HELMAR in charging station, like changing battery for a power drill. This could be as quick as normal fueling stop for internal combustion engine vehicles or even quicker. When charging station network is wide enough, there would not be a range limit.

3.3 Charging

After every transportation, the HELMAR will return to charging station, same as robot vacuum cleaners nowadays. If several charging stations would be located around a city, the HELMAR would be always close to passengers. Charging could be done wirelessly by magnetic induction plate (Shown in a picture 4) or another possibility could be magnetically separable charger, like phone chargers. Both methods would be good for automated charging as they need no human intervention.

Picture 4. MagCoil™ – wireless charging plate (Magment 2021).

4 E/E ARCHITECTURE

E/E architecture stands for electrical & electronic architecture and its aim is to create kind of a “LEGO instructions” where is descripted all electronic hardware, their software, network aspects (topology, interfaces etc.) as well as wiring harnesses. Modern passenger cars contain more than 4 km of wiring and 70 – 100 electronic control units, without E/E architecture it would be impossible to keep track all the functions and wires. (Auzanneau 2013, 2; Bosch Automotive Electrics and Automotive Electronics 2014, 115; Burcicki 2020).

Car manufacturers face great challenge to satisfy customer needs of smarter vehicles. To achieve this, innovation and integration of different subsystems is needed. Manufacturers is starting to reduce number of small ECUs and changing them to few very high computing power ECUs, so all systems would be integrated in one place. By doing so it could be possible to achieve new features. (Bosch Automotive Handbook 2018, 1483-1486; Burcicki 2020).

The second important topic of this thesis was to design E/E architecture for the HELMAR. Because the HELMARs dimensions, overall design or all wanted electronic systems is not yet decide, the architecture diagram will not be too detailed. To support the HELMAR -project, same time when designing E/E architecture diagram, couple parts got selected and few parts were presented to the project.

4.1 E/E architecture diagram

Process started with searching different computer programs, where diagram could be made. The first option for diagram-program was Microsoft Visio, but the Hochschule Esslingen did not have license for it. Next options were 4 different mind map -programs, Mindmup, Xminds, Moodle’s mind map tool and MindMeister. The best of these for was Xmind which was used for few weeks and early concept of E/E architecture was made, as seen in the Figure 3. Professor Schuler recommended free yED Graph editor-named program, which suited better for the HELMAR -project. When right program was selected, features that the HELMAR should have, were discussed.

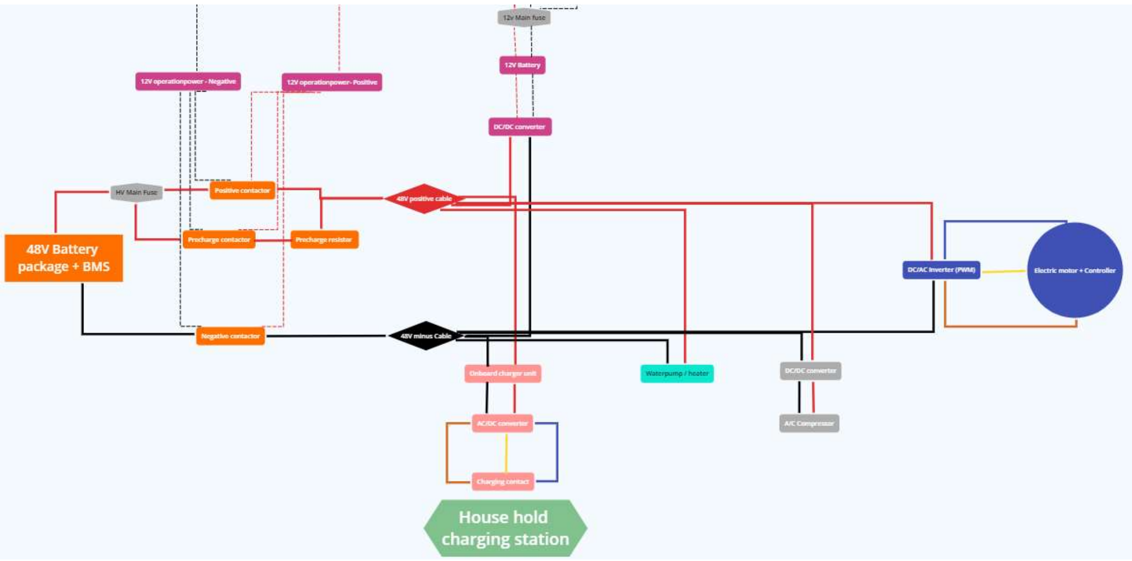


Figure 3. Early E/E diagram made with Xminds.

The HELMARs E/E architecture has divided in two circuits, due to fact that the HELMAR will be constructed in the separable chassis and the passenger compartment. Because of this, architecture will have 48-volt drive battery and 12-volt support battery. The drive battery will be installed to the chassis and the support battery to the passenger compartment. Another aspect of divided E/E architecture will be placing the components because the chassis will have to be able to drive autonomous without the passenger compartment.

Implementing the 2-stage approach, plan for quicker results led to decision that in the first stage, component placing would not to be considered. The main task was to create a graph of main components, used communication bus and propose parts that could be used in the HELMAR.

First graphs were showing electrical connections of different components and in Figure 3 could see 48-volt systems overlook. In this picture red lines presents positive side and black lines negative side of an electrical system, where thick lines are 48-volts and dash line presents 12-volt system. Early graphs did not have communication buses or all the components and was too elaborate.

Next version of E/E diagram was made in yED graph editor and Prof. Schuler had started E/E diagram before handing it forward. Lot of components were added to diagram as well as communication busses. New version is clearer and more informative than early diagrams. Overview of current diagram can be seen on Figure 4.

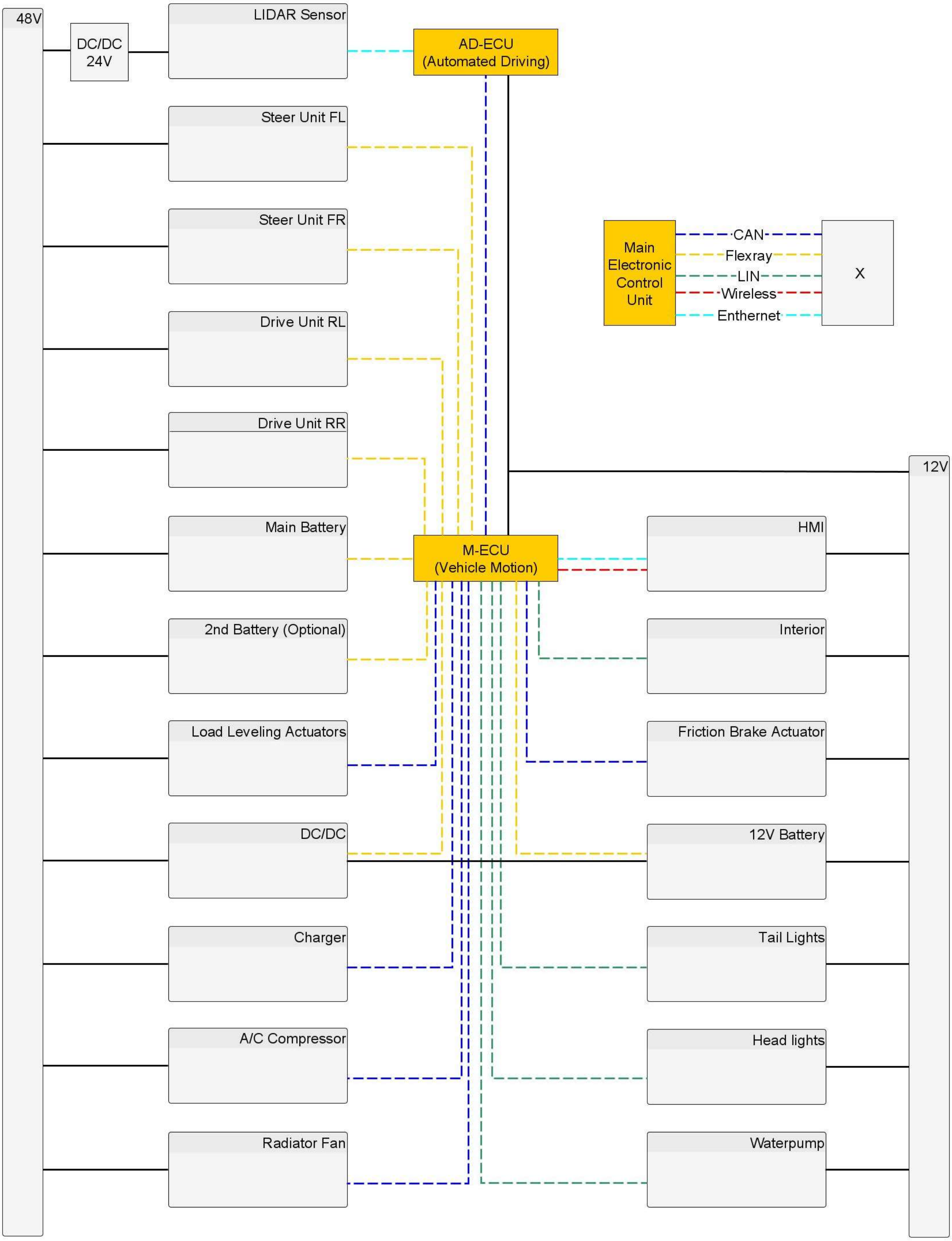


Figure 4. Overview of the HELMARs E/E architecture diagram.

