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SUMMARY
DOCTORAL THESIS

Research on the development of a new lighting system for vehicles

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Content

Costel-Ciprian RAICU: “Research on the development of a new lighting system for vehicles”

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INTRODUCTION

The current thesis titled "Research on the development of a new lighting system for vehicles" is structured in three sections, with the scope to combine the architecture and system elements for the lighting equipment designed for use in vehicles, with numerical simulations for the control strategies.

In the first part of the thesis, I am performing a literature analysis of the field, in which I describe the constituent elements for lighting equipment and the context for which they are designed, validated and used, which is a current topic for the research. Based on research carried out, I notice an increase in interest, both from a personal perspective and from the industry, for the numerical simulation for command and control of strategies, in the context of optimizing the technologies employed for different lighting equipment. Throughout the thesis I have designed numerical models based on conceptual strategies inspired by reality, using my experience as a designer in this field. Modelling of real topologies, or for some systems and architecture structures is obtained from research and the experience gained as a designer of this system. With the mentioned observations, in the second part, I describe the numerical methods used to establish a real reference model, after I implemented in the last part of the thesis the improvements and optimizations made.

In the third part, I present more realistic cases with the help of numerical modelling and I validate the strategies and the optimizations by comparing them with the generic models and their analytical profiles existent in the specialized literature to observe how some electrical parameters (voltage, current, control topology, LED placement, etc.) are influencing the behaviour for this systems. The conclusions for each analysed study are presented at the end, along with the original contributions.

CHAPTER 1.
PERSPECTIVES AND ESSENTIAL ASPECTS OF VEHICLE LIGHTING SYSTEMS

With the emergence of motor vehicles, starting in the year 1886 and until the present time, the lighting systems designated for them allowed the safe operation of road traffic by ensuring the safety of other traffic participants and pedestrians. During all of this time, the lighting of motor vehicles passed through a real evolution, from classic, based on fossil fuel, to the actual complex systems, with a modern design based on LEDs, flexible and energetically efficient.[1-4]

Vehicle manufacturers are in an aggressive competition to satisfy the market with the most innovative technologies. The quality of components used for motor vehicles is a priority, the lighting systems being the most carefully designed to attain an attractive aesthetic perception and high reliability. Lighting systems use analogue commands between the user (vehicle driver) and the components that are generating the light beams, or digital commands, like network communications, CAN or LIN. Components such as LED, OLED and LASER generate lighting beams, and they are integrated parts or satellites with the command and control units, like DC/DC, linear or LDO. The evolution of systems such as ADAS means that motor vehicles drive without the presence of the human factor, the lighting equipment being the basis for their design and offering all road participants the needed visibility. [3-9]

Intending to reduce CO_2 emissions and attain their projected targets, the electrical and electronic architectures are becoming increasingly complex, combined with a high level of autonomy. With the scope of use for exterior lighting systems, LEDs instead of bulbs [10], the contribution to obtaining a high-efficiency ratio for the Lm/W (lumens per watt) concerning the life expectancy and associated cost, will decrease the carbon footprint as well.

Lighting systems used in vehicles can be grouped into three categories, like the following:

a) components and systems dedicated to front lighting;
b) components and systems dedicated to rear lighting;
c) components and systems dedicated to cockpit lighting.

At the level of lighting areas, we encounter:

- lighting systems and components that use bulbs;
- lighting systems and components that are using semiconductor technologies like LED, OLED and laser (only in front lighting);
- lighting systems and components that are hybrid, using bulbs and semiconductor technologies;
- lighting systems with advanced architectures:
    - using communication bus and dedicated units for each lamp/system with ADAS-oriented architecture;
    - customer-oriented system (cockpit area only).[8,11,12]

The continuous development of the lighting systems meets a noticeable flexibility, as well as a superior level of quality and reliability, which ensures a high degree of satisfaction for the vehicle driver. The management models for design and development intended for automobiles are mixed and domain-oriented. Out of them, APQP or VDI are used for quality control during the design phases, conception and production, additionally using Lean or 6σ. A hybridization of these methodologies, like APQP and Lean or Lean and 6σ, for the production. For software design and development, methods like Agile and ASPICE or adaptations of them with the existing methodologies form the design area and management of the automobile industry. [12-16]

The requirements for the motor vehicles which are to reach the markets, potential customers' needs, global trends, etc. are influencing the design and development of the components and the lighting sources that will equip the future automobiles. Therefore, it is necessary to impose strategic objectives and design starting very early from the concept phase while keeping in mind the numerous inter-disciplinary constraints and considerations. To validate their capability and quality of them, before being developed and validated, the following considerations are needed to establish the product needs:

- desired type of lighting sources:
    - Incandescent or rare gas bulbs;
    - Semiconductors – LED, OLED, Laser;
- architecture and system type:
    - dimensioning of wire harnesses;
    - types of control and commands;
    - types of drivers;
- validation needs:
    - Electromagnetic Compatibility;
    - Reliability and endurance;
    - AEC-Q conformance;
    - Product and functionality at system and vehicle level;

- Regulations:
    - for lighting systems - ECE;
    - for safety – ISO.

CHAPTER 2.
ARHITECTURES OF LIGHTING EQUIPEMENT

Lighting lamps used in automobiles have a big diversity from a driving strategy and the power supply network based on the desired design and the need for functional complexity.

Powering these components is managed in the actual context with a power network of 12 V for automobiles that have an internal combustion engine. For some types of vehicles like hybrid or electrical, the power supply network varies by brand and strategy between 12 V and 120 V, or even higher than 120 V[23, 31]. The power delivered to the lighting components is done indirectly, with other command and protection units, such as these are protected from different electrical network variations and possible issues, like short circuits. The power supply and the electrical distribution in the automobile are done based on energy frameworks to avoid overloading of power supply lines, these being protected with fuses or other semiconductor components for protection and control, for example, the SMART-FETs or electronic fuses which once the issue disappears they recover in their nominal functional behaviour, same with the power distribution which comes back to nominal parameters. Each lamp may have one or more supply lines, this strategy being dependent on the safety constraints and the associated redundancies.

First architectures and command strategies for the lighting systems used wired controls, the command and control elements for their activation or deactivation were done with switches and relays. For the optimization of the power supply network and the reduction of the number of wires, but also to attain a high number of functions or proprietary functionality, it was needed to migrate towards a serial communication network to decrease the number of wires needed.

2.1 ELECTRICAL AND ELECTRONIC CONTROL ARCHITECTURES

Automobile manufacturers identified, for their products' success, the timely planning of their architecture and the design strategies that are to be used as an imperative requirement. Besides the harness requirements, the control strategy, is one critical step for the vehicle, because it offers the base strategy for the control units which are to be designed. Furthermore, for lighting systems, I present the identified strategies.

2.1.1 Digital control of lighting loads

For the lighting systems used on automobiles, from the desire to reduce the weight of the wire harness, as well as to increase the complexity and the number of features for them, it was adopted the serial communication bus. Depending on the equipment level and the number of features desired on the vehicle, the bus may be LIN, CAN-LSFT or CAS-HS. The leap from the wired commands to the communication bus is possible for the lighting loads only when LEDs are used, because they come along with dedicated drivers, and the serial communication bus is easier to integrate.

Systems, like ADAS, along with the lighting systems created the basis for the adaptive lighting systems which use the front camera of the automobile to manage obstacle recognition, the lamps manage the shut-down of specific light areas to avoid the glare of traffic participants. A high level of integration for the electronic equipment is beneficial for the exterior lighting. Sensors and collected data can be processed for advanced lighting features. One clear example is the camera utilization for high-resolution lighting, where the camera is used to detect oncoming vehicles [68]. The orientation of the used sensors for the lighting equipment is presented in Fig. 2.1.

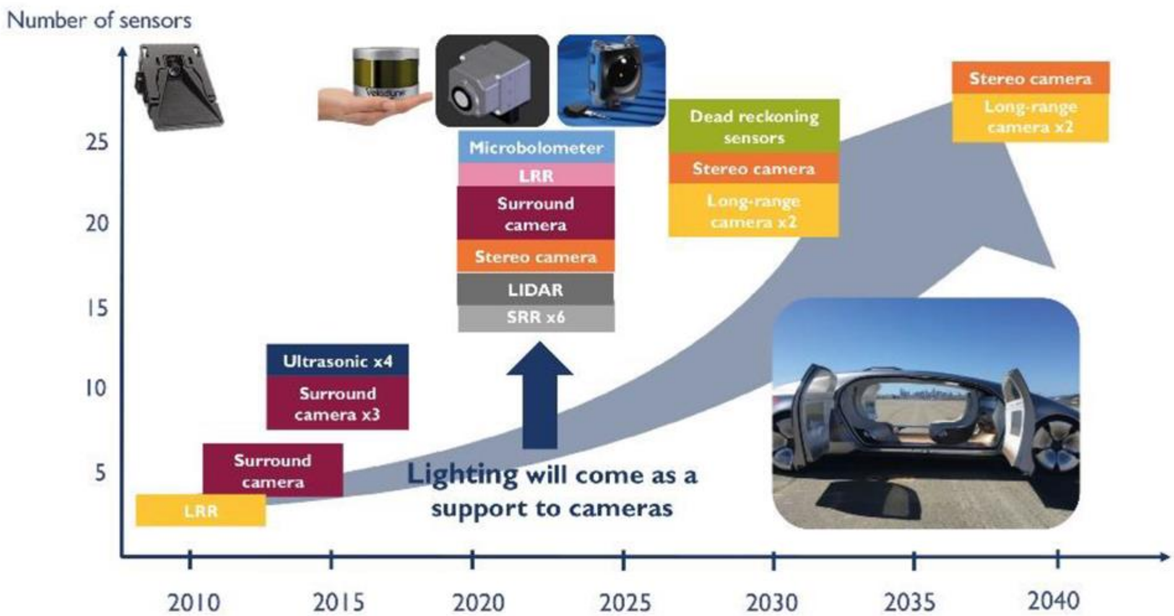


Fig. 2.1. Autonomous vehicle sensors – technology mapping [68]

The front camera of the vehicle processes the images and informs, using the communication bus the lighting driver, which decides the optimal optic distribution to avoid glare or to blind the other traffic participants, it can also switch between the low beams and the high beams. Fig. 2.2 represents the control strategy for the intelligent lighting from the ADAS system.

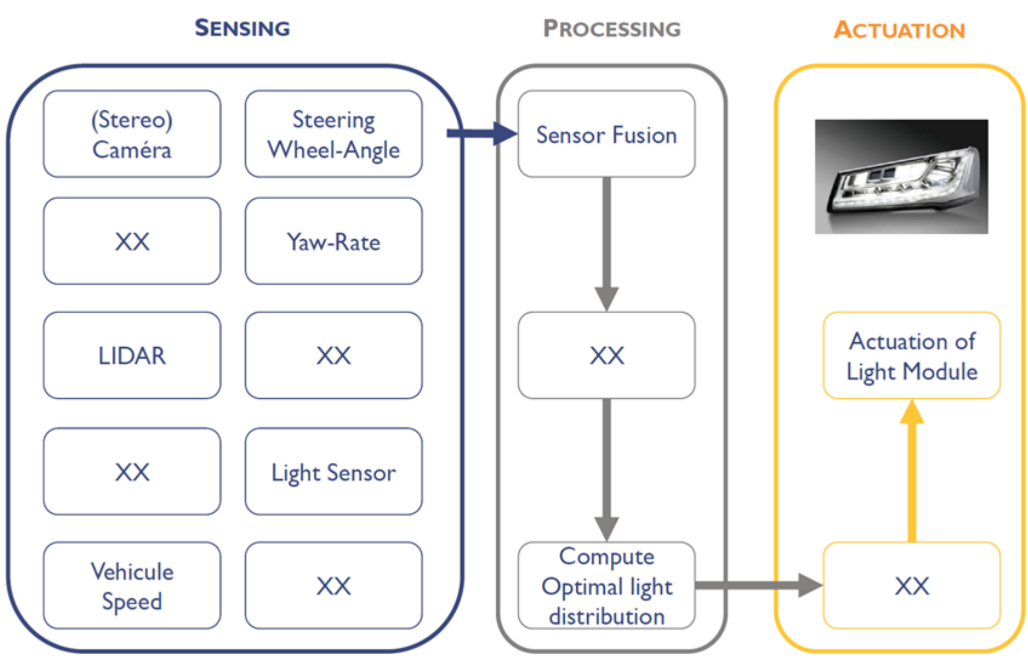


Fig. 2.2. ADAS system interaction with the front lighting [69]

The adaptive lighting systems, as defined in ECE/324-R123, are „a lighting device, providing beams with differing characteristics for automatic adaptation to varying conditions of use of the dipped-beam (passing-beam or low beam) and, if it applies, the main-beam (driving-beam or high beam) with a minimum functional content...; such systems consist of the "system control", one or more "supply and operating device(s)", if any, and the "installation units" of the right and of the left side of the vehicle“ (ECE/324, ediția 122: *Regulation nr. 123*) [70]. The adaptive front-light system (AFS) is a part of the active safety system for the medium passenger vehicle, it offers optimal visibility for the driver during nighttime and other conditions of minimum visibility by adapting the headlight angle and its luminosity flux, utilizing vehicle speed evaluation, steering wheel angle, weather condition and the yaw of the vehicle [36, 38, 71].

The features of the adaptive front-light system, with optical distribution, are represented in Fig. 2.3, are [36, 38, 71]:

- town low beam (class V): at speeds under 50 km/h, the town low beam ensures a wider light distribution on a reduced range, helping drivers to notice the pedestrians on sidewalks clearly;
- country low beam (class C): the illumination is done more widely at higher intensity on the roadsides. Typically it is activated at speed in the range between 50 and 100 km/h.
- highway low beam (class E): the highway low beam improves visibility, starting from 100 km/h, it provides better illumination for the front with more focus on the left side. It is automatically activated at a speed higher than 100 km/h;
- wet road low beam (class W): when the rain light sensor is detecting rain is automatically activated or if the windshield wipers are on for more than 2 minutes. The roadsides are better illuminated to increase driver visibility for the guiding marks from the road;

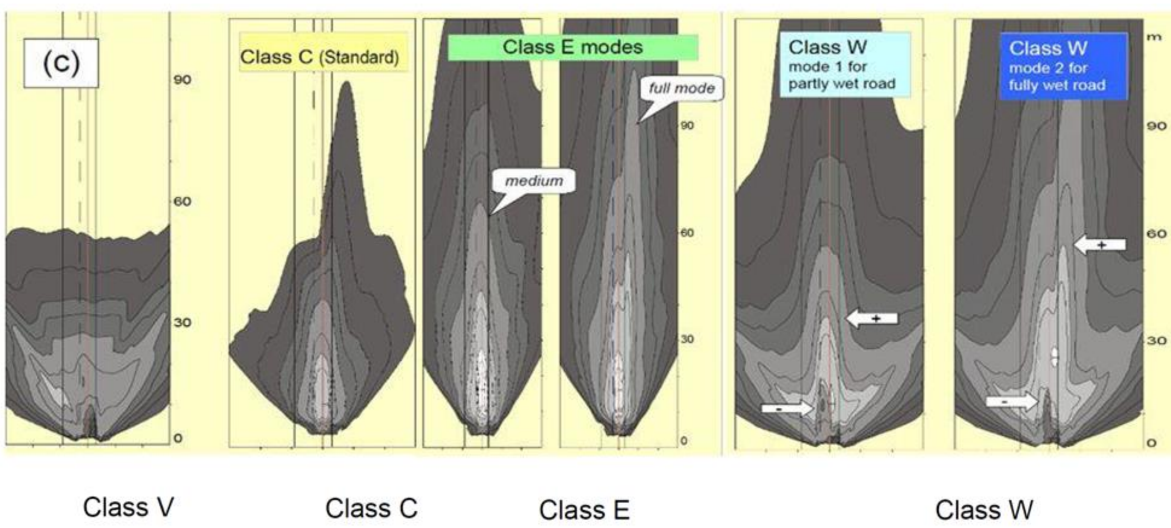


Fig. 2.3. Illumination modes [71]

- static cornering light: the cornering lights, type static, which help during manoeuvres in nighttime access roads. For speeds under 40 km/h, an additional cornering light lits when the direction indicator is activated or when the steering wheel hits an angle of 90° to the right or left [36, 38, 71].

Dynamic levelling and swivelling of optical angle for the lamps:

- levelling: AFS is adjusting vertically the headlamp (projector) direction with data from the chassis rear and front sensors. The pitch angle adjustment for the headlamp based on the static load transfer of the vehicle (occupants, luggage) is named *static levelling*, while the pitch adjustment based on the dynamic load transfer (acceleration, deceleration) is named *dynamic levelling*;
- swivelling: AFS horizontally swivels the headlamps, judging the input from the direction angle and the speed of the automobile. The system offers a curvature up to 15°, helping with the obstacle visibility [36, 38, 71].

All lighting intelligent systems require a complex architecture for their environment so that the entirety of the desired features can work at a high precision and performance from a time reaction perspective. The conceptual structure of the communication network for all vehicle components, for the adaptive front light system, is represented in Fig. 2.4. The sensor position in the vehicle is connected to the body control module (BCM) with a CAN or LIN. Chassis sensors, front and rear detect the height of the vehicle and are connected in most cases over LIN, CAN-HS, or hard-wired to the BCM. Based on the electric architecture type, distributed architecture or zonal, the information about the vehicle position angle is transferred to the BCM or another electronic control unit, for example, the gateway.

