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Validation of Automotive Centrals Using Hardware in the Loop-Body Control Unit and Lights

Marley Rosa Luciano, Rodney Rezende Saldanha

***Abstract*—**The race for electrification and the need for innovation to attract customers has led the automotive industry to do something different with vehicles. New emissions control challenges and efficient technological availability are the pillars of creation. The growing demand to upgrade industrial manufacturing systems creates actions that directly impact vehicle production. With this comes the search for new prototyping methods and virtual tools for component testing and validation, and vehicle systems have established themselves. The demand for Electronic Control Units (ECU) is increasing due to the availability of intelligence and safety in today's vehicles, directly affecting their development, performance, and functional testing. In order to keep up with global changes, the automotive industry uses different virtual environments to produce, verify and validate their vehicles and test prototypes used during development. Therefore, in this paper, integration and validation were performed using the Hardware in the Loop (HIL) test platform, focusing on the ECU Body Control Module (BCM). Then, a brief commentary reviews other test medium platforms, such as the Plywood Buck (PWB), and examines the reliability, flexibility, installation time, and cost of the three test platforms, software in the loop (SIL), Model in the loop (MIL), and HIL, to review their benefits, challenges, and issues in use and information to optimize the use of each platform and test medium.

***Keywords*—**Automotive, Electronic Central Unit, xIL, Hardware in the loop.

I. Introduction

GLOBALIZATION has increased the speed of information exchange between other global regions and places so that society faces a technological development that is growing exponentially. In this context, the digital age has revolutionized various consumption sectors such as services, commerce, and industry. As a result, technological advancement has led to more product options and opportunities. With progress comes new physical and virtual features that require regulations and standards to ensure performance and safety for the customer. The automotive industry is a business model that applies these features in consideration of regulatory requirements, safety requirements, convenience, and performance requirements, and safety for the customer. The automotive industry is a business model that applies these features following regulatory requirements, safety needs, comfort, and performance requirements.

The increasing implementation of automated functions in conjunction with software has created a need for investment and support in developing simulation-based virtual environments in the automotive industry. Everything is developed in MATLAB/ Simulink in various stages of development, from implementing libraries for integration into the box for simulating power plants, sensors, and actuators in [1]. Currently, SIL development strategies are directly related to the design of the base model, which in some cases uses the same code applied in HIL and platforms using MathWorks modeling tools. In Fig. 1, you can see how the use of HIL simulators in the industry has increased in recent years. This increase is the result of research and investment in new means of automated testing that not only target the availability time of the system or component but also increase the quality of the product for the customer and provide the tester with more safety and efficiency in performing tests that in some cases require extreme stress on the component or vehicle. In this scenario, different types of platforms and test benches have used HIL for varied applications, such as:

- Test, validate, and evaluate only one behavior of the ECU, BCM, using a HIL component.
- Test, validate, and evaluate a vehicle system, including the simulated powertrain subsystem, lighting, control devices that comprise the vehicle, and various electrical components using a component HIL.
- Evaluate and analyze drivability in the software and implementation versions of the BCM using a component HIL integrated into the load box.

As HIL system usage increases, the validation team often demands improvements and upgrades, increasing the cost, complexity, and effort required to keep an application available. In this context, understanding customer demand and how the types of xIL systems are to each test facilitates optimizing time and minimizing the effort of the manufacturing process. It, therefore, lowers cost and prioritizes product quality and performance, making it efficient and competitive. To affirm the results of these questions, creating a test case to target the most suitable xIL platform for testing is necessary, with planning that includes cost x time. Several aspects need to be considered, such as:

- The time required to develop and set up the test environment.
- The flexibility and availability in executing the procedures.
- Complexity and mastery in executing the procedures.
- Time to commission and execute the procedures.
- Cost of the physical and virtual environment.
- The representativeness of the environment for the desired tests and procedures.

Thus, this paper analyzes the BCM ECU and the vehicle's internal and external light loads using the HIL platform to validate and verify the system functions for optimal use during

Marley Rosa Luciano is with the STELLANTIS SA, Brazil (phone: 5531983757031; e-mail: marleyros@gmail.com).

Rodney Rezende Saldanha, is with the University Federal Minas Gerais (e-mail: Rodney.saldanha@ufmg.br).

the development process and integration with other ECUs. In addition, the load box is a structure connected to the Simulator to test the system light loads available in the car, as it is an environment whose characteristics are closer to the final product.

The structure of the paper is as follows: The "Theoretical Framework" section presents the xIL platforms, the environments analyzed in this paper (xIL simulation platforms, national and international xIL test scenarios), and the methodology used to estimate representativeness. Section "Applications & Tools" presents the available test system tools in Hardware and Software and explains when and how to use the different types of environments analyzed in this document (platform model, platform software, virtual application, and software). The "Model-based design" (MDB functional modeling box, model hardware integration) meets the modeling tools and the creation process. The "Case Study" shares the hardware and software configuration used in testing. It analyzes the practical case study and the advantages of using the HIL component to validate the BCM ECU.

II. Theoretical Framework

Before addressing the aspects that optimize the way automotive control centers are validated and verified, it is necessary to understand better some concepts about xIL platforms and their differences, such as:

A. xIL Simulation Platforms.
B. The national and international xIL test scenario (a national scenario with HIL simulation, an international scenario with HIL simulations)

A. Simulation Platforms

The HIL platform is one of the examples of a test environment described in this article. It is a testing tool used in the development process of electronic systems to validate actual or simulated components and allow permutations between them. Simulation involves the operation of electronic and mechanical systems, especially control units in a closed loop that controls physical components and is subjected to real-time tests to analyze the operation and, in some instances, insert faults to test possible occurrences.