In Figure 4, left side of the diagram presents 48-volt circuit and right side 12-volt electrical circuit and black lines presents power lines, two yellow squares in middle presents main ECUs, gray squares mark different components and subsystems, communication buses are marked as colorful dash lines. Colors of the dash lines are explained in right side of the diagram. Next Figure (Figure 5) will be close-up from top part of the diagram.

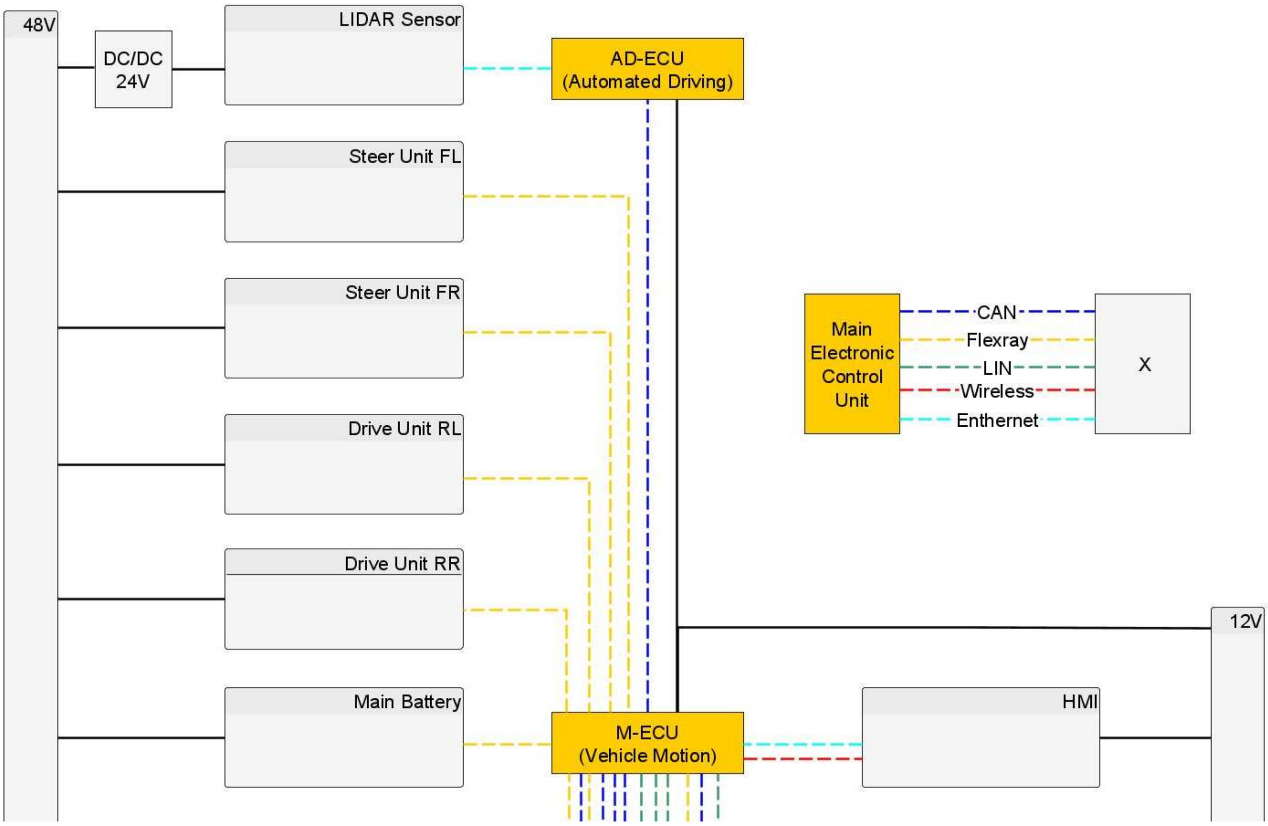


Figure 5. Upper section of the HELMARs E/E architecture diagram.

Upper section of diagram shows Main-ECUs in the middle, top one is for autonomous driving (AD-ECU) functions like imagine processing, sensor fusion and target detection. Bottom ECU (M-ECU) is for vehicle motion functions, energy management and info-/entertainment. This picture shows better the explanation of communication buses. CAN is marked as a blue dash line, Flexray as yellow, LIN as green, Wireless (Voice control, Bluetooth, etc.) as red, Ethernet as turquoise.

As seen in Figure 5. The HELMAR does not have camera for autonomous driving functions, only LIDAR sensor. However, Ouster OS1 – the selected LIDAR sensor for the HELMAR, is capable to produce infrared pictures like camera. This is additional to basic point cloud data, which LIDARs produce. Operating voltage of OS1 is 24-volts, which means, DC to DC converter is needed between sensor and 48-volt electrical circuit. Automotive Ethernet will be used to communicate between LIDAR sensor and AD-ECU. Selection of LIDAR and other sensors as well as data fusions topics are cover in thesis “Konzeption von ADAS Funktionalität und zugehöriger Sensorik” by Tobias Bayern. (Bayern 2021).

Steer units shown in diagram has not been selected, but due to design of the HELMAR, they must be Steer-by-wire style units like presented in page 35 of Dominik Stark’s Bachelor thesis (2020) called “Konzeption eines 48Volt Forschungsfahrzeugs”. Dominik Stark’s thesis was part of the HELMAR -project.

Drive units will be in-wheel motors due to same design aspect as steer units. Good alternative would be Elaphne S400 -motor as Dominik Stark presented in his thesis (Stark 2020). Negotiations with Elaphne is ongoing and final decision has not been made (Keul 2021).

HMI stands for human-Machine interface and it has two communications, Ethernet, and Wireless connection. Ethernet Is used to connect computer with Main ECUs for programming purposes. And Wireless connection is used for vehicle handling, infotainment and entertainment through Voice control, Bluetooth, etc. As the HELMAR will use steer-by-wire system, steering could be executed with joystick or computer mouse. Depending on level of autonomy achieved, actual steering instrument might not be needed at all.

The drive battery and ECUs has been selected and they will get own subsections with wider review of the selection process, so they will not be covered in this section. Figure 6 presents insight of the lower part of the E/E architecture diagram.