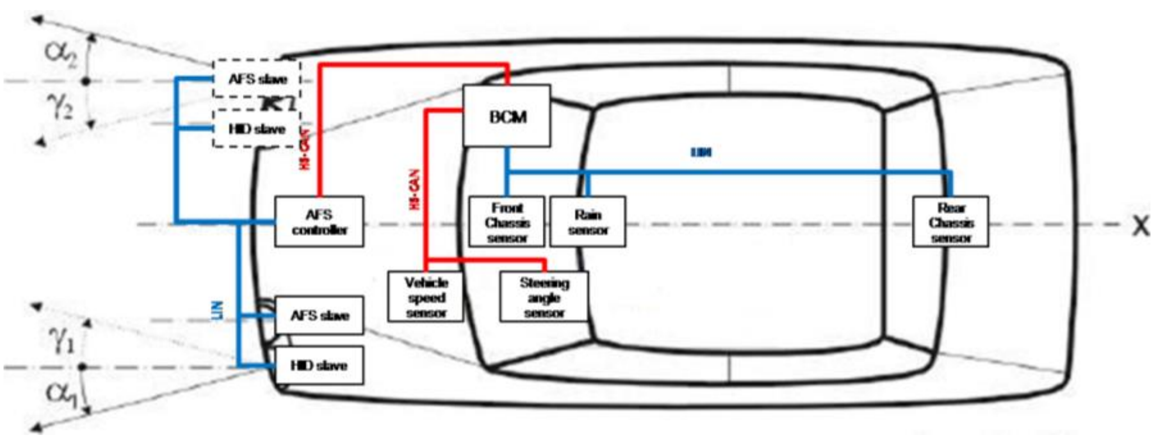


Fig. 2.4. Communication network structure for lighting equipment [71]

Rain light sensors are in most cases implemented in the washing or comfort sub-system; they, usually are inter-connected over a communication bus like LIN and send the acquisition information about the exterior environment to the BCM, the LIN master. In Fig. 2.4 is presented this connexion.

The yaw and the speed sensor of the vehicle are placed and connected to the propulsion system using CAN-HS, because is critical for other systems like braking, and the CAN bus ensures the plausibility of information.

The lighting system architecture migrates towards a high integration of as many functions inside the lamp, depending in the same of the available information on the communication bus. At the system level, the lighting equipment uses available information from other systems and sub-systems, which employs a high-cost efficiency and for the features installed, one risk which needs to be mitigated is the response time. We have this highlighted in Fig. 2.5.

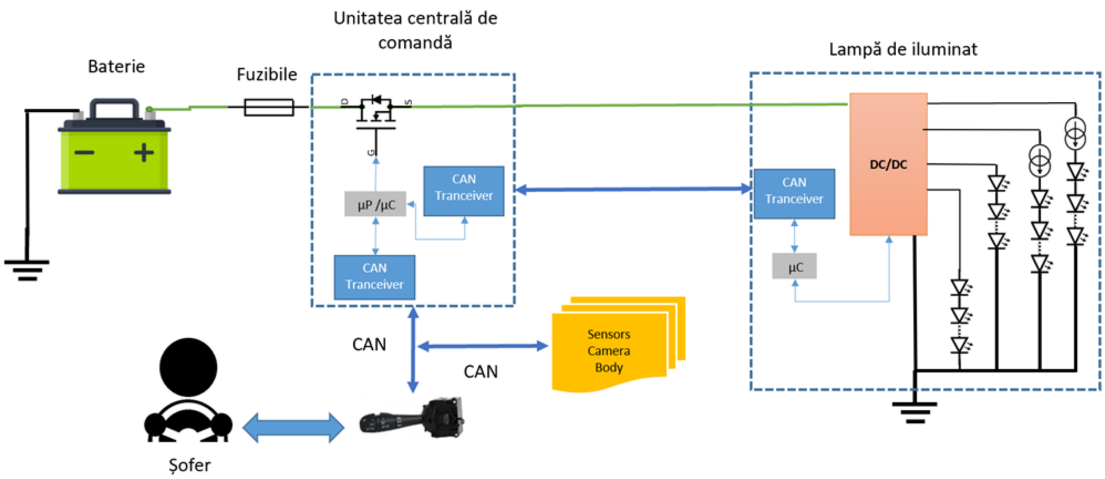


Fig. 2.5. Lamps command with a central unit for control, protection and CAN bus

The limitations of traditional adaptive headlamps determined the development of LED-based lighting systems arranged in a matrix topology, which provides intelligent front illumination and dynamic control by low beam adaptations as a response to the change of driving conditions. System-based LED projectors have sophisticated engineering, containing at the base a functional simple principal with controlling digitally the pixels which are generating the lighting beams. The light intensity is controlled dynamically and precisely with the tunning of the duty cycle for the PWM dedicated for each pixel, the dimm ability offers this module a high versability to be used even for picture projection on the roadway or animations. [36, 38, 72].

The LED headlamps and the matrix topology contain a large amount of LED drivers assembled in one common module, each LED driver being equipped with a dedicated circuit to manage the light intensity variation and on/off switch. The use of reflectors and/or lenses allows for the LED modules to offer a high number of variations for the optical distribution without the use of a dedicated mechanic pivoting mechanism. The matrix topology shares the power of the lighting beam in smaller beams, which are independently controlled, The power LEDs achieve a higher efficiency and a superior lighting flux density, allowing the beam control, compared with a colour temperature substantially higher (around 6000K), which reduces the tiredness and optical stress of the driver. Fig. 2.6 highlights an LED matrix headlamp and the different functions realized by the Audi A8 vehicle; the LED light contains a large power luminosity, without using a big space in the headlamp packaging and without high electrical energy used [36, 38, 72].

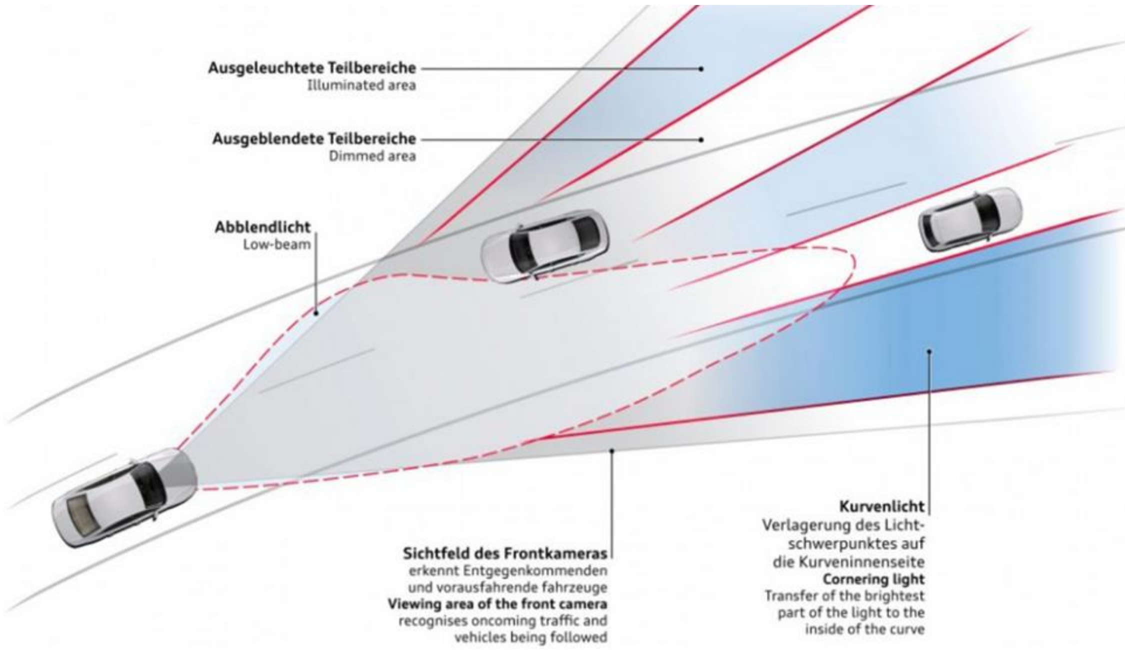


Fig. 2.6. Audi A8 – Matrix projector LED[72]

The LED matrix technology presents a high interest for vehicle manufacturers and equipment manufacturers, like Audi, BMW, Mercedes-Benz, Opel, Volvo, Varroc, Hella și Bosch. Audi and Hella introduced recently headlamps with high resolution and LED matrix, which integrated 32 small LEDs, individually controlled, placed on two rows. The decrease in 64 steps allows the LED matrix a high resolution to create millions of models for the lighting projection, the low beam system using the front camera video information, the navigation system and other sensors to provide intelligent advanced illumination with precision.

The rear lamps use matrix LED technology, adopted by the desire of styling, but without an active or dynamic scope like the headlamps. They have a low energy requirement and do not consume information from the front camera or the vehicle yaw. A possible architecture solution from Texas Instruments is represented in Fig. 2.7. The rear lamps contain dynamic animations for signalling and positions when the vehicle is not moving; the stop and fog lamps are not used in most cases for the animations due to safety constraints, as well as regulations.

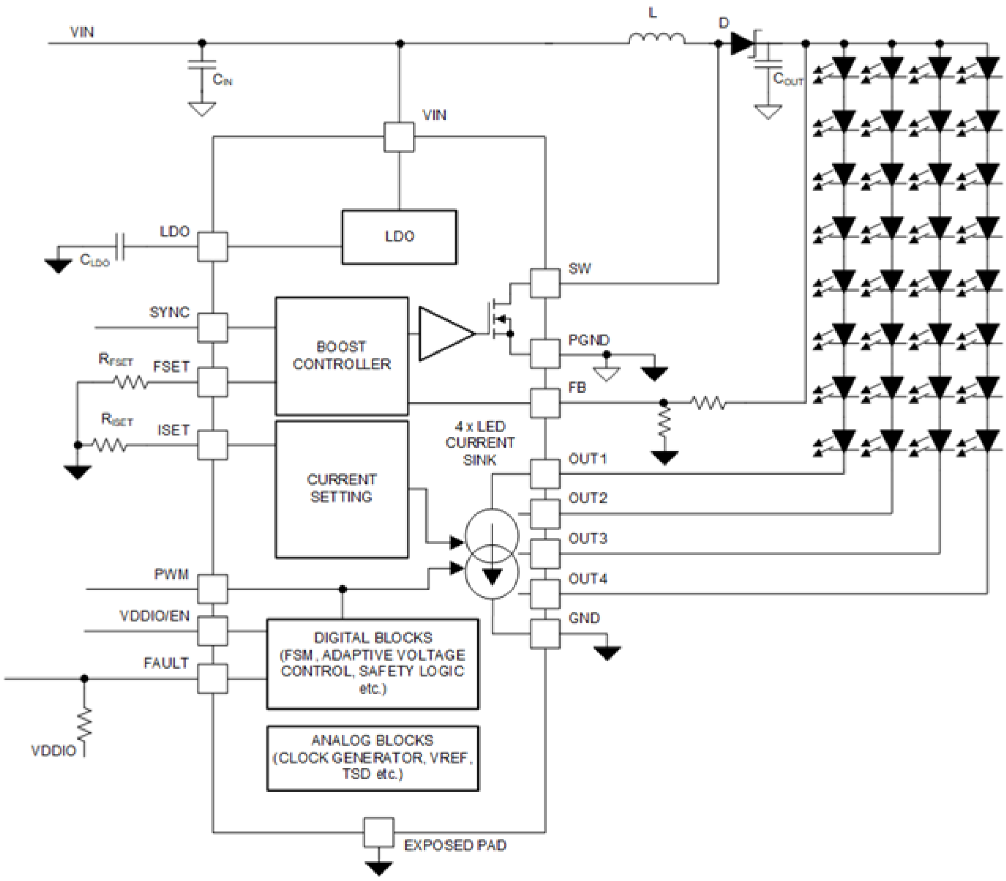


Fig. 2.7. TI solution for driving LEDs for the rear lamps [73]

2.2 OPTICAL DESIGN

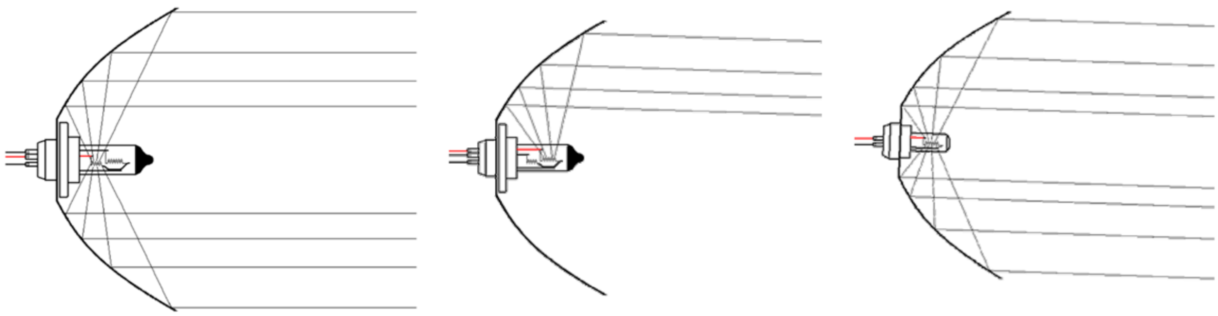
The elements of the lighting system are generating the shape and personality of the vehicle. The optical design for the lighting elements is linked with the styling of the optical units as well as the capability of them to comply with the ECE regulations. To attain the regulation norms, for the lighting loads with LED and bulbs, use reflectors, to focus the lighting beams, towards a median area, in continuation I reflect the types and structure of the optical reflectors.

2.2.1 Optical elements for the headlamps

The front lamps have an extensive diversity from a functional perspective, they can be split in:

- position(or tail) light/lamps;
- principal light/lamps;
- additional lamps;
- fog lamps;
- reserve lamps.

From the system perspective, the front lamps (principal lamps) may have two or four lighting sources on each side of the vehicle. An architecture for the front lamps with a different number of lighting sources with bulbs is represented in Fig. 2.8.

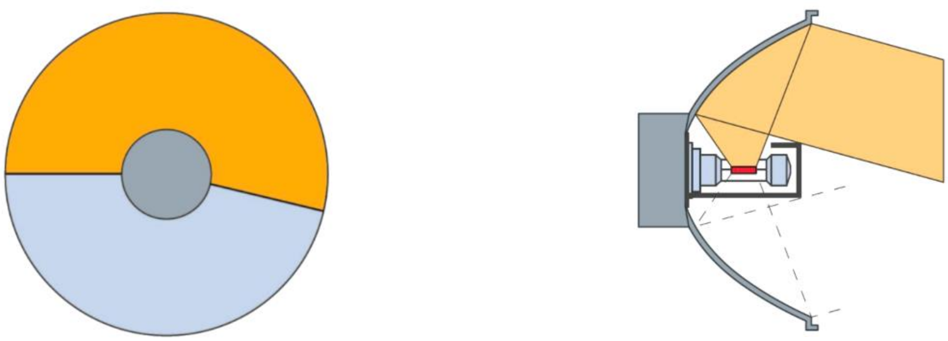


a) Illustration for the principal lamp; b) Illustration for position lamp; c) Illustration for lighting mono-source

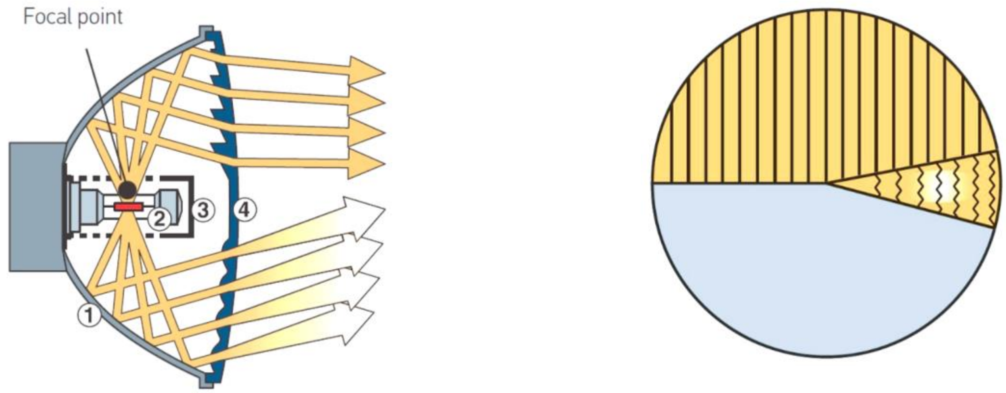
Fig. 2.8. Reflector optic design[74]

In the scope of improvement for the lighting dispersion generated by the lighting sources, in practice are using reflectors to generate a higher lighting area[74, 75, 76]. These types of reflectors can be of multiple types:

- paraboloid reflectors – Fig. 2.9
- free-form reflectors – Fig. 2.10
- Super-DE reflectors – Fig. 2.11

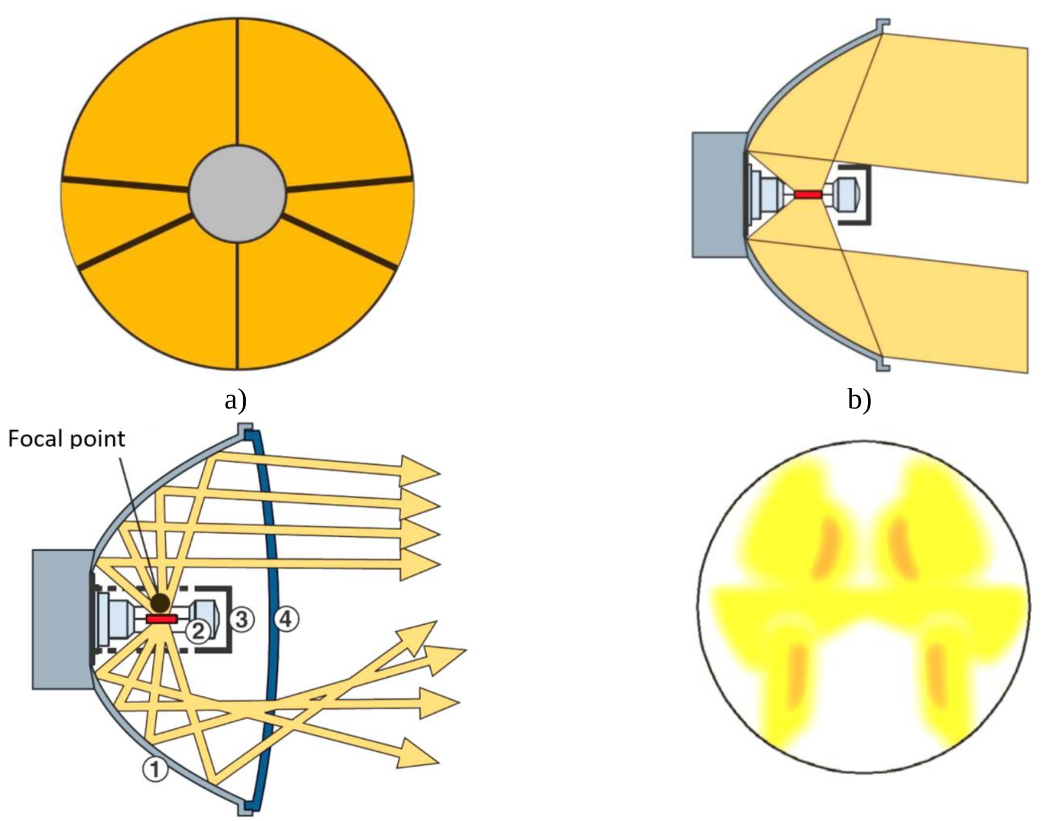


a) b)



c) d)