Among validation and verification tools, the HIL platform enables reusable and scalable testing of actual and simulated ECU control systems in a test environment closer to reality. The system allows tests with autonomy and availability in the laboratory, shortens validation times, and increases the range of test scenarios [3]. In addition, HIL allows testing of critical and complex cases compared to other systems and avoids safety issues since there is no human dependency that could affect the device under test or the closed-loop environment, as well as in open-loop test setups, e.g., when retesting data [2]. The complexity and increasing changes in architectures and topologies reflect the evolution of embedded systems and the impact of communication protocols between CAN networks. It is essential to highlight the electrification and reliance on safety systems compatible with current technology.

The Simulator has the flexibility to update modules for different applications, which allows it to meet most of the tests required in Development. Its operation depends on the physical installation and software integration, the application model. In this article, we have chosen the tool developed by the German company dSPACE. [4] The hardware developed by this company contains several modules and configuration units divided into a power supply system, a processing and logic module, input and output boards, signal modulation boards, fault insertion, and network communication boards.

The simulator configuration depends on the test application; considering the phase and component, the hardware is designed with the vehicle information. This configuration includes all analog and digital signals needed to configure the sensors and actuators, and the drive and power boards are connected to the simulator source. The HIL development sets up the model used in the system. It contains signal information and test logic; everything is modeled in MATLAB/Simulink, using dSPACE software responsible for integrating the hardware and parameterizing with the defined simulator.

B. National and International xIL Testing Scenario

Real-time simulation platforms are increasingly used to accelerate product development in the industrial domain for applications in various technical areas such as energy process control, power electronics, automation, and microgrids. Among the available technologies, HIL systems allow a plant with characteristics close to the actual model to be emulated in a simulator in real time [5].

The possibility is the ability to perform tests to validate plants by integrating control systems with sensors and actuators to obtain satisfactory results. In addition, the platform is configurable to emulate different types of systems, providing flexibility and customization for studies and research in various fields and reducing the cost and duration of the project.

Among the significant national technology industries in the Brazilian market, EMBRAER is a successful reference for user validation and verification tools with HIL. It is responsible for citations and business models among companies and universities that collaborate with the know-how of applying highly reliable complex systems, justifying the investment in automated simulators [6].

The HIL platform is versatile and able to guarantee the final product's quality and increase the competitive power in the market due to the performance of the test performed in simulation, bringing more quality and benefits when applying virtual testing [5]. The simulated system has programmable drives and ports in the functional structure, making it easy to create automated tests. The ability to catch faults early in the project can prevent severe budget damage, reduce debugging costs, contribute to short-term development, and resolve complex bugs.

The premise of the ease of use of simulators to test complex systems points out the advantage that the Simulator offers in simulating subsystems that cannot be physically included in the tests, making it possible to thoroughly test each embedded control unit before the system in a natural environment. Thus, the system's reliability can be guaranteed while considering meeting the requirements while reducing testing costs and time to market.

In the international scenario, the historical consideration of using xIL simulators is due to the challenges faced by engineering teams, i.e., within the automotive sector, power electronic systems and various disciplines have contributed to this development [7]. Several vendors such as National Instruments, dSPACE, and Typhoon HIL are simulator manufacturers and soon-to-be software developers such as MATLAB Simulink Real-Time Toolboxes and Speed goat hardware systems that provide powerful tools for efficient and successful investigations in various industries [4]. Therefore, the international scenario started the practice of HIL simulation a long time ago and is under the premise of investing in research and development in partnership with education to prepare students for professional assignments in the industry.

Due to the different challenges faced by engineering, i.e., the automotive industry, it is visible to compare domestic development with global product demand. Market competition is breaking down and requires perfect products, making development and testing critical. The practice of HIL simulation has long been studied and is on the premise of investing in research and development in partnership with education to prepare students for professional tasks in the industry [8]. The automotive industry is investing heavily in electromobility and primarily looking to improve and innovate systems where power electronics are the main component, from vehicle architecture topology and connectivity to communications, battery, and of course, the powertrain [9]. Sophisticated power electronics allow central control units to work with sensors and actuators to control the vehicle.

The automotive simulator producer, dSPACE, currently one of the leading international simulator providers, offers safe testing through robust and modular hardware systems whose tools influence the history of power plant simulation to validate ECUs with SIL in HIL environments requires adjustments and changes from the virtual to the natural environment [4].

The Software ECU is critical to HIL and SIL solutions and impacts virtual and natural environments. The platform software can be approved without ECU hardware because the signals can be emulated. The required object model is the software running on a virtual platform using vendor-specific tools and shared via GitHub.

The use of xIL simulators for validation is present in several industries; among them, the energy sector shares the application in the development of solar thermal cells in power generation systems. The simulator works on real and simulated platforms and can easily predict important long-term application results. A positive feature is an ability to change and remove the modules that simulate sensors and actuators to create a controlled test environment, such as the test methodology used to validate the ECU BCM [8].