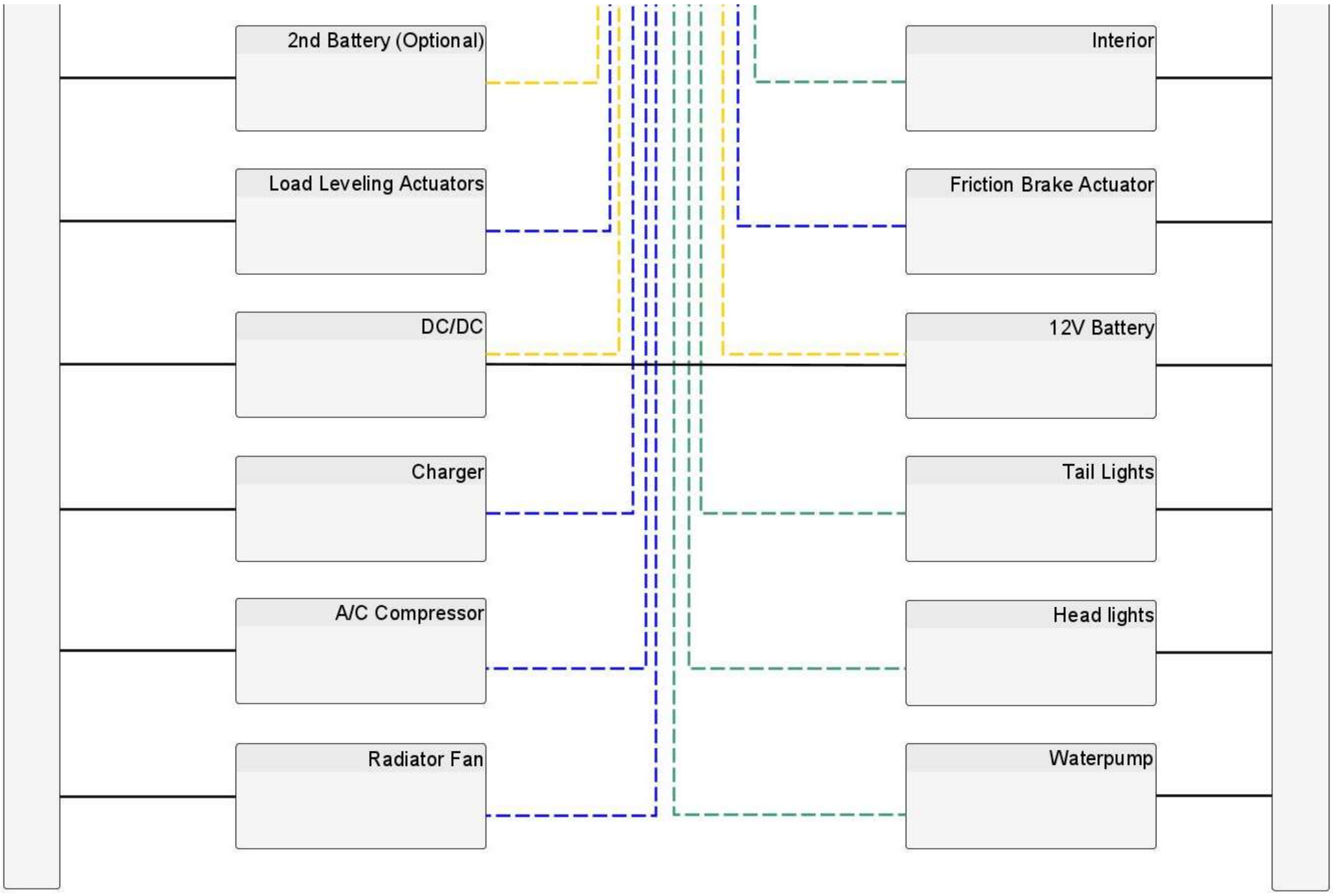


Figure 6. Lower section of the HELMARs E/E architecture diagram.

Figure above shows clearly that Flexray and CAN bus is most used communication bus system. It also shows that 12-volt circuit is much needed for different components. Not all components in this section have been selected, due to related component selection process.

Secondary battery is optional battery, what could be placed in the chassis of the HELMAR next to the drive battery. It could be small 48-volt battery like in diagram or small 12-volt battery for electronics, when the HELMAR is not driving. Need of a small the secondary battery depends on functions, what is wanted to be achieved.

Load leveling actuators will add comfort and more important, make sure the HELMARs driving dynamics, handling and stability stays same nevertheless load changes (Jänne 2019-b). In the HELMARs case, these play huge role, because load changes are bigger than normal passenger car due to the separate passenger compartment. Load leveling actuators has not been selected, because of open design.

DC/DC converter is needed to convert 48-volts to lower, compatible voltage for small electronics. Main task is to empower and recharge 12-volt circuit. Like said earlier 24-volts will be needed for LIDAR sensor at least. The DC/DC converters will be custom made in the Hochschule Esslingen, by Professor Cello, who is specialized for different electrical converters (Haag 2021).

Charger unit is very important piece as it converts alternating current to direct current that is suitable for the drive battery. It also controls heating or cooling of the battery, when necessary. For the first stage charger is provided by the selected drive battery manufacturer (Chassaing 2020). The second stage, depending on selected battery chemistry, custom made charger might be needed. If charger would be custom made, different concept connection types could be implemented.

Air condition compressor and Radiator fan is drawn to this diagram if they would be needed. Interior of the passenger compartment has not been designed and decisions of using an air condition has not been made. Depending on selected high voltage components cooling might not be needed in the first stage at all, if so, there is no need for radiator fan either. Separate cooling diagram has been made and this will be explained in detail down below. If radiator fan will be needed AVID technology -named company has suitable products for the HELMAR, one of these is eFAN FiX-15 electric cooling fan with 48-volt operating voltage and CAN bus connection (AVID Technology-a).

The passenger compartment will have the support battery, so interior can be powered by own 12-volt circuit. Communication over LIN bus might not be fast enough depending on wanted functions. When all the function (like audio, lighting, video, internet, etc.) are decided for interior, communication bus can be selected. Two electrical circuit could be connected each other by ODU DOCKING MATE connector (picture 5), which was presented in 2019 to the HELMAR -project (Hochschule Esslingen).

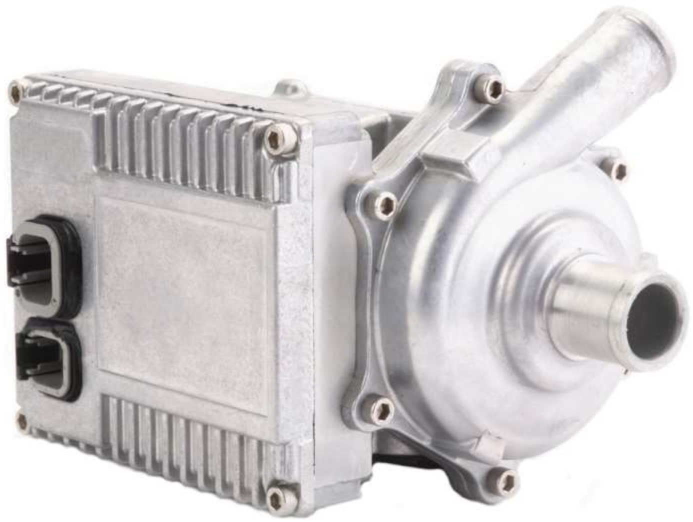
Picture 5. Docking Mate connector by ODU (Hochschule Esslingen 2019).

Brake actuator are important for driving of course. Optimum stopping power must be calculated for the HELMAR and different method of implementation scanned, like air operated, electromechanical, or electrohydraulic brake-by-wire system (Bosch Automotive Handbook 2018, 1101-1105; Wikipedia 2020-a). Electromechanical widely used nowadays and could be good option for the HELMAR, but selection has not been made. In-wheel motors will have great impact which kind of actuators could be able to use.

The 12-volt support battery will be in the passenger compartment and depending on used chemistry it could need control electronics. The easiest option would be to use basic lead-acid battery, but they are heavy and ineffective compared to li-Ion batteries. This topic will be covered down below in very detailed manner. Lithium iron phosphate battery could be good solution for the support battery for the passenger compartment.

Head & taillights have enormous effect on vehicles design and feeling that vehicle transmits. Design of the HELMAR is in drawing board and that’s why lights have not been selected. However, lights will use 12-volt circuit and LIN communication, which should be fast enough.

Water pump has addressed to the diagram for same reason than radiator fan if cooling is needed. Proposed water pump, eCP80 or WP29 (in picture 6), uses 12, 24 or 48 -volt operating power and communication bus is CAN. AVID Technology -company has variety of water pump suitable for the HELMAR as well as the Fans mentioned earlier. (AVID Technology-b).