Fig. 2.9. Paraboloid type reflector:
a) Reflective surface – front view; b) Low beam reflection – lateral view; c) Ligh deflexion through prisms and other lens elements (1 – reflector, 2 – bulb, 3 – bulb protection, 4 – lens) – top view; d) Light typical distribution for low beam on the lens – front view [76]



c) d)

Fig. 2.10. Free-Form type reflector:
a) Reflective surface split in segments – front view; b) Low beam reflection – lateral view; c) Ligh deflexion through prisms and other lens elements (1 – reflector, 2 – bulb, 3 – bulb protection, 4 – lens) – top view; d) Light typical distribution for low beam on the lens – front view [76]

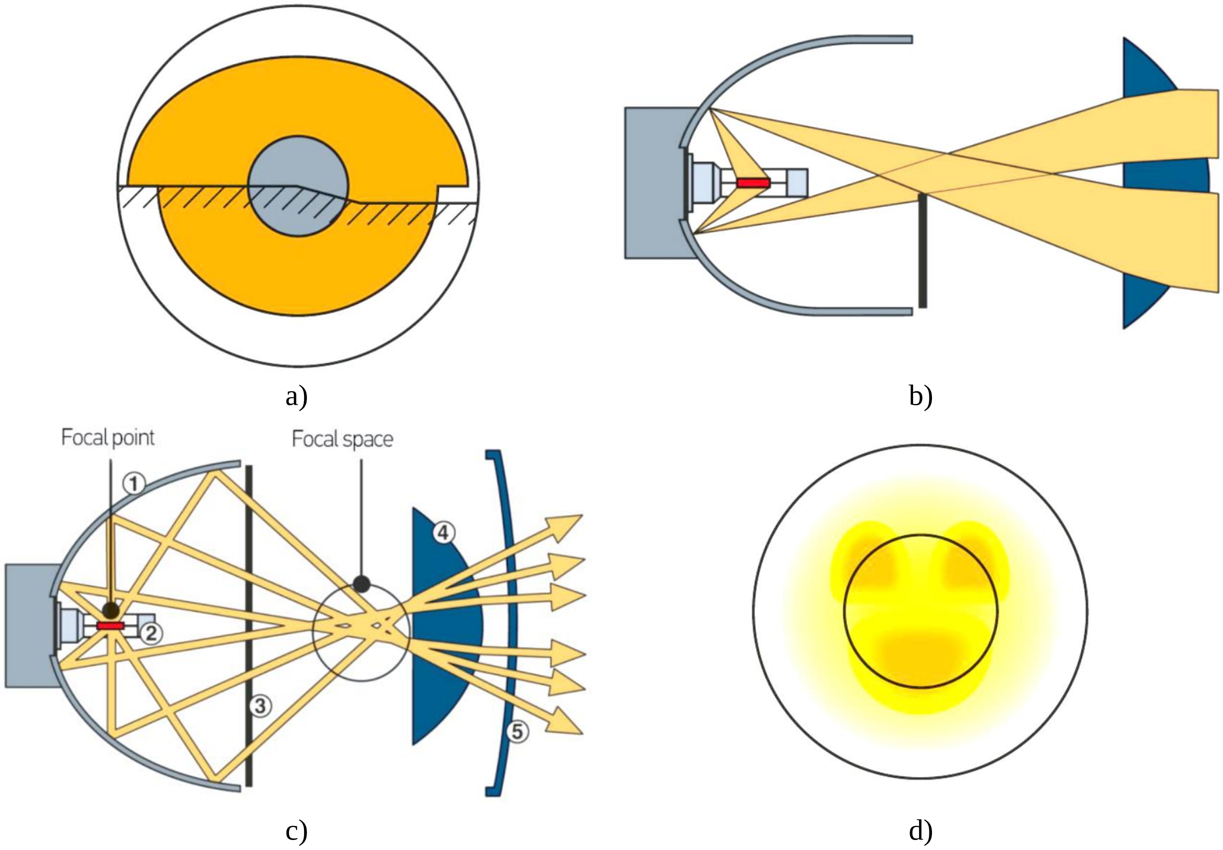


Fig. 2.11. Super-DE type reflector:
a) Reflective surface and protection – front view; b) Light reflection and light generation modes – lateral view; c) Light direction and focus (1 – reflector, 2 – bulb, 3 – bulb protection, 4 – lens, 5 – lens protection) – top view; d) Typical light distribution for low beam on the lens – front view [76]

The reflectors and their technology play an important role in the quality and optimal distribution of the light beams. Light beam distribution is defined in the regulation norms according to ECE R48[77]. The light source's efficiency is impacted by the reflector's presence, but their role is uncontestably for attaining the regulation needs [78], Table 2.1 resumes this aspect according to the three types of reflectors mentioned above.

Table 2.1. Reflector efficiency is based on the degree of light utilization from the bulb for the desired luminosity of the beam [76]

Reflector	Paraboloid	Free-form	Super-DE
Successfully used light [%]	27	45	52

CHAPTER 3.
PRESENT SOLUTIONS AND OPTIMISATIONS FOR ARCHITECTURE OF LIGHTING SYSTEMS

3.4 ARCHITECTURE METHODS

The control and functionality of vehicles are tied by electrical, electronic and software architecture, and the management of those defines the efficiency and number of functionalities that it can maintain. Each architecture has benefits as well as disadvantages, these architectures are represented in Fig. 3.1.

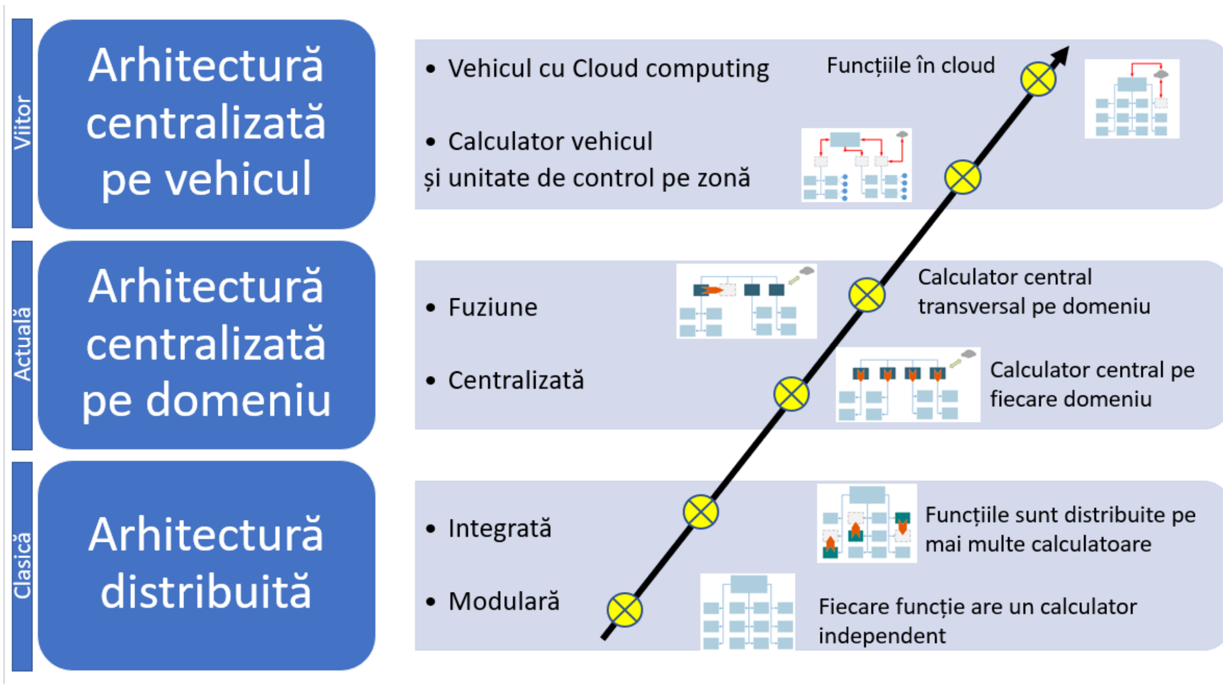


Fig. 3.1. Electrical and electronic architecture for vehicles[84]

The E/E architecture is known as being the key point for sustaining the vehicle applications as the integration of navigation platforms with Android or Apple, but as well for the growth of complexities in automobiles too, by point of view of functionalities it can support and safety. By many considerations, the E/E architecture is an integrated network infrastructure that contains electrical, electronics and communication elements which is utilized for interconnecting and organizing the electronic control units and mechanic/electronics components, including sensors, alimentation systems and harness for reaching the expected functions, especially the interaction and interdependence between these elements.

From a perspective of functional or constructive requirements, there are two mechanisms for designing a stable E/E architecture, one oriented on the physical/hardware part, and the second one based on functions/software. The hardware method has a design based on existing architecture and it develops by adding new devices and functions above this base. On the other hand, the software method implies the modification of the entire design process, and it starts from functional requirements analysis. For a design based on existing hardware E/E architecture, the price and difficulty for the process development are relatively smaller, but limited by the original structure which cannot sustain intensive software systems distributed or complex. The design method starting from software is a new design process, which follows complex developing steps, it is being used in normal circumstances in developing new vehicle platforms, but it is expensive and time-consuming. [84-89]

Regarding the design method starting from software, as a first step, it is necessary to define the requirements and break down the functions by areas or control units according to the desired design method, from Fig. 3.1, generating in this case functional modules. In E/E systems concepts we use two architectures, functional architecture (logical level) and technical architecture, for offering in the following steps easier changing flexibility, with no complex hardware changes.

Functional modules must be determined according to specific design requirements, taking into consideration ways of implementation of designing on the software and hardware level which implies the physics topology of the vehicle network, closely related by the weight, model and costs of the harness.

From here forward I am presenting the functional methods of architecture, such as placement for system requirements on automobiles.

3.5 ARCHITECTURE OPTIMIZATIONS

In this subchapter, I propose adaptations and optimizations of lighting systems, taking into consideration the available electronic architecture on vehicles. The proposed strategies help the cost optimization and functional safety through distributivity, but also the improvement of the electronic efficiency for the lighting system. The architectural solutions are orientated only on the lighting system, not taking into consideration the supply network of the vehicle, but as well the controlling units from them.

3.5.3 Adaptive solutions for mixed architecture

Mixed architecture offers the possibility of reusing a part from the architecture and the consecrated UCE on both networks, maintaining the benefits of both supply networks. The lighting system would be, in this way, segregated. Front lighting, which needs the most electrical power, remains on the 48 V network, and rear lighting on the 12 V – in this way the efficiency will grow at the network level. The system costs could also be controlled, and the effectiveness of the front architecture from financial considerations, could be redistributed towards the rear lighting for optimization. Under these considerations, I propose a mixed architecture model for power supply and control networks, represented in Fig. 3.2.

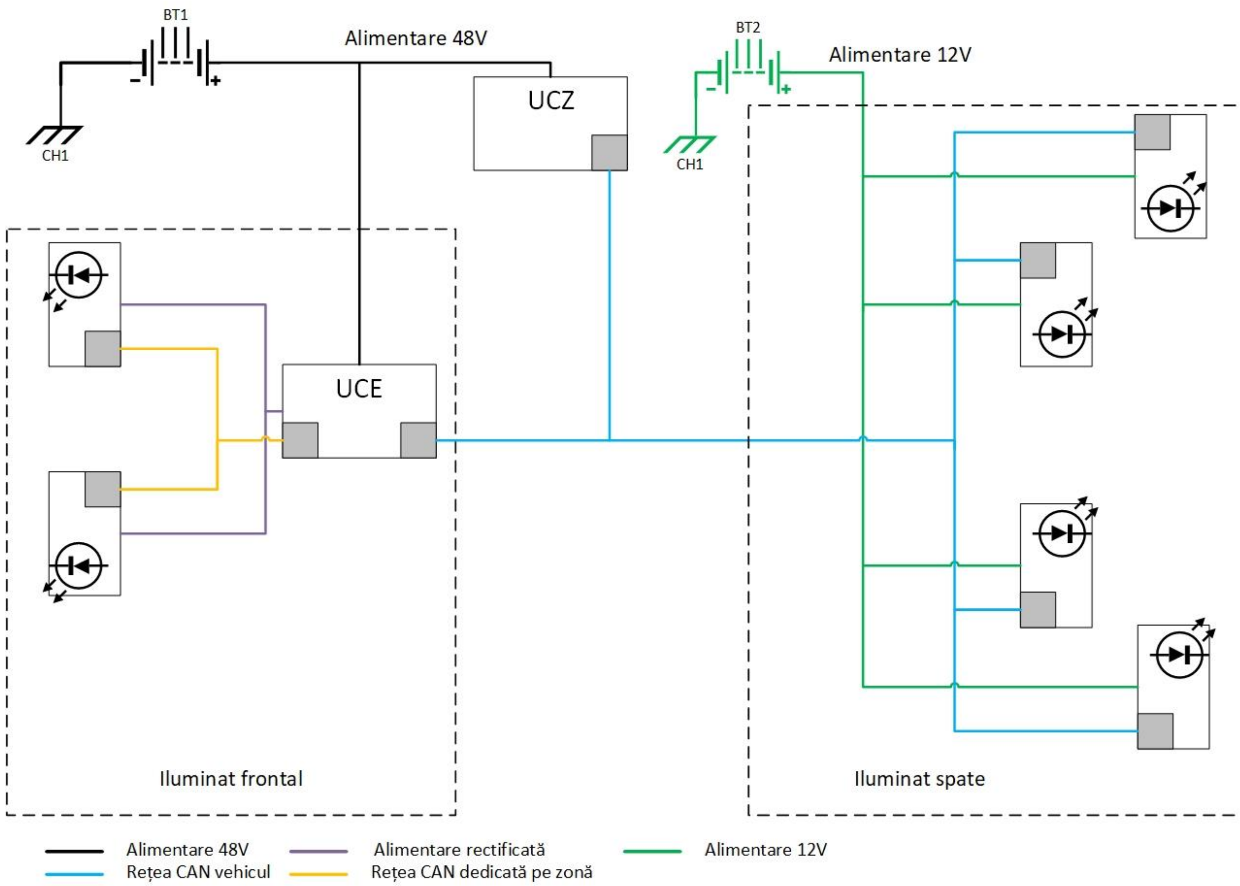


Fig. 3.2. Lighting system on mixed power supply and control

CHAPTER 4.
ARCHITECTURE, FUNCTIONALITY AND DESIGN MANAGEMENT

In this chapter, I bring improvements, optimizations and solutions for lighting systems and treat the architecture problem, lighting system functionality, and the management for the design and development.

4.1 ARCHITECTURE AND PLACEMENT

By setting the requirements and needs, I choose the hardware architecture which will be utilized to maximize the benefits and decrease the disadvantages of the lighting system.

Lighting system requirements:

a) LED lighting loads;
b) Electrical efficiency higher than 70%;
c) Reduced number of wire harnesses;
d) ECE and ISO regulation compatibility – according to subchapter 1.3;
e) Validation requirements compatibility – according to subchapter 1.4;
f) Support for advanced lighting features – according to subchapter 2.1.1;
g) Stability and fault recovery.

In Table 4.1, for each item listed in the lighting system requirements, I addressed each area as a way of power supply and a type of architecture to satisfy them.

Table 4.1. Requirements analysis and lighting system orientation

Requirement	Front lighting	Rear lighting	System
a)	LED and dedicated driver	LED and dedicated driver	LED, dedicated driver and architectural control elements
b)	48 V power supply and buck drivers	12 V power supply and linear drivers	Mixed power supply and DC/DC converter for the 12 V power stability
c)	CAN network	LIN network	Pins and wire reduction on the central unit for control and command
d)	Static, dynamic and fault recovery behaviour	Static, dynamic and fault recovery behaviour	Control, diagnosis and safety requirements
e)	Decrease of illumination fluctuations during transition phenomena	Decrease of illumination fluctuations during transition phenomena	Stable power supply
f)	Dedicated module for matrix lighting	Complex control for animations	Domain-based control for decentralization
g)	Functional prioritization	Functional prioritization	Domain-based control for decentralization

The EE architecture definition for the lighting systems is one of the most complex activities, due to many constraints, as well as its impact on the entire vehicle architecture, from an electronic and mechanical point of view.

For the new lighting system for the automobile, to answer the diverse requirements and for its adaptability to any infrastructure, I propose it to be zonal modular, so that its integration able to be made on any automobile that respects a minimum of preconditions towards benefitting the configuration lightness and satisfying all functionalities. Defining the layers of architecture is necessary for contouring the architecture and concept, in Fig. 4.1, I defined the four layers:

a) Infrastructure layer – necessary elements for the vehicle, out of which:
   i. energy source – battery and protection elements;
   ii. command – control interface between the user and the vehicle;
   iii. vehicle – sensors and acquisition medium for passive and active data;
b) Functional layer:
   i. supply – interface module for supply and adaptability to the load (e.g. DC/DC, linear);
   ii. communication – communication module and medium adaptation (e.g. CAN, LIN, analogue);
c) Abstractisation layer:
   i. front lighting – adaptation medium and functional generation for the front lighting;
   ii. rear lighting – adaptation medium and functional generation for the rear lighting;
d) Physical layer – the constituent elements for generating the light beams.