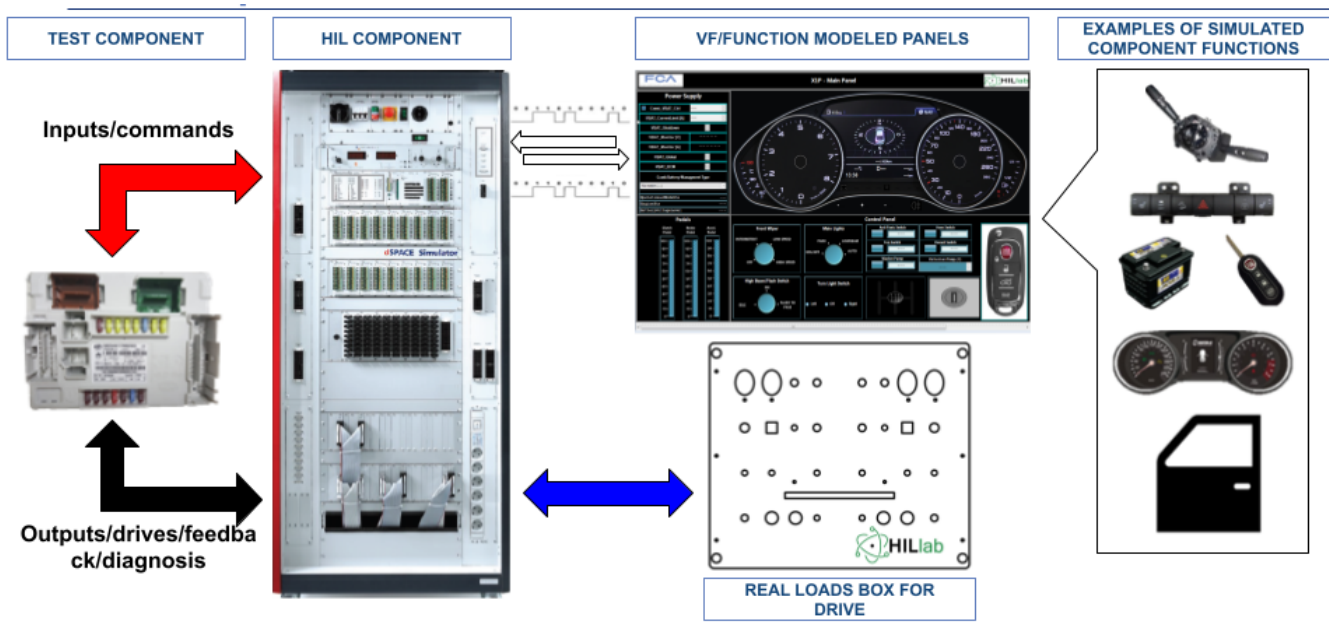

Fig. 1 HIL Test Platform

III. xIL Applications & Tools

A. Platform Model

Depending on the application and design phase, the xIL platforms can be physical or virtual. It determines the use of the platform best applied to testing; SIL and MIL virtual platforms, in some cases, it can switch between different modes, the real and the simulated. Thus, the development of the component gains more production time, and its validation is started in parallel. HIL simulators are plugged into physical structures that rely on real hardware and have fundamental vehicle components, electronic circuits, sensors, and actuators. However, this could be more didactically divided into options such as MIL, SIL and HIL, with technical dissemination and educational investment.

It is essential to consider the application to determine which platform model to use. In the process described, it is first possible to see the MIL platform, and then it is possible to compile and test the model within the Simulink tool; its development and testing are independent of the software version or the physical component. MIL performs tests in the early stages of the project, is a powerful tool for reuse, and can be used in other projects until the development phase of the SIL.

The relationship between HIL platforms' usability and sustainability is directly connected to the possibility of reusing discontinued systems applied to new projects. The simulators can be reprogrammed and modular, reducing development and labor costs. When virtual systems are selected for design, the gain is even greater because the system is independent of electronic components and can share tests in other locations and different teams.

The SIL platform has the versatility to test in a virtual environment using the vendor's software, compatible with MATLAB/Simulink, the virtual testing platform VEOS is widely used in the automotive industry, its use in complex tests tends to increase exponentially with the pandemic historic the lack of components in production made the industry create new strategies. The possibility to reuse plant models between platforms facilitates the integration between development teams [5] and improves the validation and verification in the test phase.

In summary, xIL platforms can be considered authentic and virtual test media for performing verification and validation (V&V) of electronic and mechanical systems consisting of central electronic units, protection and power supply systems, sensors and actuators, and associated software. The composite devices are accurate and highly important to represent those in the vehicle, have power supply systems and controls to improve concealability, and increase the ability to transfer information between CAN/LIN or CAN FD networks, depending on the application. When dependent on the physical structure, these devices include the control and power regulation for the communication system and the AC power supply [10].

The SIL and MIL platforms applied at the beginning of development cover a larger area than the HIL platforms because they are not hardware dependent; unlike physical platforms, all system requirements are modeled in MATLAB/Simulink. The need for existing motor control systems, drives, transmissions, and differentials for the vehicle starting system libraries can be developed and applied in the MIL model; the load state control, temperature, and voltage information are designed entirely in MATLAB [5].

When integrating a test medium, for example, a physical battery bank, this system changes from SIL to HIL. When switching from virtual to real, a test application is compatible with xIL systems. An xIL platform can be represented with common subsystems. However, each has its specificity; both run remotely and have no local infrastructure connections.

Fig. 2 Software Control Desk [4]

B. Platform Software

The two software programs used in this proposal are Configuration Desk and Control Desk, which integrate the model developed in MATLAB/Simulink and other data entry tools, such as Excel. Configuration Desk is an intuitive graphical configuration and implementation tool ideal for handling applications ranging from small rapid control prototyping (RCP) developments to significant HIL tests based on real-time.