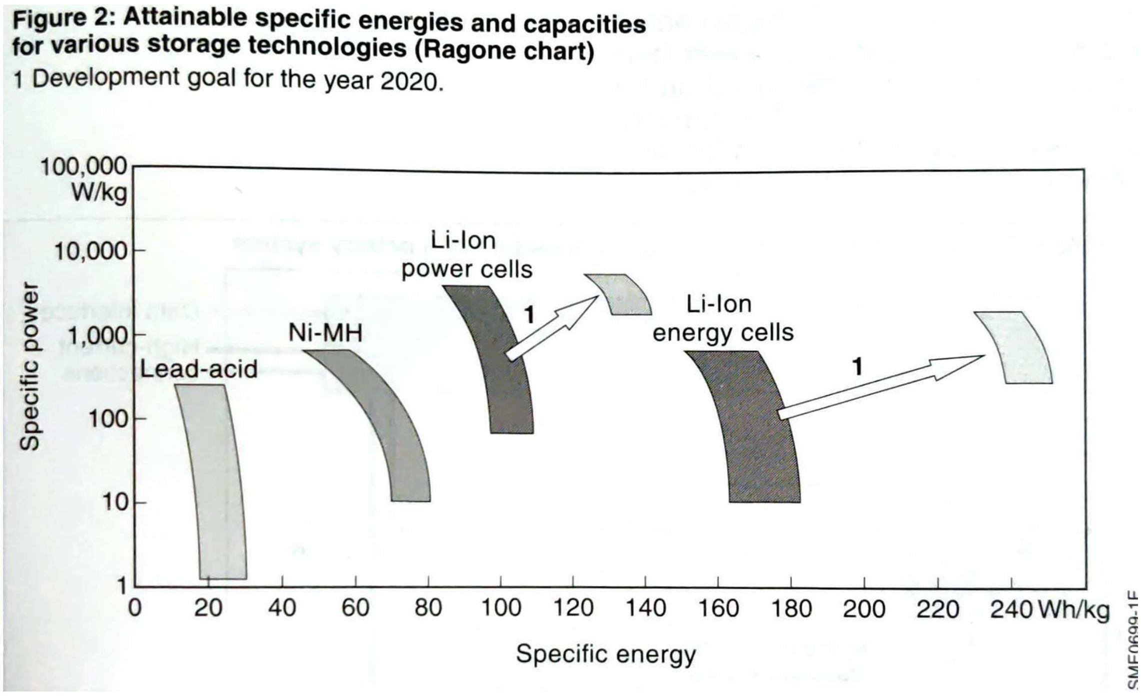
Picture 6. AVID WP29 electric water pump (AVID Technology 2021).

4.2 Battery selection

One Aspect of E/E architecture was the drive battery selection for the HELMAR. Requirements for battery package is 48-volts, capacity 7-13 Kwh, safe, durable and because of the pandemic I had to consider shipping times too.

Implementing 2-stage approach for this project, mean the battery package should be quick and easy to set up (Plug & Play) in the first stage and in the second stage the drive battery could be custom made for needs of the HELMAR.

It was clear that the drive battery will be Lithium-Ion battery because its advantages over normal lead batteries or NiMH batteries (picture 7). Few of Li-Ion battery advantages are weight, energy density, longer cycle life, lower self-discharge, higher cell voltage and lack of maintenance. (Battery University 2017-c; Albright, Al-Hallaj and Edie 2012; Epec Engineered Technologies; Hall-Geisler; Lithium-Ion Technologies).



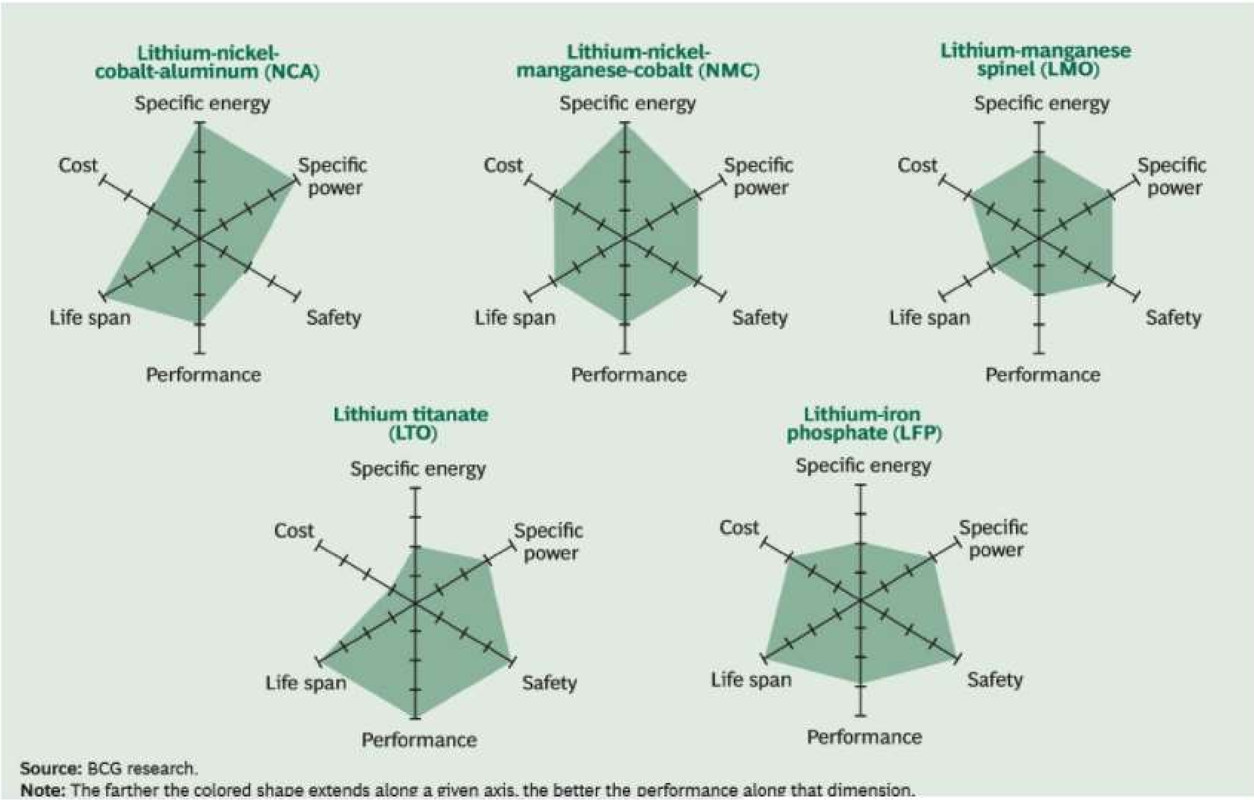
Picture 7. Lithium-Ion advantages over Lead-acid and Ni-MH (Bosch Automotive Handbook 2018, 1323).

Lithium-ion batteries is used widely today in different consumer electric devices such as phones, laptops, and electric vehicles. Li-ion is commonly used name for all different lithium-ion based battery chemistries. Most of the Li-ion batteries use Graphite as anode (Negative side of the battery) and cathode (positive side) is made of different Lithium metal oxide. Next, we are looking into different lithium-ion chemistries. (Atwell 2018; Battery University 2020-b).

The first step was to compare different Li-Ion battery chemistries. In Table 1 is comparison between 6 different chemistries, which are LCO (Lithium Cobalt Oxide), LFP (Lithium Iron Phosphate), LMO (Lithium Manganese Oxide), LTO (Lithium Titanate), NCA (Lithium Nickel Cobalt Aluminum Oxide) and NMC (Lithium Nickel manganese Cobalt Oxide). Spiderweb-graphs shows clearly differences between different chemistries in picture 8. Figures for Table 1 has been collected from different sources. (Attia *et al*., 2014; Battery University 2020-b; Betzin *et al*., 2016; Lambert 2017; Marsh 2019; Rudisuela 2020).

Table 1. Comparison of different Lithium-ion chemistries.

Chemistry	LCO	LFP	LMO	LTO	NCA	NMC
Voltages: Nominal (V) Operating range (V/cell)	3,6 3.0 – 4.2	3,3 2,5 - 3,65	3,7 3,0 - 4,2	2,4 1,8 - 2,85	3,6 3.0 – 4.2	3,7 3,0 - 4,2
Energy Density (Wh/kg)	150-200	90-120	100-150	50-80	200-260	150-220
Cycle Life	500-1000	< 2000	300-700	3000-7000	500-1500	1000-2000
Thermal runaway (°C)	150	270	250	One of the safest choices	150	210



Picture 8. Spiderweb models on different Lion battery chemistries (Nickel institute 2020).

Time of the writing LCO and LMO chemistries were outdated and no longer the best choices for the drive battery. LTO chemistry is considered very expensive and that is the reason for not searching more information about it. Next, we will focus on LFP, NCA and NMC chemistries and choose what could be the best for the HELMAR.

4.2.1 Lithium Iron Phosphate chemistry

LFP is mainly know of its high safety and long lifecycle. LFP battery uses graphite as an anode and lithium iron phosphate as a cathode. The $LiFePO_4$ batteries are used different applications, such as Aviation, Naval, e-Scooter and little Electric vehicles. (Deveney 2010; Grepow 2019; Powertech-a).

Massachusetts Institute of Technology (MIT) has published small prototype of LFP battery, where small Lithium Iron Phosphate particles are covered with lithium pyrophosphate. This allows rapid charge and discharge. The small prototype battery can be fully charged within 10-20 second versus standard LFP cell of 6 minutes charging time. (AENews 2009; Martin 2009).