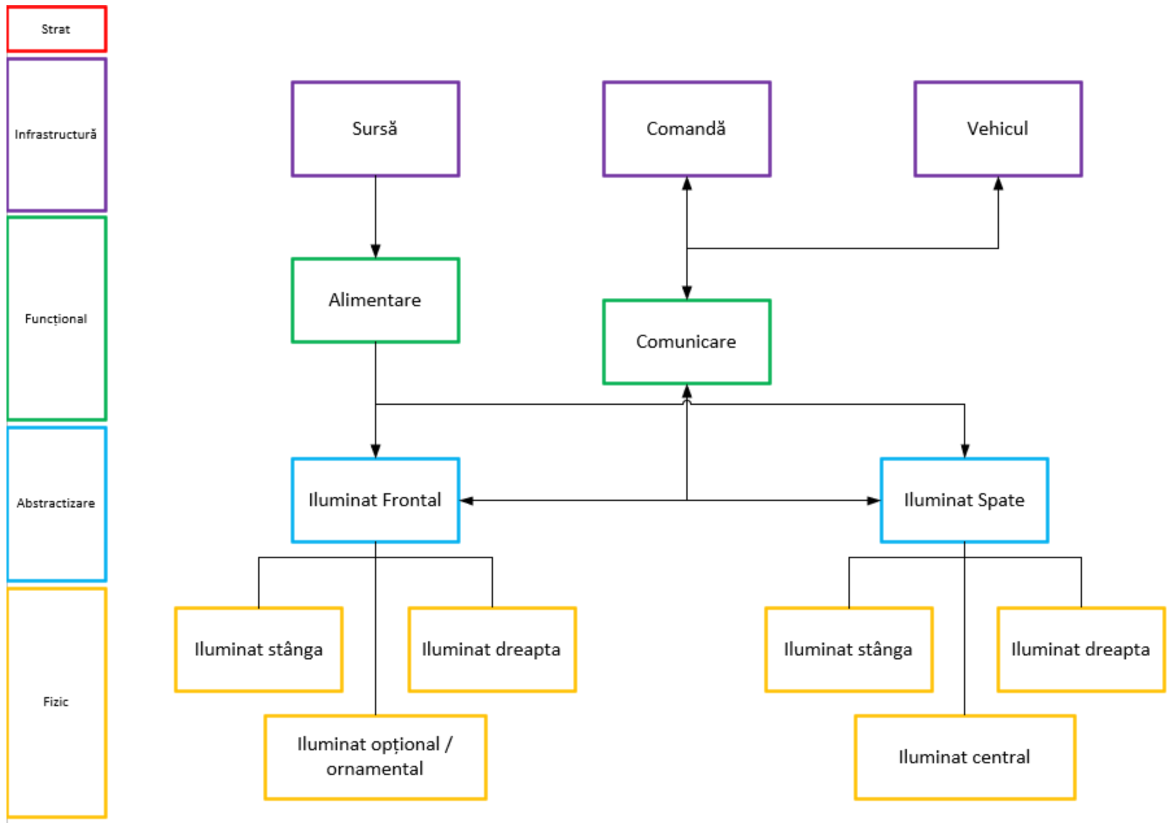


Fig. 4.1. EE architecture layers for the new lighting system

The defining way of architecture orientated on layers allows an overview of necessary preconditions of a stable structure that offers success criteria of the desired strategy. In Fig. 4.2 I illustrated the functional layered diagram for one feature and its decisional constraints.

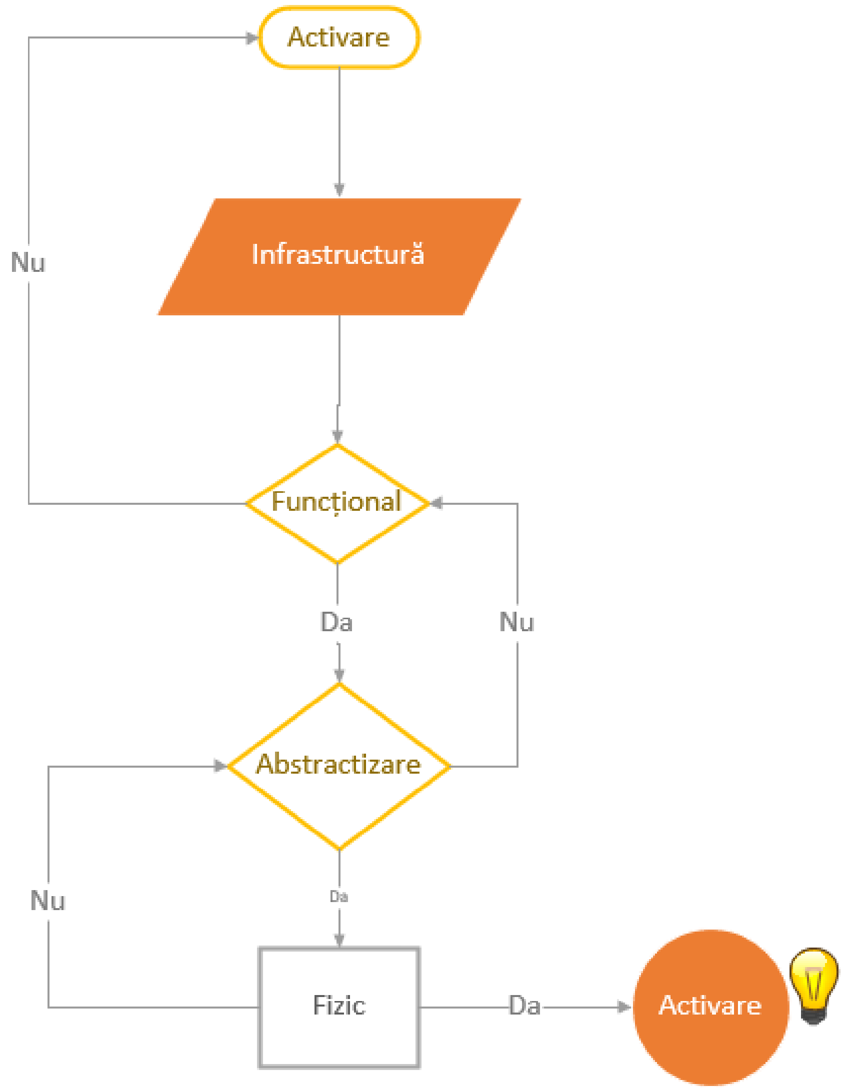


Fig. 4.2. Decisional control diagram for a lighting feature

The novelty of this strategy, compared to those existing in the industry, consists of an abstractisation of functions, that reside in the software code, thus, I conceived this strategy to eliminate the need to integrate a function dedicated to a unit. The functions can with this be modulated and distributed on multiple units or over software clusters.

4.2 MAPPING AND DISTRIBUTED FEATURES

Each lighting feature presents a series of functional requirements and constraints, thus it is distributed, in some cases, for ensuring functionality under some constraints, but also for some performance requirements.

Lighting functions are of two categories: automated and manual; the automated ones need a set of preconditions and data from diverse sensors, and the manual ones depend on the explicit task of the driver to be active. In the next subchapters on the system level, I present the control modes and mapping strategy of functions for lighting systems, for the two modes. These functions belong to the architectural strategy proposed as a new concept.

4.3 THE MANAGEMENT DESIGN MODEL

The lighting system for the vehicle requires a management model for the design, development and launching. Thus, the quality assurance and system viability are satisfied. This management model is created on levels, from system level to component level, segregated by discipline level. For the good execution of project management, it will be organized according to the diagram from Fig. 4.3.

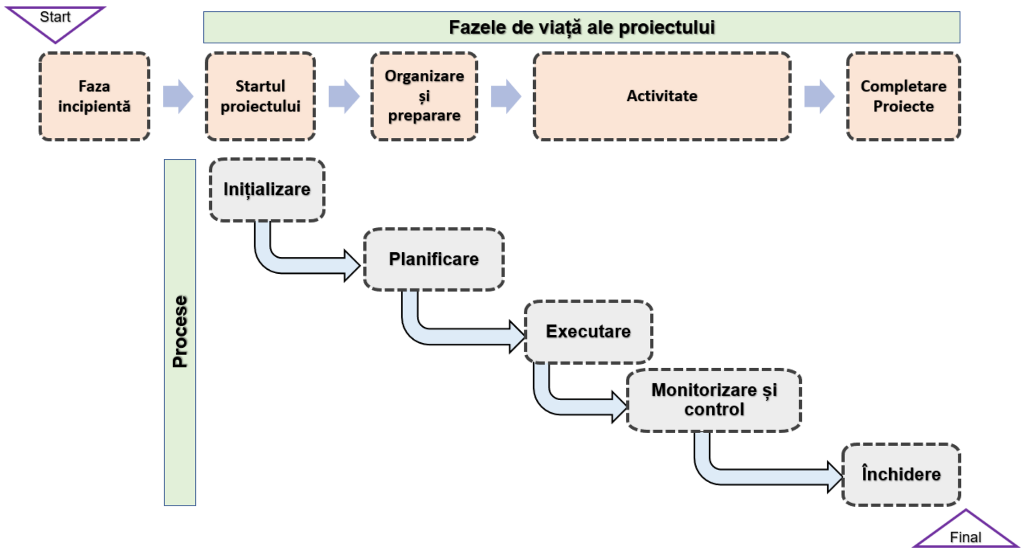


Fig. 4.3. Management model for the development[90]

Out of system engineering considerations, the development model, under the “V” topology, is represented in Fig. 4.4, in this case for the lighting system I cover all needed elements for good project execution.

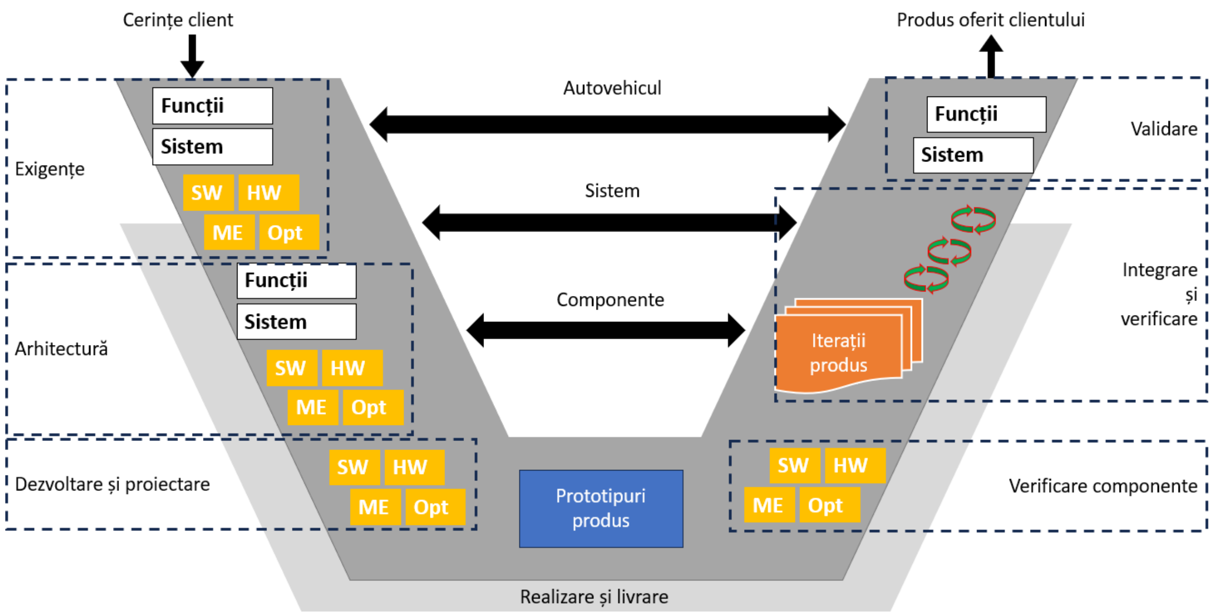


Fig. 4.4. Lighting system development cycle

In Fig. 4.4, with the following abbreviations:

a) SW; software – all activities of development associated with software domain, diagnosis, communication, abstracting hardware, modelling and micro-controller or micro-processor architecture;
b) HW; hardware – all activities of development associated with electrical and electronics, inter-system connections, PCB design, power and signal architecture, thermal management and EMI;
c) ME; mechanical – all activities of development associated with mechanic and industrialization, CAD, matrix injections, volume and isometrics;
d) Opt; optics – all activities of development associated with optics equipment requirements, lighting flux, optical angles, chromaticity, ECE requirements conformance and the optics regulations.

At this moment a model dedicated to lighting equipment design management does not exist, a norm for good coordination between the vehicle manufacturers and the suppliers of lighting equipment.

During the research of the specialized literature and from personal experience, the architectures utilized for lighting systems are in some cases complex, in other cases simple, but a management interface standardized for assuring good coordination does not exist. In practice, the usual methodology for assuring the design is the APQP standard, which is not adapted for lighting equipment and systems, especially distributed ones.[12]

The lighting system proposed by me is in a distributed architecture, the requirements and the architecture are analyzed on a macro system level, so, it is a developed system based on the requirements or software needs and it is based on expert AGILE, the quality assurance on ASPICE, assuring at the same time an interface with APQP. In Fig. 4.5, I propose the iterative delivery and development model for the equipment delivery and the lighting systems, which are software-defined.

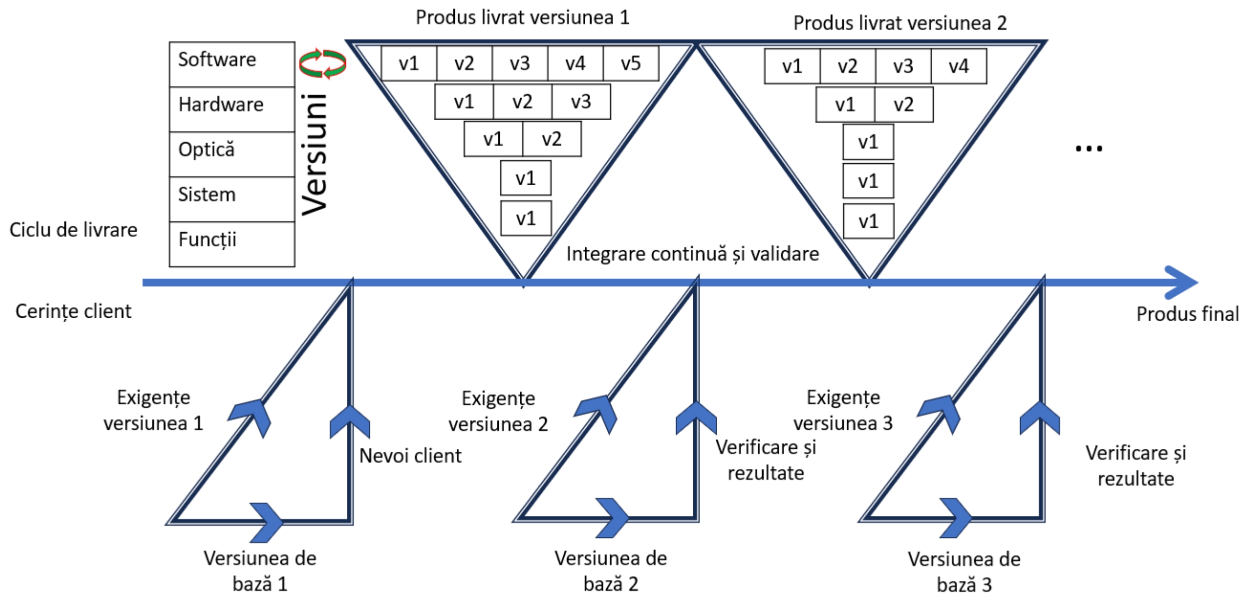


Fig. 4.5. Software iterative delivery model at the component level

In the delivery and development model, I named with client, the entity which will utilize the system or the developed component. In the case of system utilization, the client is the vehicle, and in the case of the component, it is the system.

Development management is a critical one, in a distributed architecture, thus, each module can accept or deny a functionality, based on its constraints or accessibility. In some cases, the constraints or safety requirements can impose that one functionality to be retained by a specific equipment.

The functions and system represent the first principle level in which it decides the implementation of some strategy in a vehicle, as well as the feasibility of those, based on the marketing needs or business. The decomposition of functionalities on the vehicle level impacts the system, and the system imposes the acceptance or denial of those responsibilities. For illustration of the decomposition, I present the example of its conduct in Fig. 4.6, for two features, signalling and the stop.