The xIL simulator developer dSPACE provides the software to configure and operate the simulators. The configuration console provides a structured overview of external devices, for example, the BCM used in this project, configured with all software signals and functions, including real-time application configuration, graphically enabling test automation, and data management process.

The Control Desk tool, which is responsible for the control of the Simulator, integrates all the information about signals and parameters of the Configuration Desk and allows the validation team to do its work, where tests and analysis of the project are performed. Control Desk software is currently at version 7.0, the dSPACE visualization and experimentation software.

Control Desk supports Wireshark plug-ins for decoding in Bus Navigator's Ethernet monitoring. In addition, signals from UDP Ethernet PDUs can now be easily instrumented and measured on layouts with the Ethernet Bus Monitoring Device, supporting two new FPGA boards for SCALEXIO [4].

The Control Desk is the software responsible for the instrumentation and development of modular experiments. The function of this software is to bring the operator closer to the simulator and allow complete control of the system to be tested, from the beginning of development to commissioning to validation.

The application includes the possibility of data acquisition, measurement, calibration, and diagnosis of the ECU, access to the CAN network, essential functions of the Control Desk, and the application of the SIL platform in virtual validation with VEOS [14].

C. Virtual Application

Before we present the solution with the MDB, it is first interesting to consider the V&V solutions without physical hardware, consolidated and distributed to all systems.

The virtual platform simulation provides a test view independent of the available hardware and physical structure since it is virtualized and requires less dependence on physical components. In the case of a connection between the user and the system, using Configuration Desk and Control Desk software brings user autonomy and ease of execution. All this and signals of system identity, functions, and operational states are generated to make the system operational [14]. Subsequently, VEOS systems became the basis for developing the design of other simulation platforms in the presence of neutral conductors and transformers for the same reason. In summary, the more complete the virtual development, the more HIL, and a vehicle in the loop (VHIL) path for ECU validation, avoiding delays due to component supplier shortages, and performing initial testing to predict future design flaws. VEOS systems generally comprise a MDB of each ECU, sensor, and vehicle actuator dimensioned so that the model is closer to the real thing because of teamwork between software, modeling, and supplier teams. Fig. 13 brings an example that illustrates the allocation of virtual plants seen by the system.

IV. MDB Case

System modeling is fundamental to the development of the MIL, SIL-HIL system and depends on inputs generated by the project team. It comprises libraries and functions of each central electronic unit, sensors, and actuators are represented virtually with their characteristics and power, control, and communication signals in the CAN network. In [12] is proposed the application of vehicular propulsion models, controlled with xIL simulators in [5]. This same technique is used to control internal vehicular systems with the example of the application of this work that aims to demonstrate the tests in the central BCM.

The modeling technology consists of the synthesis of the virtual components of the vehicle itself, the voltage signals of the components concerning the battery is configured, inserting, the communication block referring to the communication protocol and the path of sending and receiving messages between the central units, the vehicle dynamic block is responsible for the implementation of the software and calibration of the ECU´s simulating its functionality and operating states, any update, and implementation is perform in this block. For this, GitHub is the standardization tool between the teams, whose every change is documented in the repository platform, and multiple platforms access the model.

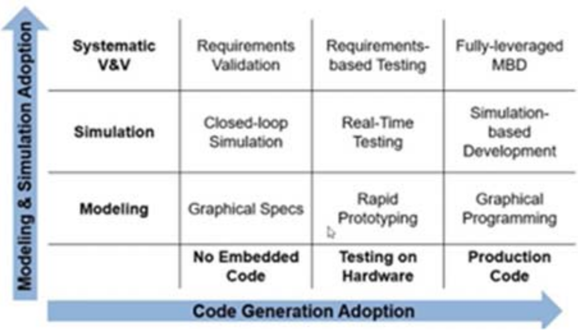

Fig. 3 MDB Development Process [15]

The ability to add a new component to the model and make these changes is due to the standardization of control blocks and compatibility between tools. The use of this tool is very versatile and can facilitate the implementation of simple or, in some cases, complex updates. These updates depend on the needs of the validation team, resulting from problems due to design flaws or even when the component is completely new, and updates are required for its better functioning [10]. In the case of a new project, an impact study is performed, and all the documentation required for the execution of the work is reviewed.

This methodology can provide a wide range of applications, and, as mentioned earlier, the model can be applied to different xIL platforms. In this study, the benefit identified was the improvement of HIL testing using a modular LoadBox structure through simulation management during model integration. It is essential to have significant technical documentation of all the ECU circuits based on the program applied to the xIL platform, enabling teamwork during project development.

It is possible to analyze in Fig. 8 the development cycle of the MDB, its versatility due to its modular characteristics, and of course, the integration with multi-access systems facilitates its implementation in real-time. The model is developed in MATLAB/Simulink software, where the integration with the DSpace tools responsible for developing the simulators is done.

The construction of mathematical models demands information about the system and what it is designed to do, called a closed box.

- Actuators: Touch buttons on the internal faces of the vehicle.
- Sensors: Touch the sensor inside the case.
- Control: External control unit.

The model should represent the causes and effects of the system actuator, plant, and sensor to test the actual controller.

Control action:

- On: Electric power P = W.
- Off: Electric Power P = W.

The demand for processing requires adequate control for each application, but the proposal to use mathematical systems with precision facilitates the Development of the models and makes the MDB close to the actual value, following the engineering requirements.