The LFP batteries can have cycle life of 2 000 to 10 000 charge/discharge cycles. Number of cycles that the LFP battery can withstand, depends greatly on C-rate and on Depth of discharge (DoD). DoD is indicated on percent’s and it tells you how much you have used the power that the battery has. C-rates express how many hours, full dis-/charge cycle takes. So 1C rate means 1 full cycle in 1 hour and 2C full cycle in half an hour. By decreasing DoD and C-rate, the LFP battery’s cycle life could be increased dramatically. (Battery University 2017-b; Battery University 2019; Beck 2019; PowerTech-a).

Advantages	Disadvantages
• Long cycle life • High stability and safety • Plug & Play systems available • Cheaper than NMC/NCA • Lower cooling demand • Stay steady when overcharged	• Lower specific energy • Weight more than NMC/NCA • Performance at low temperature

(Battery University 2020-b; Jakins 2020; Kinstar; Relion 2015; Rudisuela 2020).

Wide range of different LFP battery system are available on markets. For the HELMAR most attractive drive battery manufactures were Powertech from France, Greening and Tronic One, both from Germany. All three companies do sell custom made battery packages, but the Powertech sell also general modules. (Accutronics-a; GreenIng; Tronic one; PowerTech-c).

The best choice for the LFP battery of the HELMAR could be the PowerModule from the Powertech. The PowerModule is 48-volt 5,4 kWh modular battery package with included BMS, CAN bus communication and cell heating systems. Two of these with parallel connection would provide 10,8 kWh of capacity, which would be quite optimum. Company does not fabricate battery charger, but they sell third party chargers for their battery packages. (Chassaing 2020, PowerTech-b).

Other interesting battery of choice could be LithiumWerks U27-24XP sold by Tronic One. The U27-24XP is 24-volt 1,8 kWh battery, it does not include BMS, CAN bus communication or cell heating system. The U27-24XP is half of the size of the PowerModule, which is its biggest advantage. But the HELMAR would need 12 of these batteries for 10,8 kWh capacity. (LithiumWerks U27-24XP Datasheet, 08.12.2020).

4.2.2 Lithium Nickel Manganese Cobalt Oxide chemistry

NMC is battery chemistry used by most of the car manufactures today. It uses graphite(sometimes silicon too) as anode and cathode is made of lithium, nickel, manganese, cobalt, and oxide. General formula is $LiNi_xMn_yCo_{1-x-y}O_2$. Because NMC has high specific power, high capacity, and can withstand many recharge cycles, chemistry is widely used. (Attia *et al.,* 2014; Battery University 2020-b; Boukhalfa & Ravichandran 2019).

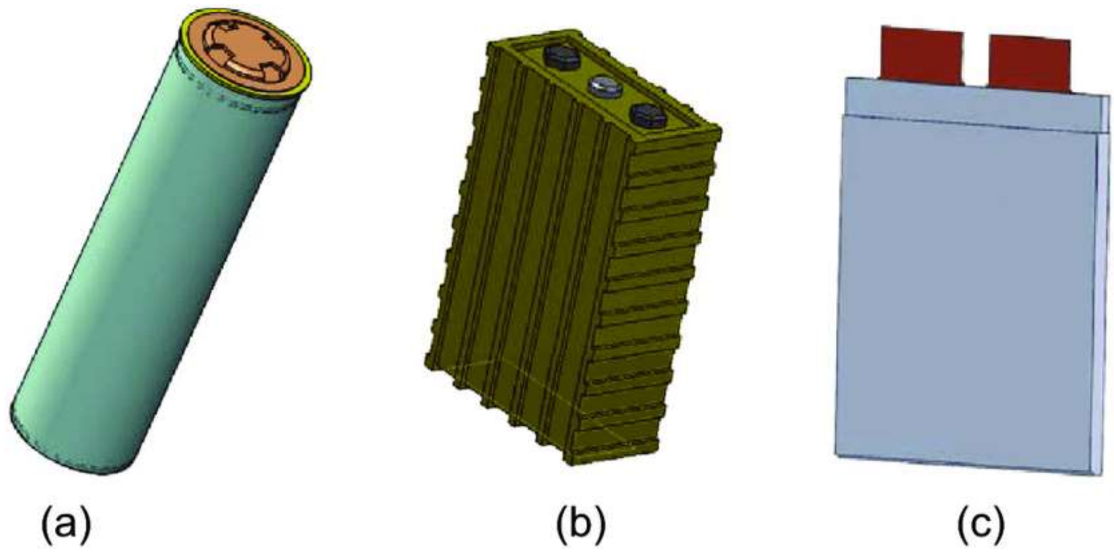
NMC622 is the most common mixture used in electric vehicles batteries now. Number after NMC reveals the portions of the metals. So NMC622 consist 60-20-20% of Ni, Mn, and Co metals. Other used formulas are NMC111 and NMC532. In near future NMC811 could be the mainly used mix. (Atwell 2018; De Rooij; Luo *et al.,* 2020; Rudisuela 2020; Targray).

By changing portions of NMC to each other, we can change characteristics of the battery and make specific batteries for specific purpose. Because Cobalt is expensive and usually unethically produced, manufacturers try to replace it with different metals. (Hynan *et al.,* 2019; Luo *et al.,* 2020; Visual Capitalist 2020).

Advantages	Disadvantages
• High energy density • Lightweight and compact cells • Lowered costs by reducing amount of cobalt • Long life span • Comes in prismatic and cylindrical shapes	• Not As safe as LFP • Price might increase in future • Needs cooling • Less Plug & Play systems on market • Costs 20% more than LFP

(Barua; De Rooij; Ep Equipment 2019; Erickson *et al.,* 2020; Fuchs *et al.,* 2014; Song).

When searching different Lithium-ion batteries with the NCM cathode, stores mostly sells cylindrical cells, like in picture 9. One criterion for the first stage Battery package of the HELMAR, was easy set-up, so called Plug & Play drive battery system. Only one, *Forsee Power*- named company, was found which produces Plug & Play drive batteries with NMC chemistry. And their products were not suitable for the HELMAR, but they were contacted for solution. The Foresee Power is in France, so transportation should not be big problem. (Bulk Battery; Forsee Power; GWL).



Picture 9. Different Li-Ion Cell types (Budde-Meiwes *el al.* 2013).

Next best solution would be Samsung INR lithium-Ion battery sold by company called EV West in United States. Products nominal voltage & - capacity is 46,8-volts and 505 Watt-hour, and it is sold by pairs. For this project 7-13 pairs would be needed to match desired capacity. Great disadvantages of this product are lack of BMS, Cooling and charging unit which must be bought separately. Company sells all required components, but construction would have to be done in the Hochschule Esslingen. This would have great impact of schedule. (EV West).

4.2.3 Lithium Nickel Cobalt Aluminum Oxide chemistry

NCA is a cathode chemistry mostly manufactured by Panasonic & Tesla. NCA is very similar than NMC chemistry, it has excellent specific energy and same kind of general formula $LiNi_xCo_yAl_{1-x-y}O_2$. Use of an aluminum stabilities chemistry and helps lower amount of expensive and hazardous cobalt. (Battery University 2020-b; Huang *et al.,* 2019; Weimar).

$LiNi_{0,84}Co_{0,12}Al_{0,04}O_2$ is said to be formula used by Tesla in their model S & model X, other Formula used by Tesla is $LiNi_{0,8}Co_{0,15}Al_{0,05}O_2$ in model 3. Tesla has been able to reduce 6,5 kg of cobalt on their vehicles between 2012-2018. One of the most interesting aspects of future NCA chemistry is specifically low cobalt volumes and high specific energy. (Benchmark Mineral Intelligence 2018; Bower 2018; Huang *et al.,* 2019; Hwang et al., 2019).

Advantages	Disadvantages
• High specific energy • Higher energy density than NMC • Better charging performance then NMC • Good cycle life	• Not as safe as NMC or LFP • Needs cooling • Price might increase in future • Most battery packages sold are used • No Plug & Play systems available

(Atwell 2018; Groves 2019; Hannan *et al.,* 2018; Hwang et al., 2019; Weimar).

Because NCA chemistry is more dangerous and still considered to be little behind of NMC chemistry, not too many battery packages are available. Most of the NCA battery packages on market are dismantled from old Tesla’s, which mean they are used and not in perfect condition. In market there were no Plug & Play drive battery systems, which would have used NCA chemistry. (Battery University 2020-b; EV Shop; Hannan *et al.,* 2018; Stealth EV).

The best NCA battery option for the HELMAR would be 24-volt 3kWh Tesla module sold by Company called Zero-EV from Bristol, United Kingdom. Interesting features of this product is long-narrowed shape and build in cooling system (picture 10). This battery package does not include BMS system and is a secondhand product. The HELMAR would need 6 to 8 of these batteries to achieve required capacity and voltage. (Zero-EV).