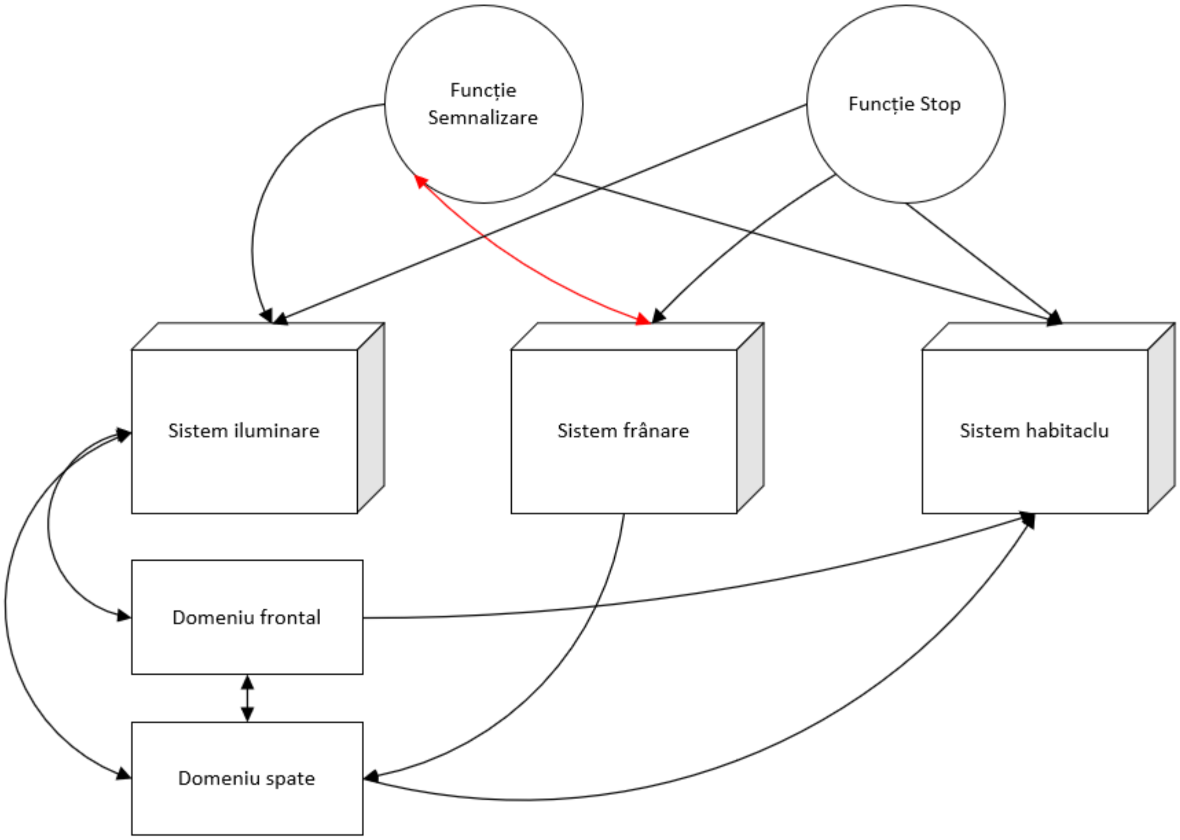


Fig. 4.6. Functional decomposition over the domain

In this mode, from Fig. 4.6, the signalling feature is denied by the braking system because of the lack of a functional scope, the lighting system has the role of satisfying this functionality, and the cockpit system consumes the driver request and offers the status for the lights.

Another critical aspect for the design and development is the validation, this offers visibility over the conformity behaviour needed, in Fig. 4.4, I represented the cyclicity for it. The lighting system, with a distributed architecture and software oriented, needs to be iteratively tested for each version, to be able to uncover the functionality errors in an agile manner and to react timely for their counter.

Conclusions:

The management model for the design and development of the lighting system is new, generated from the hybridization of AGILE models and VDI-2206 system engineering.

The management model proposed by me offers an interface with the consecrated APQP, but it also assures the novelty of absorbing in-practice methodologies of software development.

The lighting system is developed iteratively so it reduces the reaction loop for maintenance and reaction for the encountered problem resolution.

CHAPTER 5.
THE ANALYSIS AND OPTIMISATION OF THE LIGHTING SYSTEM WITH THE SUPPORT OF MATLAB-SIMULINK PROGRAM

In this chapter, I highlight and detail the principle methods to control and command lighting sources from the optimised architecture proposed in the previous chapters by system modelling and present solutions of command and control for the lighting lamps. Will do optimisations at the equipment level for the improvement of the lighting system efficiency.

5.1 THE MODELLING OF EXISTING SOLUTIONS FOR THE LIGHTING LAMPS WITH THE SUPPORT OF MATLAB PROGRAM

The optimisation solutions for the lighting system from a power efficiency perspective require LED loads, and these impose the use of drivers to stabilise the voltage and current through the LED, additionally to dim the lighting flux or to protect the loads by reducing the driving current. In this chapter I design and simulate with the support of the Matlab-Simulink program, the behaviour of the lighting equipment, with the system abstractisation.

The conversion levels are simulated for different scenarios, like stable voltage, and variable as well as in the presence of defects.

The scope of simulations is to create a representative model and stable with the studied solution in *chapter 1* and *chapter 2*, in this way, I establish a generic functional concept in *subchapter 5.1*, and bring improvements to it in *subchapter 5.2*.

5.1.1 Modelling with a fixed supply voltage of 12V

5.1.1.1 Front area lamps

The lamps from the front area represent one of the most complex lighting systems and controls, these use power LEDs, and the system efficiency represents an extremely important factor. In continuation I present in this chapter the Matlab model at a constant supply voltage of 12V, I impose the LED utilization and a control topology of type boost-buck (Fig. 5.1). For the simulation I impose the data from Table 5.1, necessary functions according to the homologation requirements, for the front illumination of the vehicle with a supply voltage of 12V, the cascaded efficiency of the boost-buck driver is followed, thermal losses due to comutation phenomena and the losses due to EMC filters are not simulated.

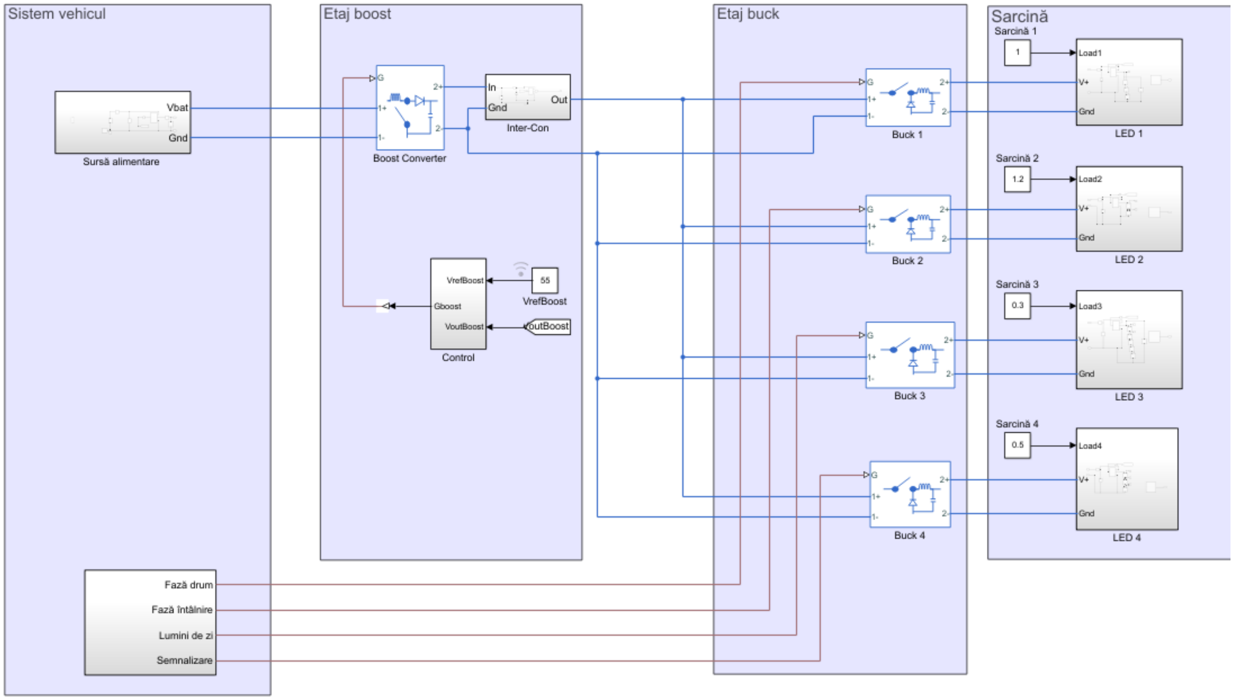


Fig. 5.1. Matlab model for the front system illumination

Table 5.1. Data considered for the Matlab model in Fig. 5.1

Feature	Sources	Number of LEDs	Current [A]	Voltage [V]	Power [W]	Total Power [W]
High Beam	Load 1	3	1	16	48	102,3
Low Beam	Load 2	2	1,2	12,5	30	
Tail lights	Load 3	5	0,3	9,6	14,4	
Signalisation	Load 4	3	0,5	6,6	9,9	

In practice, the lighting loads may have lowered values to reduce the total consumed electrical power, but helped by reflective optical elements to attain the requirements needed for the homologation. Also, all features had been activated and kept like that, the evaluation time being lower, this case is the most drastic one. The highlighted model has the scope of illustrating the lighting system topology for the exterior front lighting, used in most cases on vehicles designed for global access, for the feature activations in the given model using analogue commands, at a conceptual level same manner can be applied with digital commends using LIN or CAN, from the driver.

The block diagram for the Matlab Simulink model from Fig. 5.1, has four constituent levels. The first level is the vehicle system, which emulates the voltage source of 12V and the commands for the lighting feature activation. The control unit contains logic signal generators to command the activation or deactivation of the lighting features, it is emulating the digital or analogue buttons actuated by the vehicle driver when he’s requiring a feature to be active.

The second level, is the boost level, with the scope of pooling the output voltage based on a prescribed value and keeping it constant, regardless of the input voltage. In Fig. 5.2, the graph for the voltage input and output of the boost with the time; pot the Matlabb model design, this is prescribed at an output voltage of 55V.

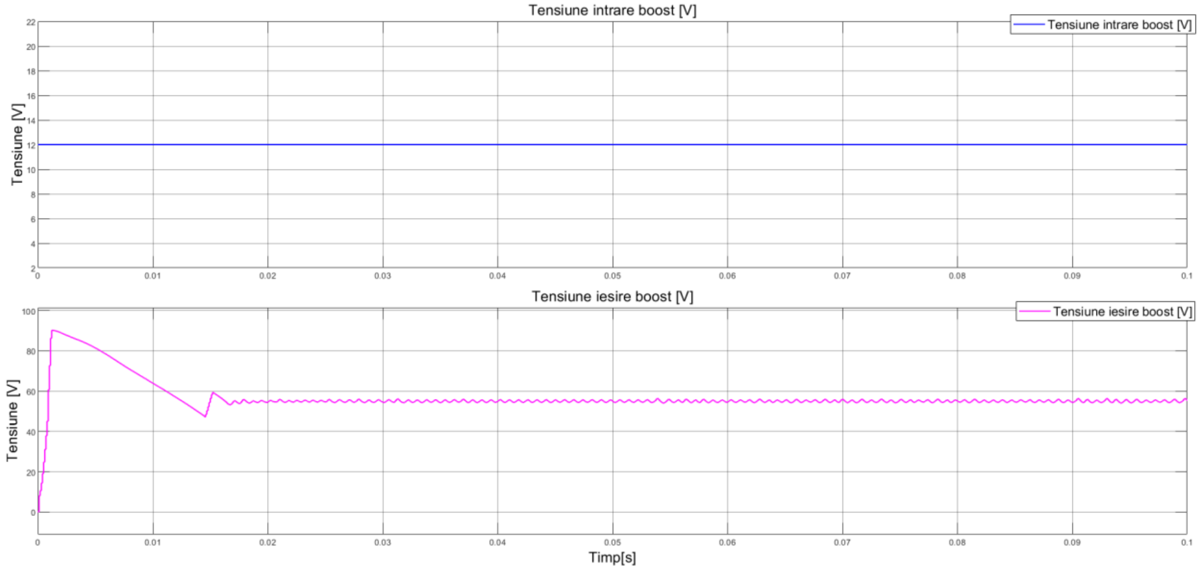


Fig. 5.2. Boost level characteristics for the Matlab model of the generic front light system

I have observed in Fig. 5.2, a transitory effect for the boost output voltage, this is due to the filter charging, but as well as the adaptation and the stabilization of the control loop, the transitory effect between 0 and 0.015s. For the boost level and the converter control, I created a control loop to modify the duty cycle, which is controlling it, to keep the same output value based on the supply voltage input. The duty cycle which controls the boost, increases when the supply voltage is below the design reference or decreases when it is above it. In Fig. 5.3 the voltage loop control for the boost from the generic Matlab model:

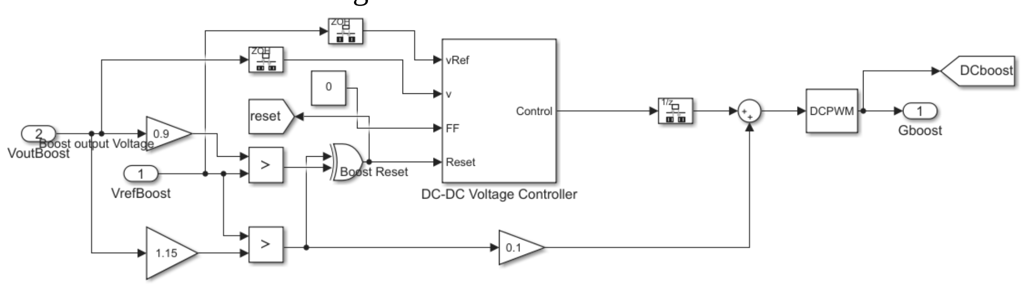


Fig. 5.3. Boost voltage loop control from the generic Matlab model

The third level is the buck level, which contains four bucks with the sole purpose for each load/function, to reduce the preset boost voltage and deliver a preset constant current in the loads. The bucks have a dedicated loop control for each load. In Fig. 5.4 I highlight the current loop control for the buck, the LEDs being current-controlled elements, in this way, the load current stabilisation is achieved.

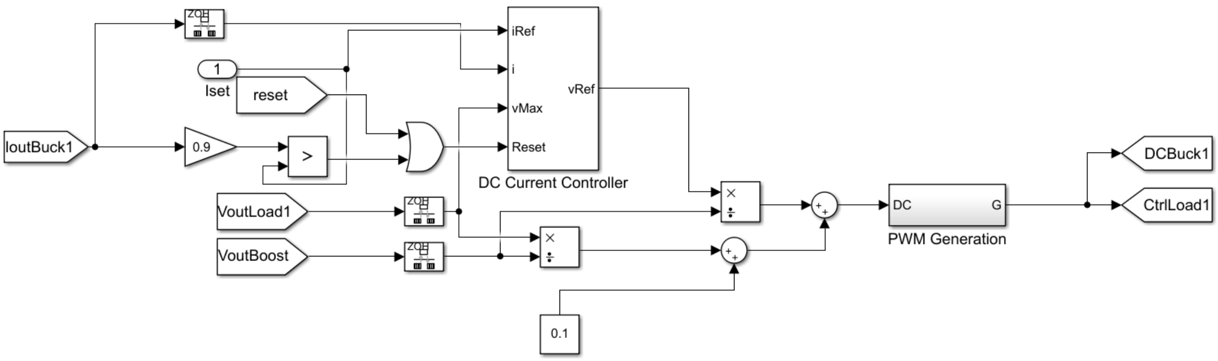


Fig. 5.4. Current loop control for the buck from the generic Matlab model

The last level, four, contains LED groups of three LEDs, with the functional scope of generating light. In Fig. 5.5 I highlight the characteristics for each load controlled by the buck based on the set values from Table 5.1.

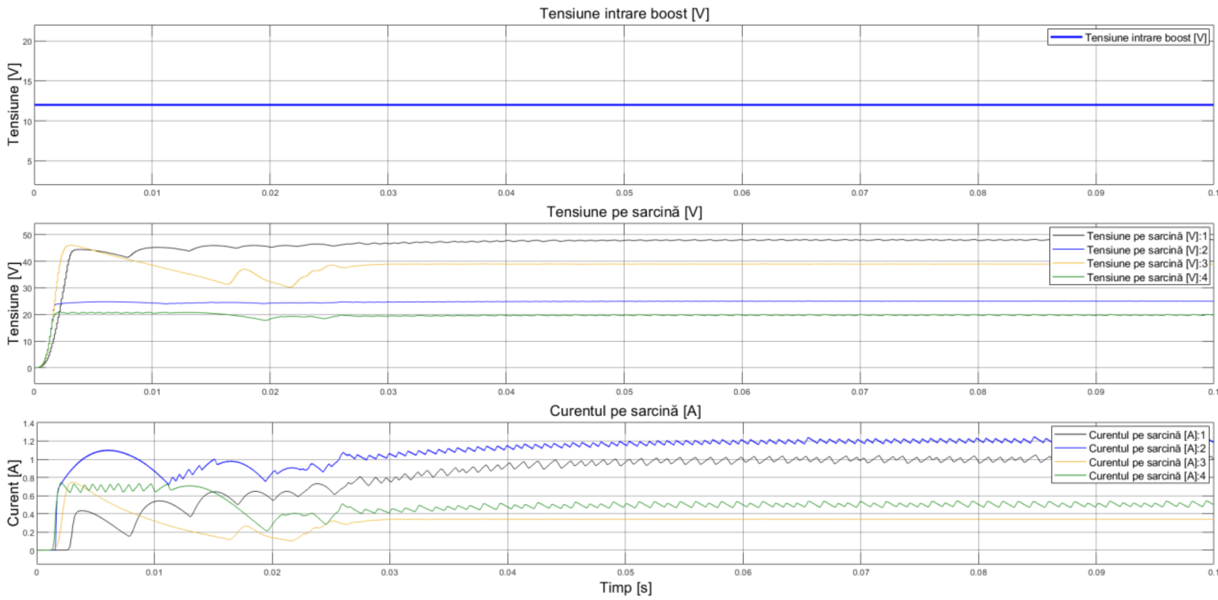


Fig. 5.5. Load characteristics for the Matlab model of a generic front light system

In the loads exists a noise which is within the acceptable limits of the LEDs, ±10% of the nominal driven current and the luminous flux varies with the LED current, but in reality, it is susceptible weak due the the working frequency of the buck which is in the range of kilohertz. Even if in this model the working frequency is 200 kHz, in the real-world application it varies between 100 kHz and 1 MHz. The human eye perceives fluctuations only under 200Hz. In Fig. 5.6 I highlight the load one characteristic for the period 0,05 - 0,08s after stabilization is achieved, to exemplify this noise.