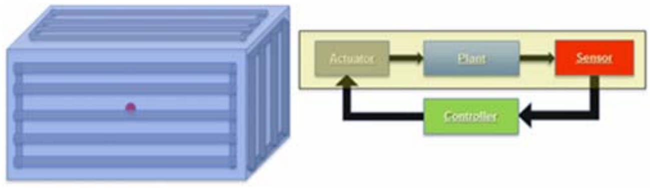

Fig. 4 Creating the Model

Fig. 5 Toolbox Create

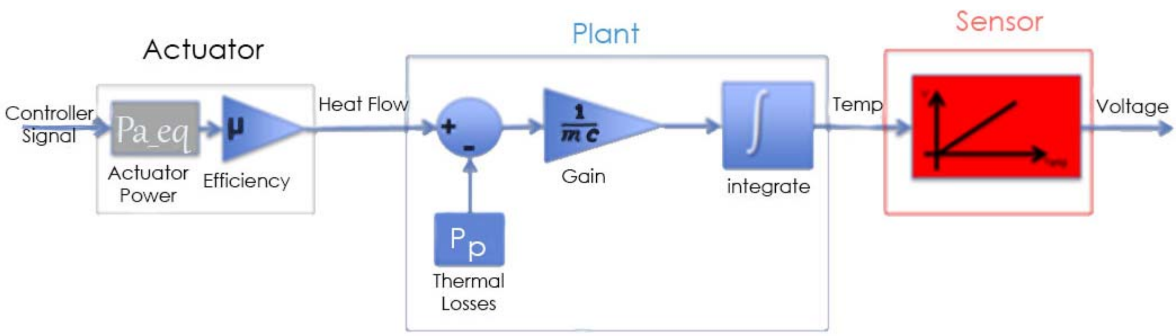

Fig. 6 System Control Block

Implementing functions in the tests depends on the complexity of the dynamic system and its actual characteristics in the environment.

A. Hardware Integration Model

The components present in the model are the same as described in the hardware document; each electronic unit of the plant has its configuration block where the physical hardware's characteristics can be virtualization; the connection interface between Hardware and Software is visible in Fig. 1. In an installation like the one in Fig. 11, this plant comprises central units and possible sensors/actuators, transforming physical signals into simulated signals. In this case, the connection is defined internally in the Simulator by choosing the type of signal and resistance to simulate other accurate loads and consequently identifying the available ports for applications [15]. In addition, the power ports are produced on the buses with the identity of each ECU and named the voltage level, depending on each signal applied in the project.

The construction of the test system depends on the functions to be tested in the vehicle; initially, the document containing all the I/O is developed, and the Simulator supports a particular application; Fig. 9 shows the boards available in the platform.

V. Case Study

A. Benefits Using HIL Component BCM Validation

The real ECUs embedded in the simulation environment have the same characteristics and information as the fundamental component. The possibility to develop meaningful virtual models facilitates test development and increases the scope of test scenarios. Additionally, HIL allows testing of critical cases, which involves maximum speed in a closed-loop environment and open-loop test setups, e.g., repeat data testing [13]. The increasing complexity of I/O architectures, electric vehicles, and ADAS/AD active safety systems make HIL testing crucial to ensure system reliability.

Key benefits of using them:

- HIL solutions ranging from component testing to system integration testing.
- For all vehicle domains, including e-mobility and autonomous driving.
- End-to-end toolchain for efficient automated testing
- Comprehensive consulting, engineering, and training offerings.
- Decades of experience with a wide range of customer projects.