Picture 10. Tesla Li-Ion Battery module (Zero-EV 2021).

4.2.4 Selected battery chemistry

After thoroughly comparing different battery chemistries and suitable products for the HELMAR, well-grounded recommendations can be presented. In line with two stage approach, it is recommended to use different battery in either stage. The biggest difference in requirements between the stages was easy setup in the first stage and customizable size in the second stage.

In the first stage the best chemistry would be lithium iron phosphate, because of its safety and availableness. The fact that LFP battery does not necessarily need a cooling circuit, makes the chemistry even better for the first stage. Lack of cooling circuit saves time and simplify installation.

Preferred product would be the PowerModule by the PowerTech, presented in picture 11, which fulfills all requirements for the first stage drive battery. This product has 5,4 kilowatt-hour capacity, integrated battery management system & cell heating system, CAN bus communication and real-time monitoring available. The biggest advantage the PowerModule has over other products is quantity and size needed, the HELMAR will need only two PowerModules, sized 40x29x23 cm per module, to achieve 10,8 kWh. While other presented products would need 6-26 pieces to achieve similar capacity and even size-wise other products cannot be compared to the PowerModule. The Powertech is French based company, which is good when considering shipping options and times. (EV West; LithiumWerks U27-24XP Datasheet, 08.12.2020; PowerTech-b; Zero-EV).

Picture 11. PowerModule, Recommended battery package (Powertech 2021).

For the second stage use preferred battery chemistry would be Lithium Nickel Cobalt Aluminum Oxide (NCA), assuming development of NCA chemistry will take over NMC chemistry in near future. Changing to NCA chemistry is recommended mostly due to great variety of NCA single cylindrical cells found in market. When fabricating the drive battery package from scratch it could be integrated to the chassis structure to minimize space taken by the battery. Reasonable advice would be second battery comparison in future when the second stage of the HELMAR -project has launched. Further recommendations for the second stage are not addressed, due to ever developing progress in battery field.

4.3 Main electronic control unit

Side task regarding E/E architecture is selection of Electronic Control Units, ECUs. Electronic control unit is kind of a junction box with powerful computers inside. ECU receive data from sensors, processes & calculate necessary changes and sends output signals to actuators. ECUs have “real-time capabilities”, and they can be operated in milliseconds, otherwise example Anti-lock brake system would not be able to manufunction fast enough. (Bosch Automotive Electrics and Automotive Electronics 2014, 196; Burcicki 2020; ECUTesting).

Automotive industry sets high requirements for ECUs and the components used in ECUs. In 10th edition of Bosch’s Automotive Handbook following requirements has been set: operational reliability in case of voltage drops, power dissipation up to 70W and resistance against electromagnetic radiation. On top of these ECUs may expose to ambient temperatures from -40°C to +125°C, temperature changes, up to 20 g vibrations, effects of moisture and operating fluids such as oil, fuel, and brake fluids. (Bosch Automotive Handbook 2018, 1420).

ECUs consist different components, which functions might be hard to understand. Computer core of ECU is microcomputer or microcontroller. Difference of microcomputer and -controller is that microcontroller is real-time capable (Bosch Automotive handbook 2018, 1423). Next Figure shows (Figure 7) different components used in ECUs microcomputer.

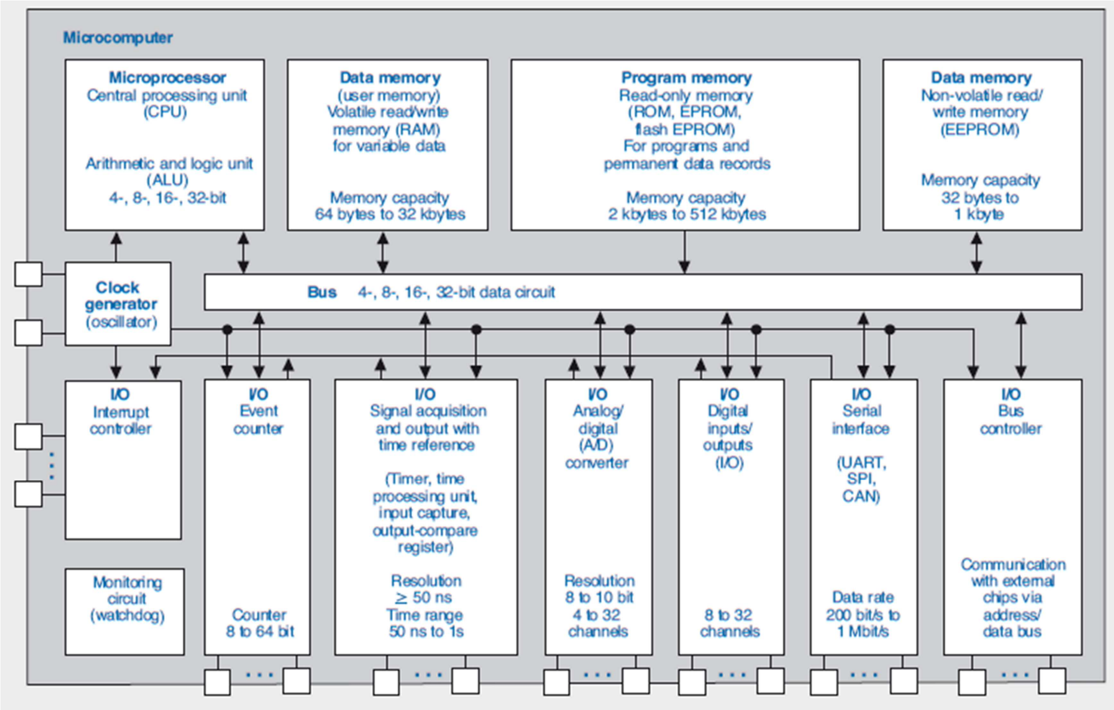


Figure 7. Microcomputers components (Bosch Automotive Electrics and Automotive Electronics 2014, 201).

Microprocessor is the central processing unit of the ECU. Two main groups of the microprocessors are CISC and RISC processors, which mainly RISC processors is used in ECUs. Microprocessor has arithmetic-logic unit and controller (also known as control unit). As its name implies arithmetic and logical operations are executed in arithmetic-logic unit. Controller is used to retrieve commands and data from memory. Higher clock frequencies are achieved by pipeline where arithmetic-logic unit is included. Pipeline is used to preprocess the commands. (Bosch Automotive Handbook 2018,1421-1422).

Program memory is the memory where ECUs software is saved. Software keeps inside all the control data, which are used to compare received data from sensors as well as commands, that should be executed, to get data from sensors match the control data. Program memory is non-volatile, which means that data will be saved even when power is disconnected. Program memory could be Read Only Memory (ROM), Programmable ROM (PROM) or Erasable and Programmable (EPROM, Flash, EEPROM). Flash and EEPROM are electrically erasable programmable read only memories. Difference is, Flash is erased with electrical flash pulses, hence the name Flash memory. (Bosch Automotive Electrics and Automotive Electronics 2014, 200; Bosch Automotive Handbook 2018, 1422-1424).

Data memory is memory, which is used to store data, which is used at the moment. Usually used data memory is random access memory (RAM), because it is fast and could be read and written. RAM is volatile memory, so when power is disconnected data is lost. Continuous power is distributed to RAM, to prevent loss of data when ignition is switched off. RAM is divided in static and dynamic; latter needs to be written repeatedly (refreshing) to prevent loss of data. Data will be available on Static RAM, even if it has not been written in long time, as long as power is continuous. EEPROM is used in data memory, if collected data should not be lost, even after disconnecting power. (Bosch Automotive Electrics and Automotive Electronics 2014, 200; Bosch Automotive Handbook 2018, 1422-1424; Jänne 2019-a).

Monitoring Circuit is a logic circuit, which monitors the microcomputer. The monitoring circuit is part of a voltage regulator, separate computer, or a separate integrated circuit. Monitoring is implemented by “question-and-answer game”, where the monitoring circuit and the microcontroller talk back and forth. If fault occurs, independent of each other, both ECUs are rendered safe by example deactivation of output stages. (Bosch Automotive Handbook 2018, 1425) .

Application-specific integrated circuit also known as ASIC chips is a chip with a specific task. ASIC chips can be used for program interrupts, or in combustion engines i.e., for operating Lambda-sensors or activate fuel injectors. Manufacturing costs and space needed can reduced when integrating functions in an ASIC chips. (Bosch Automotive Handbook 2018, 1426).