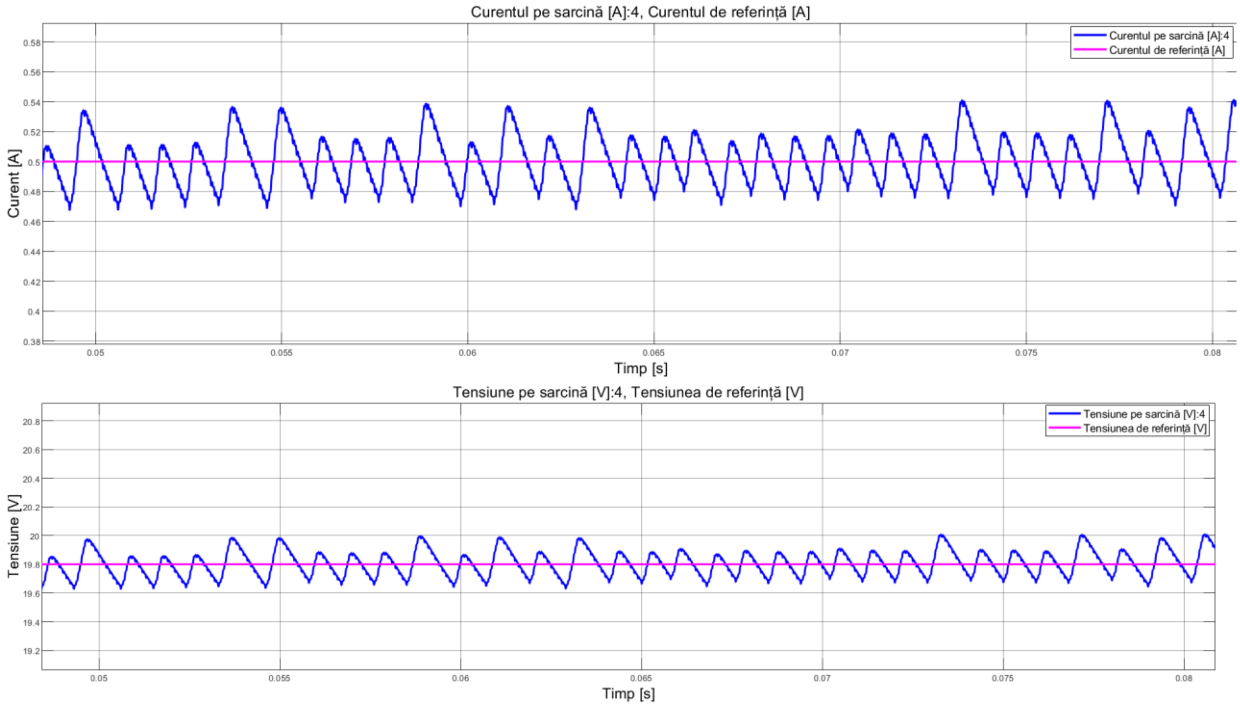


Fig. 5.6. Load one characteristic for the period 0,05 - 0,08s

Considering the Matlab generic model for the front lighting, I extracted the electrical efficiency for the system and highlighted it in the graph from Fig. 5.7, for the measured average of the values, I used an RMS block (*root mean square*). I run the model for a period of 0.2s, and after its stabilisation, I represent the efficiency interval, for the constant supply voltage of 12V.

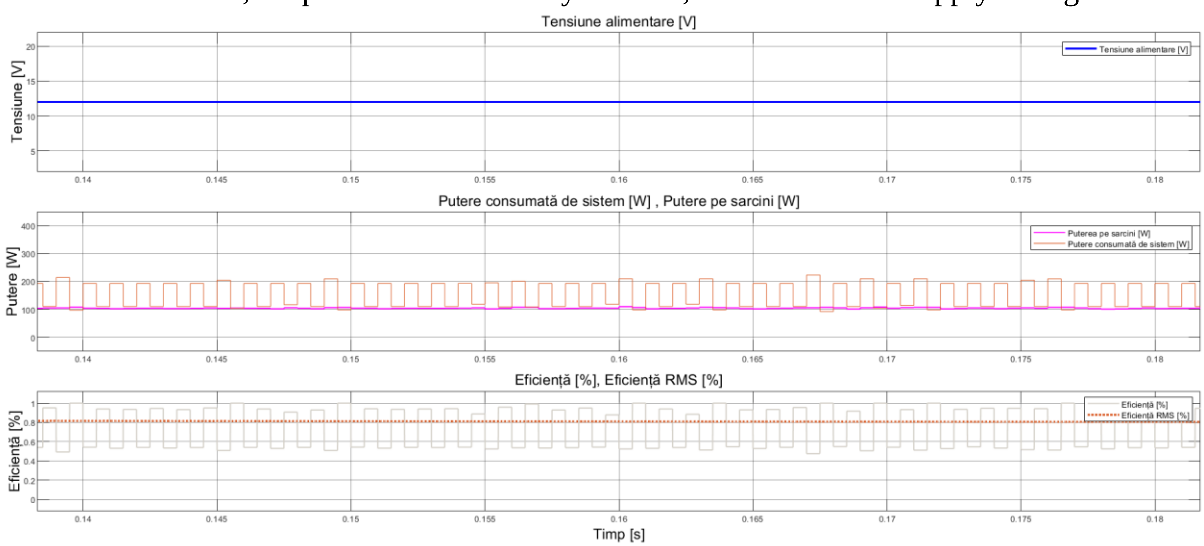


Fig. 5.7. Efficiency of the Matlab generic model with boost-buck for the front lamps

The efficiency in the tested interval has an average of 80%, between the input power and the load used to power, the boost linked with the four bucks is generating a loss of approximately 20%, due to the active and passive elements.

5.1.1.2 Observations for the front lighting

- Load modelling is an extremely sensible factor, and their simulation is difficult. For a representative behaviour, the dynamic resistance (*Rd*) for each load was calculated with the formula:

$$R_d = \frac{Vf_{max} - Vf_{min}}{If_{max}} \tag{5.1}$$

Not complying with the dynamic resistance values based on the diode voltage activation (*Vf – forward voltage*) and the current activation for them (*If – forward current*), will generate high instability and a weak concept. In the simulations, these considerations were treated and their behaviour is realistic.

- The observed noise in the loads is within the prescribed limits of +/- 10% from the set value, highlighted in Fig. 5.6.
- The control loop I created for the buck and boost to be as flexible as possible to sustain as well as other loads of different electrical characteristics. To ensure the set value, I created reset logic, to reinitialise the control loop if it deviates. These things were encountered frequently during the design phase in Simulink.
- The system efficiency between the input power and the output power used in the loads (LEDs), is approximately 80%, a relevant value, encountered in practice as well. The lighting equipment manufacturers are trying to increase the efficiency to a minimum of 80%.
- For the created model with the support of the program Matlab-Simulink, I have created a functional prototype to verify the functionality, the assembly image, is represented in Fig. 5.8. The functional results are confirmed, and the control and command topology is realized using a boost module *LT3782A*[91], buck modules *STEVAL-ILL089V1*[92] and LED loads LED[93] similar to the ones used in the numerical simulation.

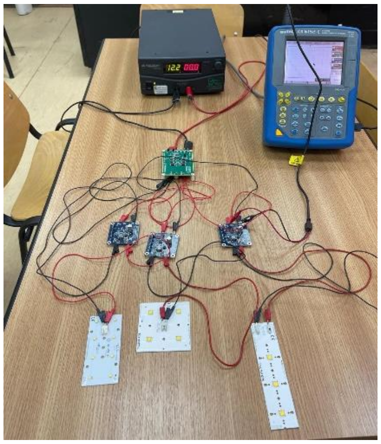


Fig. 5.8. Front lighting – practical realisation for the boost-buck cascaded topology

5.2 OPTIMIZATION FOR THE LIGHTING SYSTEM WITH THE HELP OF MATLAB PROGRAM

In the previous chapters, I have studied and analyzed with the help of specialized literature and with my own experience the current methods of control for the topologies and tipologies existing on the market for the LED load control. I have noticed the benefit of adopting the supply voltage of 48V for the improvement of the wire harness and the efficiency of the control units.

The Matlab model proposed to improve the topology of control for the lighting installation has of scope of two directions. In the first place the efficacity of the control and command for the high consumers, the low beam and the high beam, by analyzing the control methods. In the second spectrum, the control topology for the lighting sources with low power requirements.

The lighting system development will be oriented on the power grid of 14V and de 48V, in this way, will cover the electrical system needs for the market.

The architecture and requirements at the system level will be:

a) The communication between the modules at the system level will be considered with CAN;
b) The module diagnosis will be done over CAN, but as well as an additional wired mode;
c) All lighting sources will be with LEDs.

The lighting system from an architectural point of view was presented in *chapters 3* and *4*, the current chapter has the scope for improvement at the component level for the lighting elements, the drivers and the control strategy for the LEDs.

5.2.2 The optimization of control architecture

For the vehicle architecture with a power network of 12V or 14V, the control methods for the conversion levels can be diverse, depending on the lamp requirements. For the 48V network or a mixt one, where both 48V and 14V are available, the solutions to achieve a high efficiency are possible.

In Matlab-Simulink, I investigated diverse control strategies, the following topology from Fig. 5.9, with a mixed architecture was found to be with the highest applicability and efficiency.

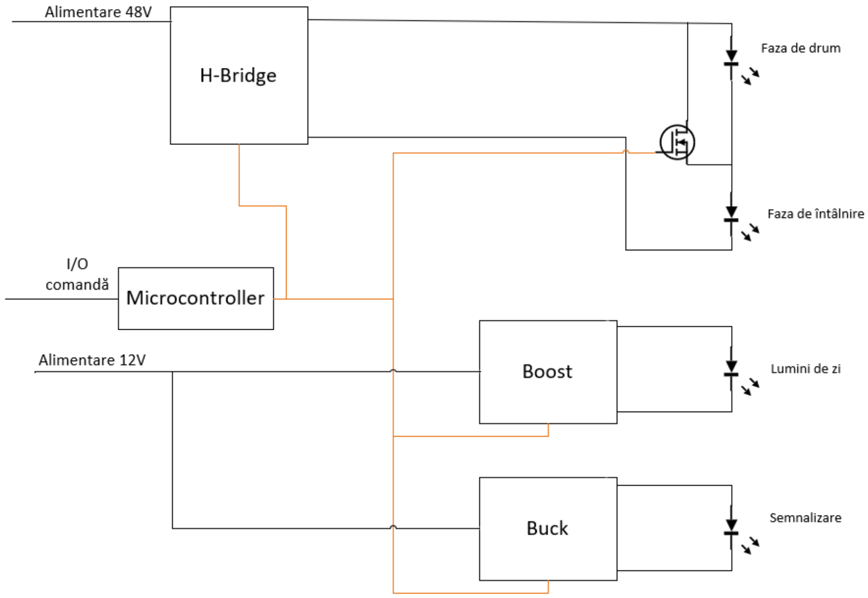


Fig. 5.9. The topology of the lighting concept with a mixed power grid

For the referencing and the applicability of this architectural concept, I considered the following data for the lighting loads:

a) The load for the low beam is to be of maximum 30W, with a voltage threshold for the LED activation of a maximum 24V;
b) The load for the high beam is to be of maximum 20W, with a voltage threshold for the LED activation of a maximum 16V;
c) The load for the tail lights is to be of maximum 12W, with a voltage threshold for the LED activation of a maximum 24V;
d) The load for the signalling lights is to be of a maximum of 9W, with a voltage threshold for the LED activation of a maximum of 9V.

For the lighting loads from a) and b), the driver in the H bridge, is used to increase or decrease the voltage across the entire LED string, in this case acting as a boost or buck, depending on the load total need. The total output voltage on the H bridge, being smaller than the input voltage, would work in boost mode only during the 48V power grid fluctuations.

The signalling from practical considerations, does not require a high power, usually controlled by a linear driver, under these considerations several LEDs can be disposed in series, to achieve a maximum of 9V to satisfy its requirements.

5.2.2.2 The optimization of the control topology for the front lighting system

The analysis and adjustment for the first module, for the power supply of 48V, was done, in the next part, I am doing its integration, along with the 12V power supply which will serve for the lighting features of tail lights and signalisation.

For the front lighting system, with all the illumination features included, I present the concept system in Fig. 5.10.

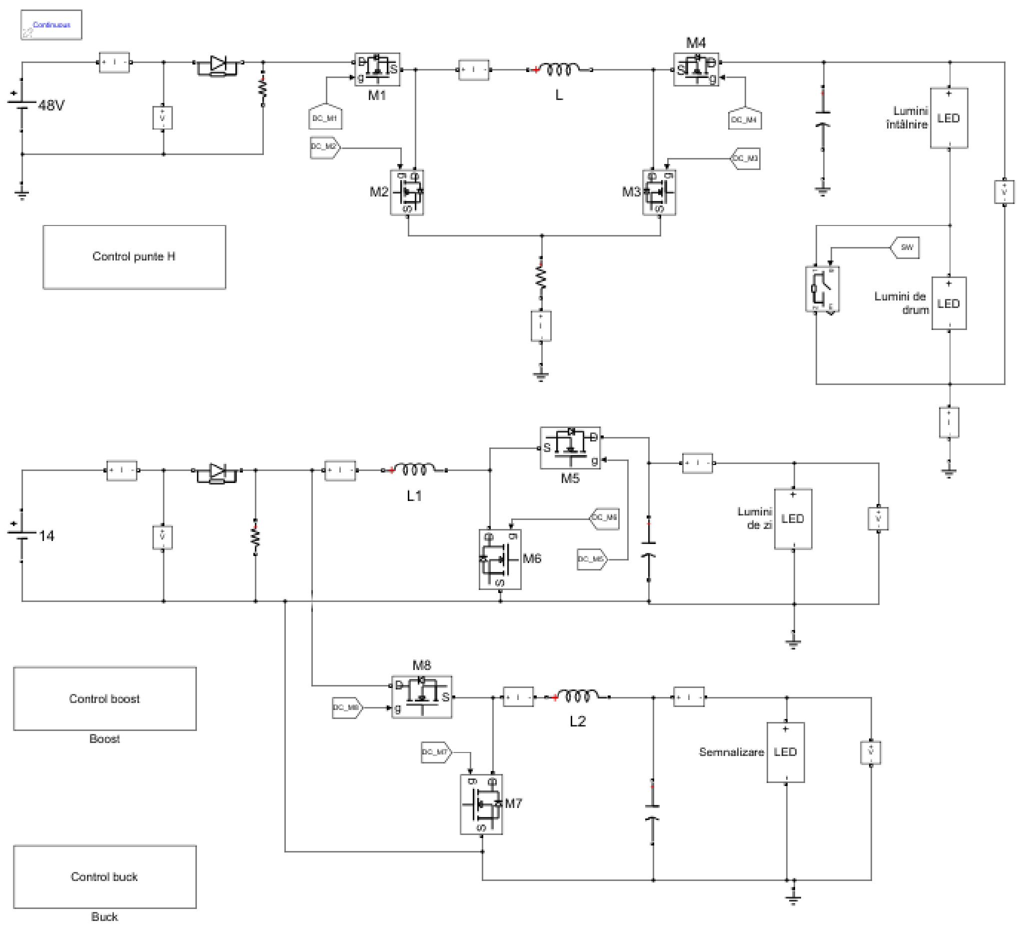


Fig. 5.10. The model for the front lighting system with all the features present

For the system in Fig. 5.10, I use an H bridge for the low beam and the high beam, which is supplied from a power supply of 48V. And for the tail lights(daytime running lights) I propose a boost and for the signalisation lights a buck, both being supplied from a power supply of 14V. I highlight the load electrical characteristics, in Fig. 5.11, and in Fig. 5.12, the efficiency of the entire system.

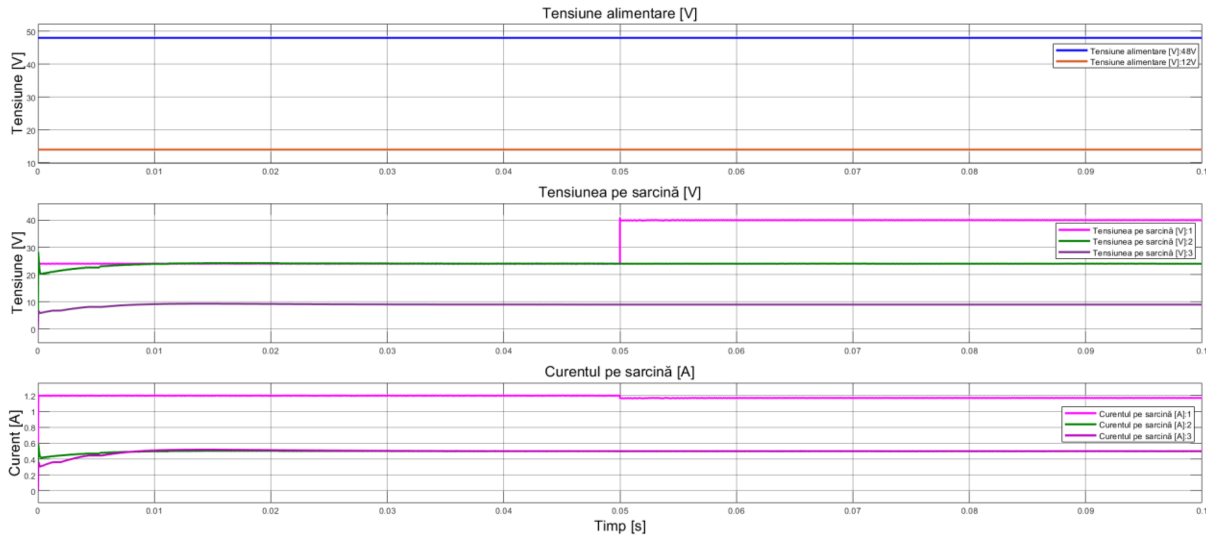


Fig. 5.11. The load electrical characteristics, for the entire front lighting system

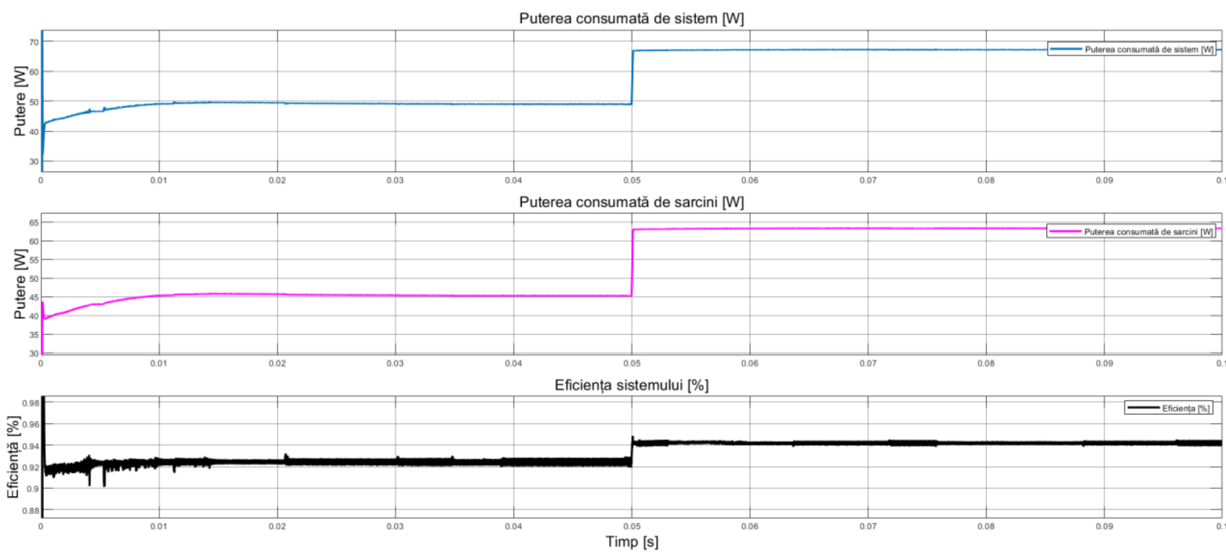


Fig. 5.12. The efficiency of the front lighting systems with all features active

I found that the entire system efficiency, is approximately 15% higher, in the case of the control topology proposed in the doctoral thesis compared with the referenced topology.