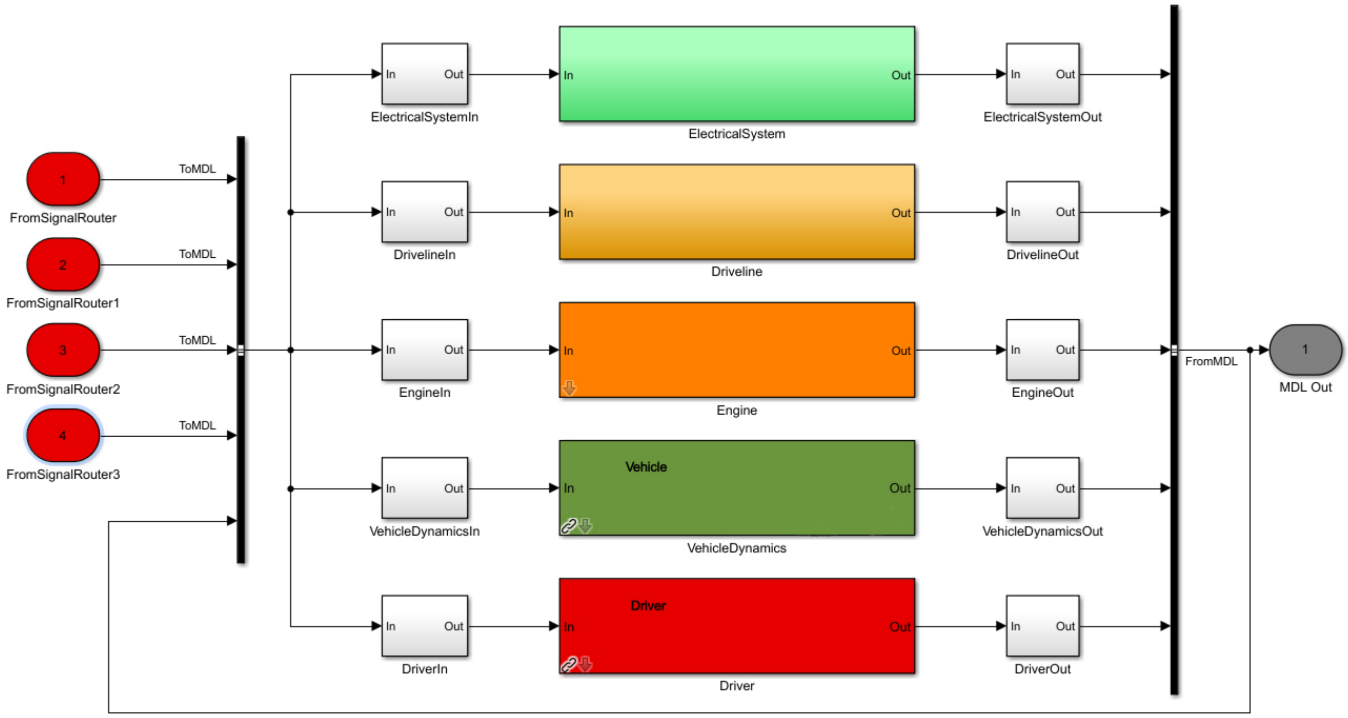

Fig. 7 Environment Representativeness

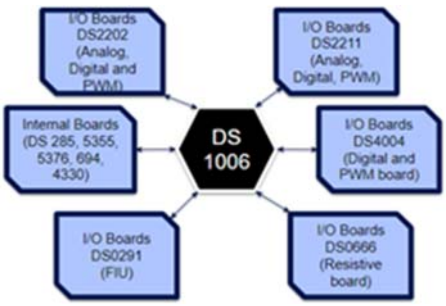

Fig. 8 Hardware & Software Integration

Available I/Os -D SPACE From Project									
CARD	Digital Output	Digital Input	PWM Output	PWM Input	Analog Output	Analog Input	Resistive	FIU	CAN
DS 2202	16	14	9	24	20	17	0	0	2
DS 2211	14	6	9	18	20	15	10	0	2
DS 4004	80	72	3	37	0	0	0	0	0
DS 0666	0	0	0	0	0	0	32	0	0
DS 291	0	0	0	0	0	0	0	180	0

Fig. 9 Table I/O Available in Simulator

Key points to define the application:

- Real-time scalable platforms.
- Support for the latest bus and automotive network standards.
- Comprehensive simulation models for applications ranging. From combustion engines to autonomous vehicles and electric vehicles.
- High-fidelity solutions for e-mobility applications.
- High-fidelity solutions for e-mobility applications: A real camera, lidar, and radar models can be calculated in real-time with dSPACE HIL systems.

ECU test systems require scalable I/O and CAN/LIN interfaces; the possibility of simulating electrical faults helps catch possible product errors. In addition, automatic testing and network control help create simulation tests by configuring between the simulators.

B. ECU - BCM

The Body Computer Module is one of the primary control devices of the vehicle because it has the responsibility of managing the exchange of information from the other central units on the CAN network; it controls all the electronics of the vehicle connected to the protection and configuration relays between the battery and other circuits.

The BCM is complex hardware with integrated circuits, data memory, protection circuits, and processing units. The automotive industry considers it the brain of the vehicle not only for all the responsibility in managing the communication between the ECUs but also for its importance in the whole vehicle operation. The control of sensors and actuators, for example, the interior and exterior lights, acts in the request of data and information on temperature and connectivity.

The vehicle's internal and external lights are the headlights, lanterns, and other lights present in the car, which have the function of alerting and communicating with the driver with other vehicles on the road, but also with the driver's comfort and practicality—is considered one of the most critical components in the Development of the car due to all the onboard electronics and compatibility with drivers and power supply modules of the system.

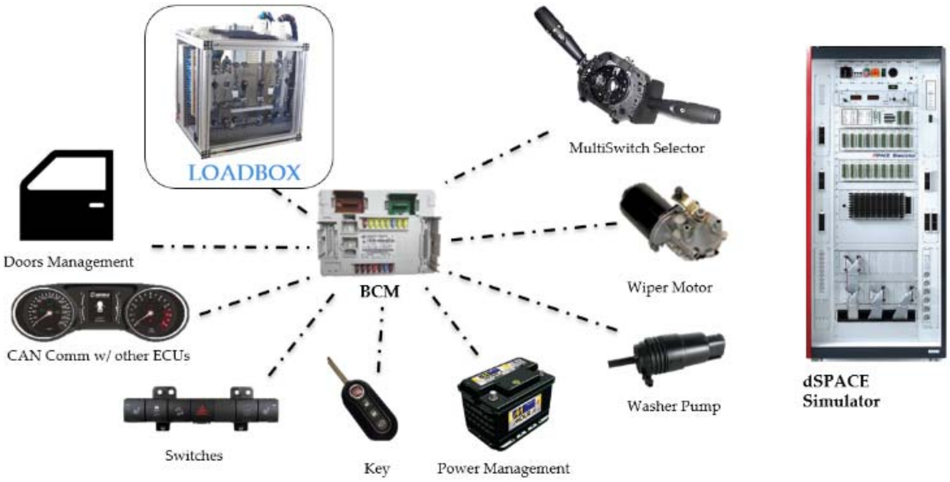

Fig. 10 Hardware Integration [4]

C. Load Box

The Load box is a metallic structure planned to allocate the loads and the fundamental ECU of the vehicle; its connections are made by terminal blocks that are detailed in the topic below; it has 2 terminal blocks that interface with the ECU BCM and the Simulator, the first connection terminal interfaces the ECU to the light loads of the project and the second terminal makes the connection between the ECU and the Simulator. The Simulator is connected to the external structure that contains the physical signals of the light loads and the actual ECU; the proposal is to realize the connection between the external and internal loads with their power and control circuits.