Bus systems is used to communicated between microprocessor and other components and as well as the external sensors and actuators. ECUs internal communication is usually parallel interface, whereas external components are connected via serial communication bus. Parallel communication is used in internal components because it is faster and time difference between bits are not significant. (Bosch Automotive Electrics and Automotive Electronics 2014, 200; Jänne 2019-a).

In automotive application microcontrollers have higher standards than in normal use. Failure rate of an automotive microcontroller must be less than 1 ppm, 200 times safer than in PCs. 40 000 hours of operation time and 30 year of availability is demanded. (Bosch Automotive Handbook 2018, 1423).

As seen Figures above the HELMAR have 2 main ECUs, one for autonomous driving functions and other for vehicle motion & basic electronics. The Hochschule Esslingen has used ECUs from company dSpace before and decided to use their products in the HELMAR too. Meeting was arranged with dSpace and their company's representative gave overview of the company and different solutions suitable for the HELMAR.

dSpace is one of the world's leading provider of ECUs and tools for developing them. It was founded in 1988 at University of Paderborn by Herbert Hanselmann and three other researchers. The dSpace launched the first hardware-in-the-loop simulator 1989 and since then has expended their product portfolio in ECUs for autonomous driving purposes. Nowadays the dSpace has over 1 800 employees, 6 countries with local dSpace companies, distributors in 8 countries and project centers in 3 German cities. (Wikipedia 2020-b; dSpace-b).

Important aspect of dSpace products is that their software can be programmed with MATLAB. The Hochschule Esslingen uses the program in various projects and teaches the MATLAB programming. This allows the software to be written in the Hochschule. (Haag 2021).

MATLAB is a programming platform and language by MathWorks. It is a fourth-generation language, and it is used to matrix calculation, implementation of algorithms, data analysis & data visualization and creating user interfaces. It was developed in late 1970s at University of New Mexico, by Cleve Moler, chairman of the of Computing Science department. More than 6500 colleges and universities and over 4 million user use MATLAB worldwide. (Educba; MathWorks; MathWorks 2020; Wikipedia 2021-b; Whatis.com).

Interesting products from dSpace for the HELMAR were MicroAutoBox 2 & 3, Autera and MicroAutobox 2 Embedded PC. The MicroAutoBox 2 & 3 are powerful ECUs mainly for whole vehicle motion and chassis & body controlling. The Autera and the Embedded PC are made for handling bigger data masses quicker than MicroAutoBox 2 & 3, and therefore are better options for the AD-ECU. (dSpace-a; dSpace-c; dSpace-d; dSpace-e).

The Hochschule Esslingen has few dSpace MicroAutoBox 2- ECUs in house and want to use one of them in the first stage of the HELMAR for Main-ECU. This will speed up the building process when components are ready on the self and the project group has the knowledge how to use them. For autonomous driving ECU functions MicroAutoBox 2 is not capable and instead MicroAutoBox 2 Embedded PC (picture 12) was selected for the first stage.

Picture 12. MicroAutoBox 2 Embedded PC (dSpace-e 2021).

For the second stage shared state of mind is to merge both ECUs to one central ECU, which would handle all the data. Depending on number of sensors and amount of data, it could be possible to use only one ECU. The selected ECU should have multicore CPUs, large amount of different memory capacity: enormous program memory for software, RAM capacity capable handling abundant amount of sensor data and extensive Non-volatile data memory for “black box” use, where all given commands could be stored for later investigation.

Competitive solution for the central ECU build, could be MicroAutoBox 3 with built-in Embedded PC. This product is made specially for Autonomous Driving functions and could be able to handle all the grand amount of data in real-time. The MicroAutoBox 3 with built-in Embedded PC has quad-core CPU, 2 GB of RAM and 240 MB Flash memory. Optional WLAN is available as well USB interface for data logging purposes. The MicroAutoBox 3 supports 12V, 24V and 48V operational Voltages, which is good, when deciding component placement on the HELMAR. (dSpace-d; dSpace-f).

If number of AD-sensors increases greatly, dSpace Autera Autobox could be good solution to use side by side with MicroAutoBox 3. The Autera Autobox has 32 TB of storage capacity, up-to 512 GB of RAM and 12 core Intel Xeon CPU inside. The Autera Autobox also support additional hardware like graphics cards. It has been selected OEM off highway TOP New Products Winner of 2020 in Engineering and Manufacturing. (dSpace-a; Jensen 2020).

4.4 Cooling diagram

Another task of E/E architecture was to create liquid cooling diagram, which included the drive battery, high voltage components and climate control system. Diagram was made in same program as the E/E architecture diagram. Here is presented two alternative liquid cooling systems, one where climate control and liquid cooling systems has connected and other diagram where both systems work independent.

Before presenting cooling diagrams, need of a liquid cooling circuit should be questioned. In the first stage used the PowerModule battery package does not need cooling, because used LFP chemistry is very stable and has high thermal runaway temperature. Depending on what In-wheel motors and inverters is used, the HELMAR might not need any liquid cooling system, whereas air cooling is enough.

Because component selection is open, and the second stage the drive battery would need liquid cooling circuit after all, these diagrams were made. The separate passenger compartment and the chassis of the HELMAR is good to keep in mind, when reviewing these diagrams. Figure 8 represents cooling system, where climate control has connected to cooling circuit.

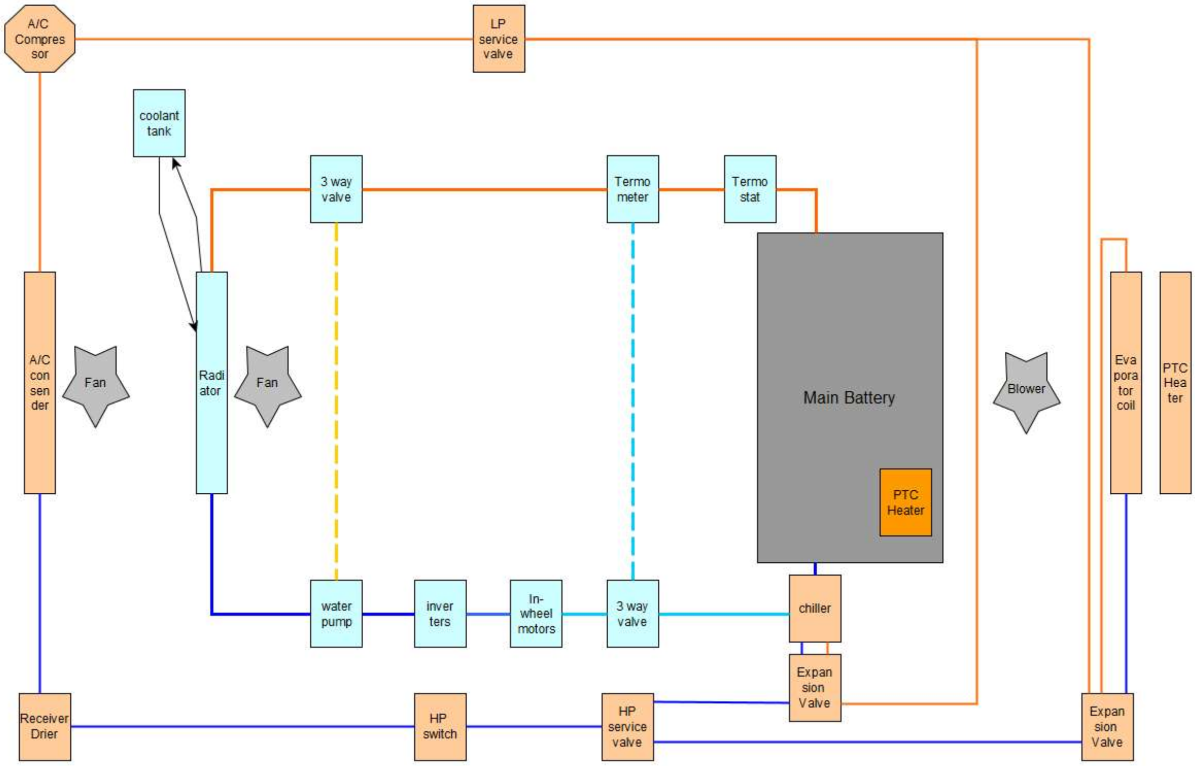


Figure 8. Connected cooling system for the HELMAR.

In Figure 8 & 9 beige color components belong into climate control circuit and light blue colored components belong to liquid cooled circuit. As seen in diagram, two radiator fans are needed due to separate construction of the HELMAR. Blue(cold) and red(warm) lines connecting different components, indicate temperature of the coolant or refrigerant.