In continuation, the new system proposed in the doctoral thesis, offers a high adaptability, with the use of the H bridge, in this case, based on the used architecture this strategy comes with an interface to pull or decrease the voltage supply for the driven loads.

5.1.1.3 The optimisation of the control topology for the rear lighting

At the system level, another issue is the detection and sharing of the status of the lighting loads, also called diagnostic ability. For the front lamps, in the advanced systems, there is a communication network, and these errors can be transmitted with ease. For the rear lighting, in many architectures, this network is not available, and the errors are detected, at the system level indirectly, with the measurement of the consumed current by the lamp. The consumed current being very small, with LED load, is extremely difficult to use [11]. In the industry, to increase the nominal current, a ballast to increase this current or expensive components which are capable of detecting these issues are used. In the case of using a ballast, a good porting of the energy is dissipated, rendering the system at an efficiency lower than 50%. In the present doctoral thesis, inspired by the PWM control logic, detailed in *subchapter 5.1.1.3*, I propose a codification on the control line of the lighting loads, In this way, the lamp receives from the system the PWM command to satisfy different features but as well to return the status of the lighting features. In Fig. 5.13, the schematic at the system level for the diagnostic ability of the LED loads is highlighted.

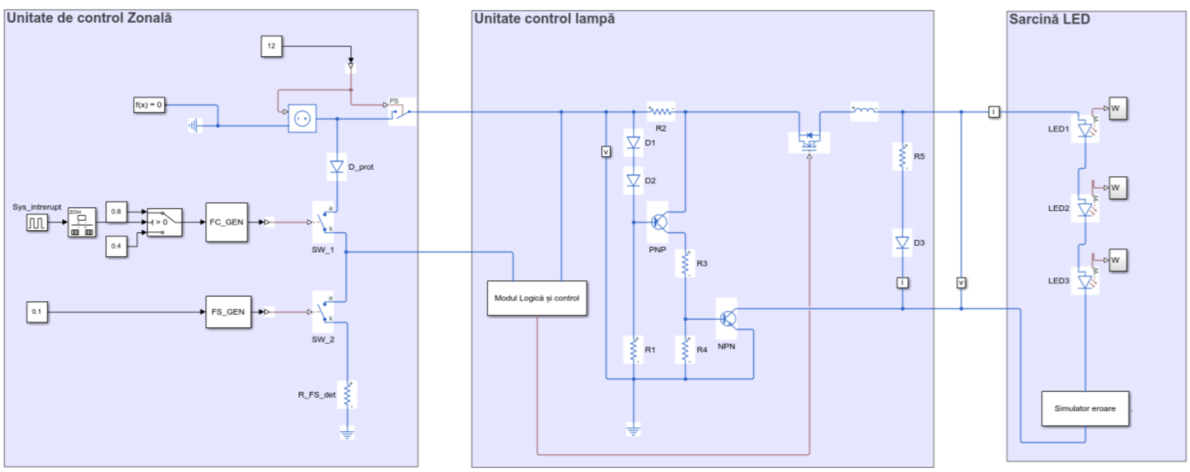


Fig. 5.13. The concept for the LED load diagnostic ability at the system level

The concept has the role of using only two wires, one dedicated to the power supply and the second for control and diagnosis. The second connector, using PWM, has the scope of activating or deactivating the feature, to allow, the luminous flux to change with the change of the duty cycle and as well to allow the information exchange for the lamp status. For good functionality, the functional specifications or the requirements for the PWM signal are necessary, for this case in Table 5.2, I specify them. In Table 5.2, I have marked with *±x%,* the error which could appear, but needs to be maintained under 2% of the nominal value, ideally would be 0.

Table 5.2. The system functionality with the rule mapping for the control and diagnostic ability [11]

Duty Cycle	Feature 1	Feature 2	Feature status
0%	Undefined	Undefined	Shortcircuit
100%	Undefined	Undefined	Open circuit
20% ±x%	Error	Active	20% ±x%
40% ±x%	OK	Error	40% ±x%
60% ±x%	Error	Error	60% ±x%
80% ±x%	Active	Active	80% ±x%

The system and the diagnosis feature are created in this case, and in Fig. 5.14, I highlight its characteristics.

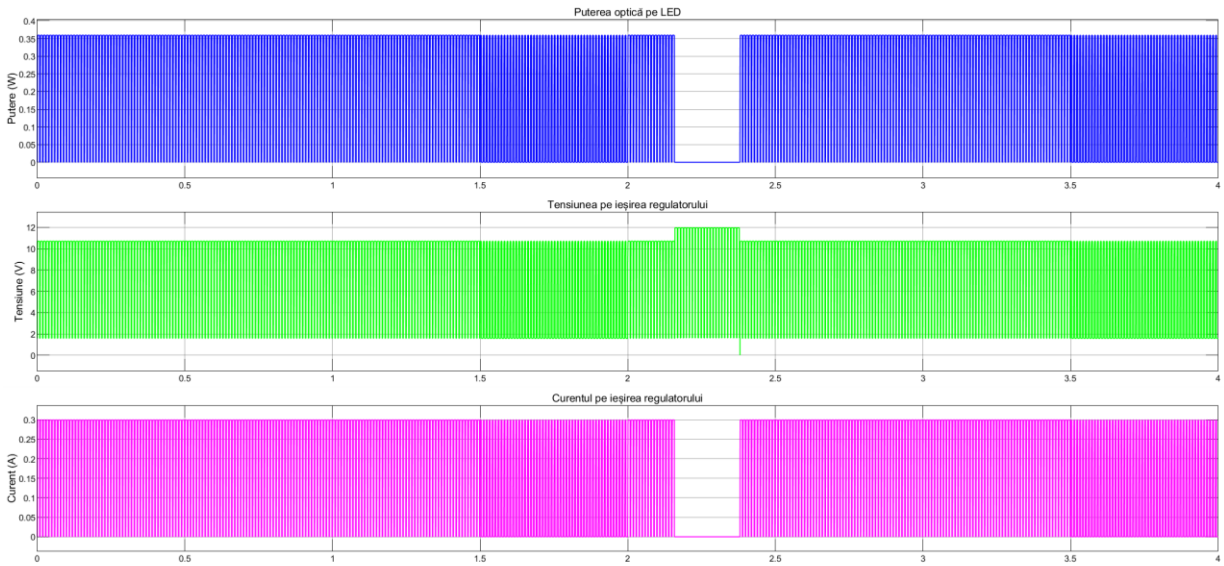


Fig. 5.14. Electrical characteristics for the lighting system of the diagnostic ability module [11]

For a better quality of the diagnostic ability of the module and the functionality of the control concept, in Fig. 5.15, I extract a capture for the passing between the functional and the error.

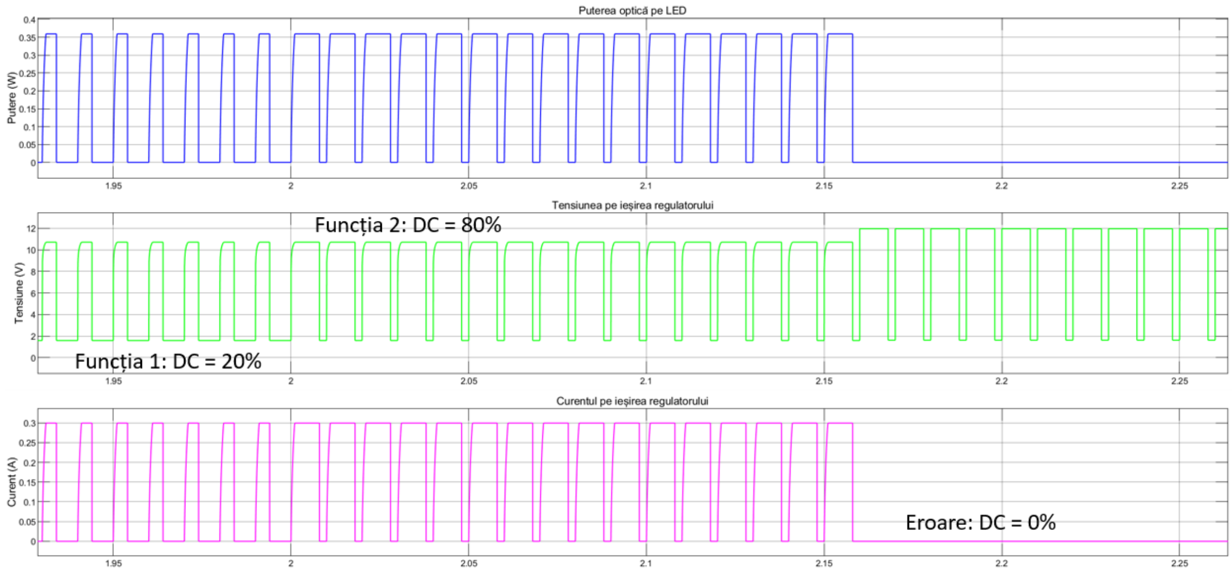


Fig. 5.15. Electrical characteristics for the control and diagnostic ability, focus on the passing between the states [11]

In Fig. 5.15 I highlight the optical power, proportionally with the LED driving current, and at a high frequency of 300Hz, the human eye can not perceive the activation and deactivation of the LED, but only a decrease in intensity.

For the error, in the quadrant *Tensiunea pe ieșirea regulatorului*, is a higher voltage at the error presence, due to the lack of the load, generated as well by the control schematic which detects the LED error.

Observations:

The diagnostic ability module brings an innovation element, and its simulated behaviour with the support of the Matlab program demonstrates good functionality,

This strategy imposes a functional mapping which requires a control logic divided at an architectural level, between the LED control unit and the area control unit.

From the study of the speciality literature, a similar method, to compare the behaviour was not identified.

CONCLUSIONS AND PERSONAL CONTRIBUTIONS

C 1. CONCLUSIONS

The present thesis addresses a subject associated with the domain of vehicle system control, the control architecture and the specificity of the lighting equipment, characterised by the use of static convertors for the increase of power efficiency. These systems need advanced methods of analysis and control, to satisfy the constraints and the regulations.

In the paper, I highlighted the complexity of these systems the needed studies and the different simulation structures and topologies, for the current as well for the future ones, to improve the system efficiency. These topology methods need structures and adaptations in the function of the available technology for the vehicle, like the electrical and electronic platform architecture.

I realized in *chapter 3* an analysis of the architecture models and I identified improvement solutions. The improvement solutions are residing in the system and architecture optimisation for the interaction of the constituent components of the lighting system. I introduced area control units, for a better decentralisation of the system and the improvement of its adaptability.

Going forward, in *chapter 4*, I created the lighting system interaction, as well as the functional diagrams under which they are functioning. The interaction at the system level is created for all the lighting functions, required by the legislation, I covered the normal behaviour and the error cases on the loads. The models and the feature interaction at the system level are at the basis of the proposed functional architecture, to ensure functional integrity conformity, ECE regulation compliance, as well as increased adaptability, being easier to integrate advanced control systems of ADAS type, use case identified from the speciality literature in *chapter 2*.

The management and the development structure for the system were proposed as well in *chapters 4*, being a result of the speciality literature research from *chapter 1*. The structure of the development, when we have a customer and a supplier, for the lighting equipment, brings sensible inter-disciplinary constraints, so the model is oriented to increase agility and the segregation of dependencies between the hardware and the software.

The optimisation of the control topologies for the front and rear lighting was analyzed in *chapter 5*. I created a reference model, based on the literature and the available research, so I identified optimisations which are brought for the lighting system. The reference model is created with the addition of cascaded conversion levels for the load control, these levels of conversion were type boost and buck for the front lighting, and for the rear lighting, the linear conversion is used. I analyzed the diverse behaviours of the system to observe its behaviour for different power supplies, from which I extracted the issues and the optimisations for the system. For the identified optimizations I analyzed the static and dynamic behaviours. This method helped with the problem referencing which is encountered, for the equipment that uses buck-boost but as well for the linear ones. This analysis brought a solution to cancel the buck for the high beam and the use of a by-pass for the lighting function, to gain 8% in efficiency and to reduce the number of components for the system, described at large in the *subchapter 5.2.1*. The realisation for this new method, with the minimisation of the bucks, drives the cost reduction of the system by almost 10% from the estimations, a high benefit, but brought a disadvantage for the constraints of independent activation of the high beam and the low beam.

The use of the development models can establish the electrical efficiency increase, for the vehicles with internal combustion engines and as well for the electrical vehicles or the hybrid ones. The efficiency of the lighting system reduces the CO2 level, the weight of the vehicle and good stability at the system level. In *subchapter 5.2*, I proposed a new model of control and command for the front lighting system, by using two power supply networks, for electrical efficiency maximisation. The new model resides in the use of an H bridge for the low beam and the high beam by reuse of the previous optimisations identified in the thesis, and the mounting of the on the 48V network. The second power network supply of 14V supplies the tail and signalling lights, in this way, the entire system, reaches an electrical efficiency of 15% higher than the conventional system.

For the rear lighting, I identified a method for diagnosis optimization of these lights, a solution which is applicable for each lighting source, and the model is presented for the units which use a linear control. For this diagnosis mode and the method of transmitting at the architecture level the error, has no basis in the literature, and was designed based on the trials and the discoveries done during the simulations.

Each studied method and explained in the current thesis, generated a published article and was accepted by the community.

References

1. *Cheng, Y.K. & Cheng, K.W.E.*. (2006). General Study for using LED to replace traditional lighting devices. 2006 2nd International Conference on Power Electronics Systems and Applications, ICPESA. 173 - 177. 10.1109/PESA.2006.343093.
2. *Liao, Z.; Ruan, X*. Present status and developing trend of the semiconductor lighting. Trans. China Electrotech. Soc. 2006, 21, 106–111.
3. *Marty, C.; Howard, C.; Ken, M*. Solid-state lighting: The new normal in lighting. IEEE Trans. Ind. Appl. 2015, 51, 109–119.
4. *Sun, C.C.; Ma, S.H.; Nguyen, Q.K.* Advanced LED Solid-state Lighting Optics. Crystals 2020, 10, 758.
5. *E. F. Schubert*, Light-Emitting Diodes, 2nd ed. Cambridge, U.K.: Cambridge Univ. Press, 2006.
6. *G. Sauerlander, D. Hente, H. Radermacher, E. Waffenschmidt, and J. Jacobs*, “Driver electronics for LEDs,” in Conf. Rec.
7. *H. Sun, T. Nakane, N. Zhang and C. Zhang*, "Evolutionary Rear-Lamp Tracking at Nighttime," in IEEE Access, vol. 9, pp. 86667-86676, 2021, doi: 10.1109/ACCESS.2021.3087238.
8. *Ying, S.-P.; Chen, B.-M.; Fu, H.-K.; Yeh, C.-Y*. Single Headlamp with Low- and High-Beam Light. Photonics 2021, 8, 32. https://doi.org/10.3390/photonics8020032
9. *Arias, Manuel & Vazquez, Aitor & Sebastián, Javier*. (2012). An overview of the AC-DC and DC-DC converters for LED lighting applications. Automatika – Journal for Control, Measurement, Electronics, Computing and Communications. 53. 10.7305/automatika.53-2.154.
10. *Raicu, C. C., Serițan, G. C., & Enache, B. A.* (2023). Power LED efficiency for automotive headlights. EMERG: Energy. Environment. Efficiency. Resources. Globalization, 9(2). DOI: 10.37410/EMERG.2023.2.07
11. *Serițan, G. C., Raicu, C. C., & Enache, B. A*. (2023). Single-Wire Control and Fault Detection for Automotive Exterior Lighting Systems. Sensors, 23(14), 6521. WOS:001039842200001
12. *Raicu, C.-C.; Serițan, G.-C.; Enache, B.-A.; Stănculescu, M*. Development Approach Model for Automotive Headlights with Mixed Delivery Methodologies over APQP Backbone. *Appl. Sci.* **2021**, *11*, 10581, WOS:000725460900001
13. *Hohl, Philipp & Ghofrani, Javad & Münch, Jürgen & Stupperich, Michael & Schneider, Kurt*. (2017). Searching for Common Ground: Existing Literature on Automotive Agile Software Product Lines. 10.1145/3084100.3084109.
14. Advanced Product Quality Planning and Control Plan – Reference manual, 2nd, Chrysler motor company- Ford Motor Company- Generals Motors Corporation, (2017, 04, 20)
15. Chrysler Corporation, Ford Motor Company and General Motors Corporation, Advanced Product Quality Planning (APQP) and Control Plan (Reference Manual, 1995).
16. *J. Gausemeier, S. Moehringer*, VDI 2206- A New Guideline for the Design of Mechatronic Systems, IFAC Proceedings Volumes, Volume 35, Issue 2, 2002, Pages 785-790, ISSN 1474-6670
17. Automotive lamp guide [Online]. Available: https://www.bulbamerica.com/pages/automotive-lamp-guide
18. Lighting Technologies [Online]. Available: https://energypedia.info/images/f/f7/Lighting_technologies.pdf
19. *M. M.A.S. Mahmoud*, ‘Economic Applications for LED Lights in Industrial Sectors’, Light-Emitting Diodes and Photodetectors - Advances and Future Directions [Working Title]. IntechOpen, Jan. 11, 2021. doi: 10.5772/intechopen.95412
20. HID High Intensity Discharge [Online]. Available: https://www.bulbs.com/learning/hid.aspx
21. CIE1931 Chromaticity Diagram [Online]. Available: http://www.ledtronics.com/html/1931ChromaticityDiagram.htm
22. Luxeon LED Datasheet [Online]. Available: https://www.lumileds.com/uploads/610/DS109-pdf
23. *C-C. Raicu, G-C. Seritan, B-A. Enache*, 48 V network adoption for automotive lighting systems, RRST. et Énerg. Vol. 66, 4, pp. 231–236, Bucarest, 2021. WOS:000754884700004