The test setup integrated into the xIL platform is critical for investigating possible failures and testing complete systems in the validation phase, with purpose of using the load box in the project is due to its flexibility in performing hardware upgrades and easy access to the power and signal connections to both the ECU and the light loads, helping the validator to perform its tests as close to the component as possible:

- Practicality in maintenance.
- Robust low-cost structure.
- Simple operation for BCM V&V Team.

Initially, a survey is made of all the materials used in the construction of the light load panel, coupled with a structure developed for testing. Assuming that the set would be positioned near the BCM simulator, the metrics and parameters for the product's construction were defined.

D. Structure Load Box

The box is built with structural aluminum profiles attached by universal connectors.

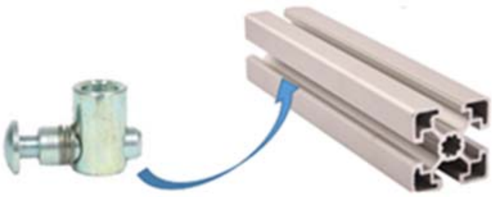

Fig. 11 Universal Connector

TABLE I
LOAD BOX STRUCTURAL COMPONENTS

Amount	Model - mm	Component
1	700x700x4 mm	Acrylic sheet
20	38 Inch	Universal Connector
12	6x16 mm	Chipboard Screw
6	720x40x40 mm	Pan Chipboard
4	700x40x40 mm	Aluminum Structural Profile
4	100 mm – 65 kg	Metallic support p/BCM

Table I contains information on the materials needed to assemble the physical structure where the central BCM and the vehicle's internal and external lighting loads will be placed, and the test bench will be developed and connected to the Simulator to perform tests.

E. Harness

The detailing here considers the internal part of the box and the harnesses that connect it to the BCM HIL. These connect the BCM to the Light Box. Regarding the accommodation of the wires in the ducts, taking care of the organization and robustness, the cables were conformed to avoid as little loss of length as possible, route by route.

Fig. 12 is the model of the physical structure of the load box represented in orthogonal views, showing the occupation area and the physical model designed to serve the connection between the BCM central office and the connection between the HIL simulators.

The proposal to build a rectangular box to meet the project specifications considered the amount of connection present in the project, the size of the components and loads to be connected, and all the internal and external lights of the vehicle and the BCM central office.

F. Load Box Build

The frame construction was designed to the necessary measures, and the profiles have acrylic cuts and holes in the ends. This test bench version of the load box is lighter, being a model for tests on accurate loads, the original concept applied in functional and systemic tests.

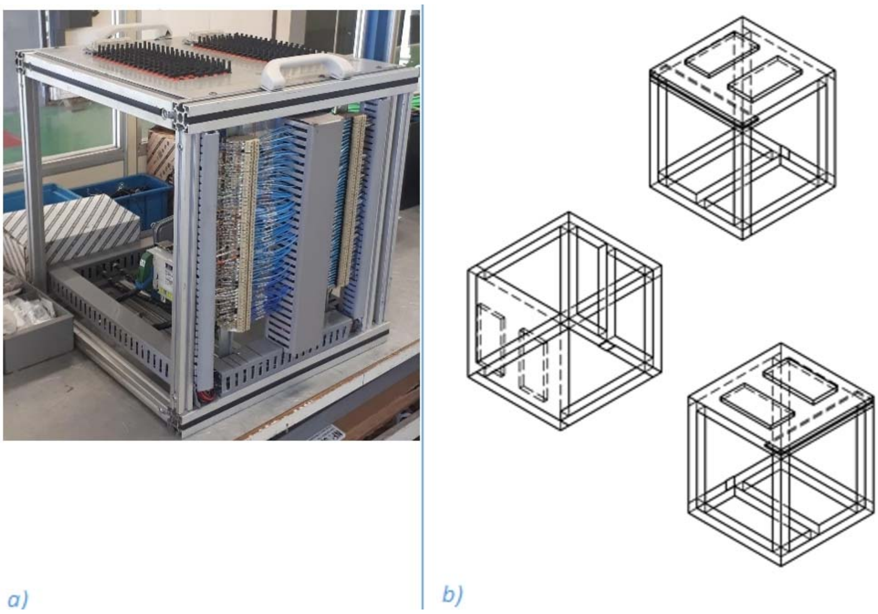

Fig. 12 Orthogonal views on a 1:6 scale

Fig. 13 ECU and Simulator Connection in Platform

Fig. 14 Structure with connection lights

The idea of facilitating access to the internal components is applied due to more space between the allocation of cables and terminals, the load box version still has challenges, but the update of the project and its new model of loads was necessary to increase the size of the structure. Therefore, it was chosen to use structural profiles without any fixed connection, being a fully modular structure and easy to transport.

G.Load Lights

Each Light Box project must be dimensioned by the amount and type of loads used. This main parameter is to be surveyed before starting the product's construction.

VI. Validation and Verification Report

The development of tests requires knowledge of the system and the component to be tested, which are fundamental characteristics to validate the system with performance and quality [2]. The consolidation of standards and their representativeness is essential so that it is possible to define the responsibilities of all those involved in the process of creating tests, from software vendors, manufacturers of simulators and hardware for testing, in addition to encouraging the correct use of the assignments is to charge the application of penalties for those who do not comply with these standards. In the case for learning and referencing, industrial technical standards are used as quality control of V&V by ISO 26262.