In diagram above low electrical conductivity coolant comes from radiator and enters the first inverter, then In-wheel motors before 3-way valve. When the drive battery needs cooling, coolant will be directed through chiller to the battery, where thermostat will maintain optimum operating temperature. If the drive battery would not need cooling, 3-way valve directs coolant past the battery. Depending on temperature, liquid will be directed either back to circulation or to radiator for cooling.

Climate control systems operates with high- and low-pressure refrigerant, where compressor first compresses refrigerant to circa 14 bar and 65°C. After compressor, gaseous refrigerant heads to consender, where it is liquefied in 14 bar pressure to 55°C temperature. Condensation water is then filtered and dried from liquid refrigerant. Expansion valve allow liquid refrigerant to expand, which leads to drop of pressure and temperature. At this point refrigerant has pressure of 1,5 bar and temperature circa -7°C.

As its name implies evaporator coil vaporize the refrigerant, while the passenger compartment air is flown through this coil and heat is transferred to cool passengers. After evaporator coil, work cycle starts again with compression of the gaseous refrigerant. High pressure switch is a safety valve, which monitors pressure of the systems and shut down the A/C system, if pressure rises too high. (Katila 2019).

Climate control circuit in Figure 6 is very basic except it has electric compressor, chiller, and PTC heater. These modifications are made so, climate control would work on an electric vehicle. In combustion engines A/C compressors are driven by auxiliary belt and warm air for cabin is (not always) heated by hot coolant circulating through heating coil. The HELMAR use electricity for empowering compressor and for PTC heater, which heats the passenger compartment.(Bosch Automotive Handbook 2018, 1581).

Chiller is a component used in hybrid and electric vehicles, that is connected A/C circuit and liquid cooling circuit of the drive battery. Water passing through chiller is cooled down further by cold vaporized refrigerant, before entering the battery package. Vaporized, low pressure refrigerant is then directed to low pressure side of a A/C system and all to way to compressor. (Hella).

The HELMARs separate structure addresses big challenge for cooling diagram seen above. This is because chiller is connected both circuit, and cooling circuit is in the chassis while A/C circuit is in the passenger compartment. Solution could be quick connectors on cooling circuit, which will attach automatically to chiller when the passenger compartment is picked up. And meantime bypass line without chiller, could connect cooling circuit to the drive battery.

Temperature of the coolant, after cooling other components, might not be enough to cool the drive battery without chiller. To tackle this problem alternative cooling diagram was created, where both circuits are separated from each other, as seen in Figure 9.

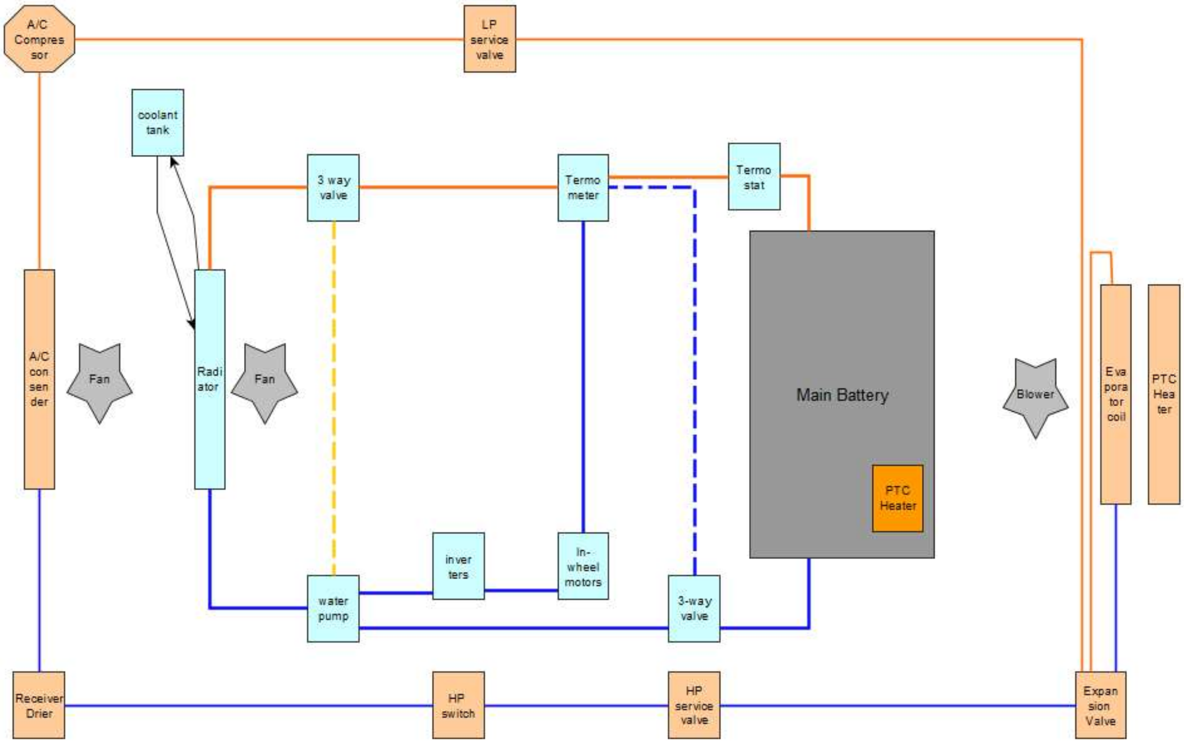


Figure 9. Separated cooling system for the HELMAR.

As seen significant difference between two cooling diagrams, is changes in liquid cooling circuit. Coolant circuit has been divided after water pump to ensure sufficient cooling for the battery package without chiller. Otherwise, coolant circuit will follow same principles than before.

Climate control circuit in Figure 9 is like previously presented, only chiller has been left out. Because of this, climate control circuit has no connection to liquid cooling circuit and could be installed the passenger compartment of the HELMAR without major obstacles. Working principle of the A/C circuit has not changed at all.

Figures 8 & 9 coolant is circulating all the time, and 3-way valves is used to maintain optimum working temperature of the components as well as coolant itself. This way electricity would not be used to cool down the coolant if it is not necessary. All electricity which could be saved, will extend range of the HELMAR.

Cooling need can be calculated, only after selecting In-wheel motors, inverters/motor controllers and other components, that could need liquid cooling. After calculations cooling circuit components and tubes can be sized correctly.

5 CONCLUSION

This chapter will focus on reviewing the thesis. Objectives of the thesis used methods and results are recalled & evaluated. Self-critical view of my own work is carried and presented. Suggestions for improvements and further developments for future are expressed. It is good to keep in mind, that even when acquired results are well-suited for the HELMAR -project, the results might not present best options for other projects. The thesis can be presented as successful, because it carried out important information for the project and is in a centric role of an electrical and electronical structure of the HELMAR.

5.1 Objective, used methods and results

Objective of this thesis was to create E/E architecture diagram, present clear vision for the project and select components as a part of E/E architecture. Vision for this thesis is based on my own view of future of Automotive and modified with additional information, that the group had decided earlier. Designing the E/E architecture kept inside lot of research of different components and learning a new computer software's. Especially battery selection was deep dive to different battery chemistries and required broad research of the topic, which was completely new for me personally. It took quite some time to get required knowledge. Results are excellent, considering the schedule, wide theme, and state of the whole the project. The thesis achieved all the objectives, that was addressed at the beginning. E/E architecture diagram is quite shallow and not as broad as I first planned, due to long component selection process. Despite this, main components & structure was created.

5.2 Own assessment of the thesis

Starting points for this thesis were quite extreme, some would say. The thesis was written in ERASMUS student exchange period; therefore, I did have to take two other lectures and of course move abroad for five months. Another added layer of inconvenience was the prevalent pandemic situation of the World.

Overall, I am satisfied with the achieved results. I was able to deepen my knowledge, answer widely to presented objectives and benefit the project group. Schedule was tight but achievable. Narrowing down the topics at the beginning, for this thesis was struggling and primary target of this thesis was changed to E/E architecture to serve better for the HELMAR -project. On my mind the ECU selection was not as thoroughly as it could have been, and this was due to tight schedule. Still, I acquired lot more information from ECU, that will be useful for me on future. I think the thesis is good base of the HELMARs E/E architecture and open for coming developments on the project.

5.3 Development ideas

When more components have been selected, I think it would be good to add these components to the E/E architecture diagram and make it more detailed. Cooling power could not be calculated in this thesis, but it should be calculated to ensure sufficient cooling for all components. For coming semesters, it would be helpful to make overall data sheet for new project members, which would include project vision, progress that has been made earlier and clear goals for the semester. The project vision & other details should be clarified few times in semester and ensure every project member is in the same page.

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