24. *Pradhan, A.* (2011, December). Current trends in automotive wire harness design. In Proceedings of the International Conference on Mechanical, Production and Automobile Engineering (ICMPAE'2011), Pattaya, Thailand (pp. 28-29).
25. *Trommnau, J., Kühnle, J., Siegert, J., Inderka, R., & Bauernhansl, T.* (2019). Overview of the state of the art in the production process of automotive wire harnesses, current research and future trends. Procedia CIRP, 81, 387-392.
26. *Lin, C. W., Rao, L., Giusto, P., D'Ambrosio, J., & Sangiovanni-Vincentelli, A. L.* (2015). Efficient wire routing and wire sizing for weight minimization of automotive systems. IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, 34(11), 1730-1741.
27. *G. Toney and C. Bhargava*, "Adaptive Headlamps in Automobile: A Review on the Models, Detection Techniques, and Mathematical Models," in IEEE Access, vol. 9, pp. 87462-87474, 2021, doi: 10.1109/ACCESS.2021.3088036.
28. *Fei Chen, Kai Wang, Zong Qin, Dan Wu, Xiaobing Luo, and Sheng Liu,* "Design method of high-efficient LED headlamp lens," Opt. Express 18, 20926-20938 (2010)
29. *Mügge, M. & Hohmann, C.* (2016). Signal lights – designed light for rear lamps and new upcoming technologies: innovations in automotive lighting. Advanced Optical Technologies, 5(2), 117-128. https://doi.org/10.1515/aot-2015-0061
30. Halogen to intelligent-the evolution of lighting technology [Online]. Available: https://www.automotive-iq.com/events-iqpc-automotive-lighting/downloads/jaguar-land-rover-presentation-halogen-to-intelligent-the-evolution-of-lighting-technology
31. *B. Anton et al*, methods of maximizing power efficiency for hybrid vehicles, RRST. Vol. 64, 1, pp. 57–62, Bucarest, 2019
32. *J. Garcia, M. A. Dalla-Costa, J. Cardesin, J. M. Alonso, and M. Rico-Secades*, "Dimming of high-brightness LEDs by means of luminous flux thermal estimation," IEEE Trans. Power Electron., vol. 24, no. 4, pp. 1107–1114, Apr. 2009.
33. *Y. Cho and J. Kim*, "Lifetime Decrease of Halogen Lamps for Automotive by Duty Cycle Stress," in IEEE Transactions on Reliability, vol. 60, no. 3, pp. 550-556, Sept. 2011, doi: 10.1109/TR.2011.2135730.
34. *X. -X. Wang, L. Jing, Y. Wang, Q. Gao and Q. Sun*, "The Influence of Junction Temperature Variation of LED on the Lifetime Estimation During Accelerated Aging Test," in IEEE Access, vol. 7, pp. 4773-4781, 2019, doi: 10.1109/ACCESS.2018.2885578.
35. *Hocenski, Zeljko & Keser, Tomislav & Nenadic, Kresimir*. (2007). Distributed intelligent control of car lighting system with fault detection. IECON Proceedings (Industrial Electronics Conference). 498 - 503. 10.1109/IECON.2007.4460169.
36. *Chen, Y.; Ahmadi, A.; Ahamed, M.J.*, Optimizing Non-Glare Zone Width of Adaptive Driving Beam (ADB) Using Fuzzy Logic Control. Appl. Sci. 2021, 11, 8840. https://doi.org/10.3390/app11198840
37. *Orlovska, J., Wickman, C., & Soderberg, R.* (2020). The use of vehicle data in adas development, verification and follow-up on the system. Proceedings of the Design Society: DESIGN Conference, 1, 2551-2560. doi:10.1017/dsd.2020.322
38. *Lee, Jun Ho, Byeon, Jina, Go, Dong Jin, & Park, Jong Ryul.* (2017). Automotive Adaptive Front Lighting Requiring Only On/Off Modulation of Multi-array LEDs. Current Optics and Photonics, 1(3), 207–213. https://doi.org/10.3807/COPP.2017.1.3.207
39. *Shanker, Shreejith*. (2016). Enhancing Automotive Embedded Systems with FPGAs. 10.13140/RG.2.1.4001.1768.
40. Presentation of the future trends in automotive headlamp systems[Online] Available: https://www.automotive-iq.com/events-iqpc-automotive-lighting/downloads/presentation-on-the-future-trends-in-automotive-headlamp-systems
41. Jaguar-Land-Rover presentation halogen to intelligent, the evolution of lighting technology[Online] Available: https://www.automotive-iq.com/events-iqpc-automotive-lighting/downloads/jaguar-land-rover-presentation-halogen-to-intelligent-the-evolution-of-lighting-technology

42. *M. Lucanu, O. Ursaru, C. Aghion, N. Lucanu*, efficient high frequency single-phase ac chopper, RRST. Vol. 64, 1, pp. 69–74, Bucarest, 2019
43. *J. M. Alonso, J. Vina, D. G. Vaquero, G. Martinez and R. Osorio*, "Analysis and Design of the Integrated Double Buck–Boost Converter as a High-Power-Factor Driver for Power-LED Lamps," in IEEE Transactions on Industrial Electronics, vol. 59, no. 4, pp. 1689-1697, April 2012, doi: 10.1109/TIE.2011.2109342.
44. *Q. Hu and R. Zane*, “LED driver circuit with series-input-connected converter cells operating in continuous conduction mode,” IEEE Trans. Power Electron., vol. 25, no. 3, pp. 574–582, Mar. 2010.
45. *Wenrui Yan, Bingxian Hao, Meijuan Ma, Yun Wang*, Design of a high-voltage resistant and highly reliable LDO for automotive applications, IEICE Electronics Express, 2022, 19 巻, 21 号, p. 20220408.
46. *Sayers, M. and Duszkiewicz, A.*, "Performance Considerations for LED Automotive Signal Lamps," SAE Technical Paper 2002-01-0381, 2002, https://doi.org/10.4271/2002-01-0381.
47. Lighting systems from light to advanced vision technologies[Online] Available: https://www.dalroad.com/wp-content/uploads/2015/06/lighting_systems_from_light_to_advanced_vision_technologies_technical_handbook_valeoscope_en_998542_web.pdf.
48. *Noble, I. E.* (1994). Electromagnetic compatibility in the automotive environment. IEE Proceedings-Science, Measurement and Technology, 141(4), 252-258.
49. *V. Rodriguez*, "Automotive component EMC testing: CISPR 25, ISO 11452–2 and equivalent standards," in IEEE Electromagnetic Compatibility Magazine, vol. 1, no. 1, pp. 83-90, First Quarter 2012, doi: 10.1109/MEMC.2012.6244955.
50. *M. O'Hara and J. Colebrooke*, "Automotive EMC test harnesses: standard lengths and their effect on conducted emissions," *2003 IEEE International Symposium on Electromagnetic Compatibility, 2003. EMC '03.*, Istanbul, Turkey, 2003, pp. 233-236 Vol.1, doi: 10.1109/ICSMC2.2003.1428237.
51. *H. Rakouth, C. Cammin, L. Comstock and J. Ruiz*, "Automotive EMC: Key Concepts for Immunity Testing," *2007 IEEE International Symposium on Electromagnetic Compatibility*, Honolulu, HI, USA, 2007, pp. 1-7, doi: 10.1109/ISEMC.2007.168.
52. *Kuryło, K.; Sabat, W.; Klepacki, D.; Kamuda, K*. Comparison of Two Measurement Methods for the Emission of Radiated Disturbances Generated by LED Drivers. Energies 2022, 15, 9372. https://doi.org/10.3390/en15249372.
53. *B. Wang, X. Ruan, K. Yao, and M. Xu*, “A method of reducing the peak-to-average ratio of LED current for electrolytic capacitor-less ac–dc drivers,” IEEE Trans. Power Electron., vol. 25, no. 3, pp. 592–601, Mar. 2010.
54. Automotive Crancking Pules [Online] Available: http://www.flexautomotive.net/CEMFLEXBLOG/post/2015/09/10/automotive-cranking-pulse
55. *Zhu, Hailong & Zhou, Wei & LI, Zhiheng & Li, Li & HUANG, Tao*. (2021). Requirements-Driven Automotive Electrical/Electronic Architecture: A Survey and Prospective Trends. IEEE Access. PP. 1-1. 10.1109/ACCESS.2021.3093077.
56. *Moon-Hwan Chang, Diganta Das, P.V. Varde, Michael Pecht*, “Light emitting diodes reliability review”, Microelectronics Reliability, Volume 52, Issue 5, 2012, Pages 762-782, doi: 10.1016/j.microrel.2011.07.063.
57. *Y. X. Qin and S. Y. R. Hui*, “Comparative study on the structural designs of LED devices and systems based on the general photo-electrothermal theory,” IEEE Trans. Power Electron., vol. 25, no. 2, pp. 507–513, Feb. 2010.
58. *S. Y. Hui and Y. X. Qin*, “A general photo-electro-thermal theory for light emitting diode (LED) systems,” IEEE Trans. Power Electron., vol. 24, no. 8, pp. 1967–1976, Aug. 2009.
59. Bosch, “Design Requirements for Automotive Reliability,” 08 Jul 2006. [Online]. Available: http://www-g.eng.cam.ac.uk/robuspic/pub_present/ESSDERC06/6-ROBUSPIC-Workshop-ESSDERC06-VVonTils.pdf. [Accessed Aug 2018].

60. *J. Hokka, T. T. Mattila, H. Xu*, “Thermal Cycling Reliability of Sn-Ag-Cu Solder Interconnections. Part 1: Effects of Test Parameters”, Journal of ELECTRONIC MATERIALS, Vol. 42, No. 6, 2013
61. *Xi, J., Wang, X., Tao, Z., Lu, H., Wah, C. C., TawMing, L., ... & Liang, T*. (2022, August). Enhanced Thermal Stress Reliability of Photodetector Devices Based on Thermal-Mechanical Simulation and Temperature Cycling Experiments. In 2022 23rd International Conference on Electronic Packaging Technology (ICEPT) (pp. 1-6). IEEE.
62. ***AEC-Q102 “ Failure mechanism based stress test qualification for discrete optoelectronic semiconductors in automotive applications” (2017). [Online]. Available: http://www.aecouncil.com/Documents/AEC-Q102_Rev_A.pdf
63. *** Automotive Electronics Council [Online]. Available: http://www.aecouncil.com/
64. Zhang Xinbo et al, Functional safety in automotive electronics, IJSSST - International Journal of Simulation Systems, Science & Technology, Vol. 17, 27, pp. 27, Shangai, 2016, DOI 10.5013/IJSSST.a.17.27.27
65. Z. Hocenski, T. Keser and K. Nenadic, "Distributed intelligent control of car lighting system with fault detection," IECON 2007 - 33rd Annual Conference of the IEEE Industrial Electronics Society, 2007, pp. 498-503, doi: 10.1109/IECON.2007.4460169.
66. HITFET – BTS3050EJ Datasheet, Infineon. [Online]. Available: https://www.infineon.com/dgdl/Infineon-BTS3050EJ-DS-v01_00-EN.pdf?fileId=5546d462576f34750157be8fab3b43ce
67. ***”ISO/DIS 26262", Road Vehicles - Functional safety, 2018.
68. Automotive lighting: from “Vision” to “Driving Assistance” press release, Yole [Online]. Available: http://www.yole.fr/iso_upload/News/2020/PR_AFLS_From_Lighting_to_ADAS_YOLE_April2020.pdf
69. Automotive Lighting: Technology, Industry, and Market Trends - 2016 Report by Yole Developpement [Online]. Available: https://www.slideshare.net/Yole_Developpement/automotive-lighting-technology-industry-and-market-trends-2016-report-by-yole-developpement
70. Uniform provisions concerning the approval of adaptive front-lighting systems (AFS) for motor vehicles [Online]. Availeble: https://unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2016/R123r2e.pdf
71. Automotive Adaptive Front-lighting System Reference Design, Texas Instruments [Online]. Available: https://www.ti.com/lit/ug/spruhp3/spruhp3.pdf?ts=1594129711619&ref_url=https%253A%252F%252Fwww.google.com%252F
72. Matrix LED Headlights: Redefine Adaptive Front-lighting With Smart High Beam Technology [Online]. Available: https://www.manufacturer.lighting/info/162/
73. Datasheet Texas Instruments - *LP8867C-Q1, LP8869C-Q1 Low EMI Automotive LED Driver with 4-, 3- Channels* [Online]. Available: https://www.ti.com/lit/ds/symlink/lp8867c-q1.pdf?ts=1647814499246
74. Automotive Light Sources (headlights) [Online]. Available : https://www.fh-muenster.de/ciw/downloads/personal/juestel/juestel/Automotive_Light_Sources_MalteWantjer_.pdf
75. The automotive technology and automotive platform [Online]. Available: https://www.kfztech.de/
76. HEADLIGHTS [Online]. Available: https://www.hella.com/techworld/ae/Technical/Automotive-lighting/Headlights-219/
77. ***UNECE R48 [Online]. Available: https://unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2015/R048r12e.pdf
78. *Bielawny, Andreas*. "Reflectors in lighting design: Reflector-based non-imaging optics for lighting applications" Advanced Optical Technologies, vol. 8, no. 6, 2019, pp. 469-481. https://doi.org/10.1515/aot-2018-0052
79. *Kumawat, Aditya & Thakur, Amrit.* (2017). A Comprehensive Study of Automotive 48-Volt Technology. International Journal of Mechanical Engineering. 4. 13-20. 10.14445/23488360/IJME-V4I5P103. (2019)

80. 48 V/12 V Dual Battery Automotive Systems Require Bi-Directional DC/DC Controllers for Optimum Performance By Bruce Haug, Senior Product Marketing Engineer, Linear Technology [Online]. Available: https://www.analog.com/media/en/technical-documentation/technical-articles/P395_EN-Automotive.pdf.
81. Worldwide Emission Standards and Related Regulations Passenger Cars / Light and Medium Duty Vehicles May 2019 [Online]. Available:https://www.continental-automotive.com/getattachment/8f2dedad-b510-4672-a005-3156f77d1f85/EMISSIONBOOKLET_2019.pdf
82. *Xiaodong Zhang, K. T. Chau, and C. C. Chan*, " Overview of Power Networks in Hybrid Electric Vehicles," in Journal of Asian Electric Vehicles, Volume 8, Number 1, June 2010.
83. *G. Livinţ, V. Horga, M. Răţoi, and M. Albu*, "Control of Hybrid Electrical Vehicles", in Electric Vehicles - Modelling and Simulations. London, United Kingdom: IntechOpen, 2011 [Online]. Available: https://www.intechopen.com/chapters/19573 doi: 10.5772/16637
84. *Navale, V., Williams, K., Lagospiris, A., Schaffert, M. et al*., "(R)evolution of E/E Architectures," SAE Int. J. Passeng. Cars – Electron. Electr. Syst. 8(2):282-288, 2015, https://doi.org/10.4271/2015-01-0196.
85. *A. Frigerio, B. Vermeulen and K. G. W. Goossens*, "Automotive Architecture Topologies: Analysis for Safety-Critical Autonomous Vehicle Applications," in IEEE Access, vol. 9, pp. 62837-62846, 2021, doi: 10.1109/ACCESS.2021.3074813.
86. *Bandur, V., Pantelic, V., Dawson, M., Schaap, A. et al.*, "A Domain-Centralized Automotive Powertrain E/E Architecture," SAE Technical Paper 2021-01-0786, 2021, https://doi.org/10.4271/2021-01-0786.
87. *S. Sommer et al*., "RACE: A Centralized Platform Computer Based Architecture for Automotive Applications," 2013 IEEE International Electric Vehicle Conference (IEVC), Santa Clara, CA, USA, 2013, pp. 1-6, doi: 10.1109/IEVC.2013.6681152.
88. *V. Bandur, V. Pantelic, T. Tomashevskiy and M. Lawford*, "A Safety Architecture for Centralized E/E Architectures," 2021 51st Annual IEEE/IFIP International Conference on Dependable Systems and Networks Workshops (DSN-W), Taipei, Taiwan, 2021, pp. 67-70, doi: 10.1109/DSN-W52860.2021.00022.
89. *D. Wang and S. Ganesan*, "Automotive Domain Controller," 2020 International Conference on Computing and Information Technology (ICCIT-1441), Tabuk, Saudi Arabia, 2020, pp. 1-5, doi: 10.1109/ICCIT-144147971.2020.9213824.
90. Project Management Institute. A Guide to the Project Management Body of Knowledge (PMBOK Guide). 6th ed., Project Management Institute, Newton Square, PA, 2017.
91. Fișa de catalog pentru boost [Online]. Available: https://www.analog.com/media/en/technical-documentation/data-sheets/3782afc.pdf
92. Fișa de catalog pentru buck-uri [Online]. Available: https://www.st.com/resource/en/data_brief/steval-ill089v1.pdf
93. Fișa de catalog pentru LED-uri [Online]. Available: https://lumileds.com/wp-content/uploads/files/DS158.pdf