The validation team uses the desktop with the software mentioned in this document to operate the HIL component simulator and performs the hardware configuration with its case tests; each application has a modeling and configuration file [11]. This test was performed remotely due to the platform's ability to operate in different locations.

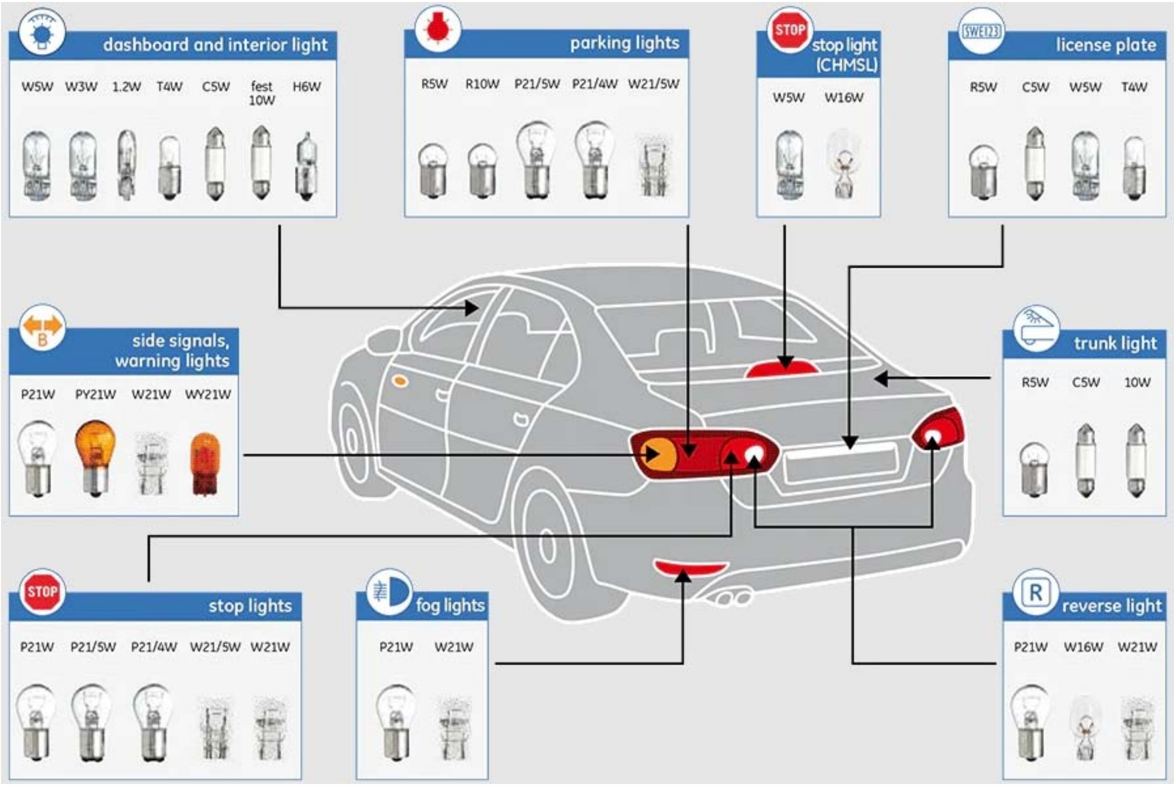

Fig. 15 Structure with connection lights

The test loop was designed to include factual day-to-day information regarding the environment, climate, and the possibility of external noise. The test sequence is shared in Figs. 17-20, and all its command logic was performed using Simulink.

A. Test Performed to Analyze External lights

The stress tests on the Turn Light to check for possible failure or misbehavior of the component were performed using the left xIL Turn Light platform 'which are prototype parts', so, to obtain an adequate diagnosis, the test was performed only with the appropriate Turn Light.

The test followed a procedure by the validation team to catch possible failures during operation. It is possible to check how the turn light works and how its behavior is maintained during the test cycles.

Analysis performed of the operation of the correct lamp and making it possible to test its functions and integration with the updated central.

B. Automatic Test Routine Case Study

- 1st loop (4X) = 20 min right arrow on - 20 min left arrow on / DRL On; Monitor signals: (ParkingLightFault=1 / LHTurnLightFault=1 / RHTurnLightFault=1).
- 2nd loop (4X) = 20 min right arrow on - 20 min left arrow on / DRL Off + Low Beam On; Monitor signals: (ParkingLightFault=1 / LHTurnLightFault=1 / RHTurnLightFault=1).
- 3rd loop (4X) = 20 min right arrow on - 20 min left arrow on / DRL Off + Low Beam On + High Beam On; Monitor signals: (ParkingLightFault=1 / LHTurnLightFault=1 / RHTurnLightFault=1);
- 4th loop (4X) = 10-sec right arrow on - 10 sec left arrow on / DRL On; Monitor signals: (ParkingLightFault=1 / LHTurnLightFault=1 / RHTurnLightFault=1);
- 5th loop (4X) = 10-sec right arrow on - 10 sec left arrow on / DRL Off + Low Beam On; Monitor signals: (ParkingLightFault=1 / LHTurnLightFault=1 / RHTurnLightFault=1).
- 6th loop (4X) = 10-sec right arrow on - 10 sec left arrow on / DRL Off + Low Beam On + High Beam On; Monitor signals: (ParkingLightFault=1 / LHTurnLightFault=1 / RHTurnLightFault=1).

This test aims to analyze the operation of the BCM ECU, and the External/Internal lights connected. We are ensuring that there are no problems in BCM-related issue detection.

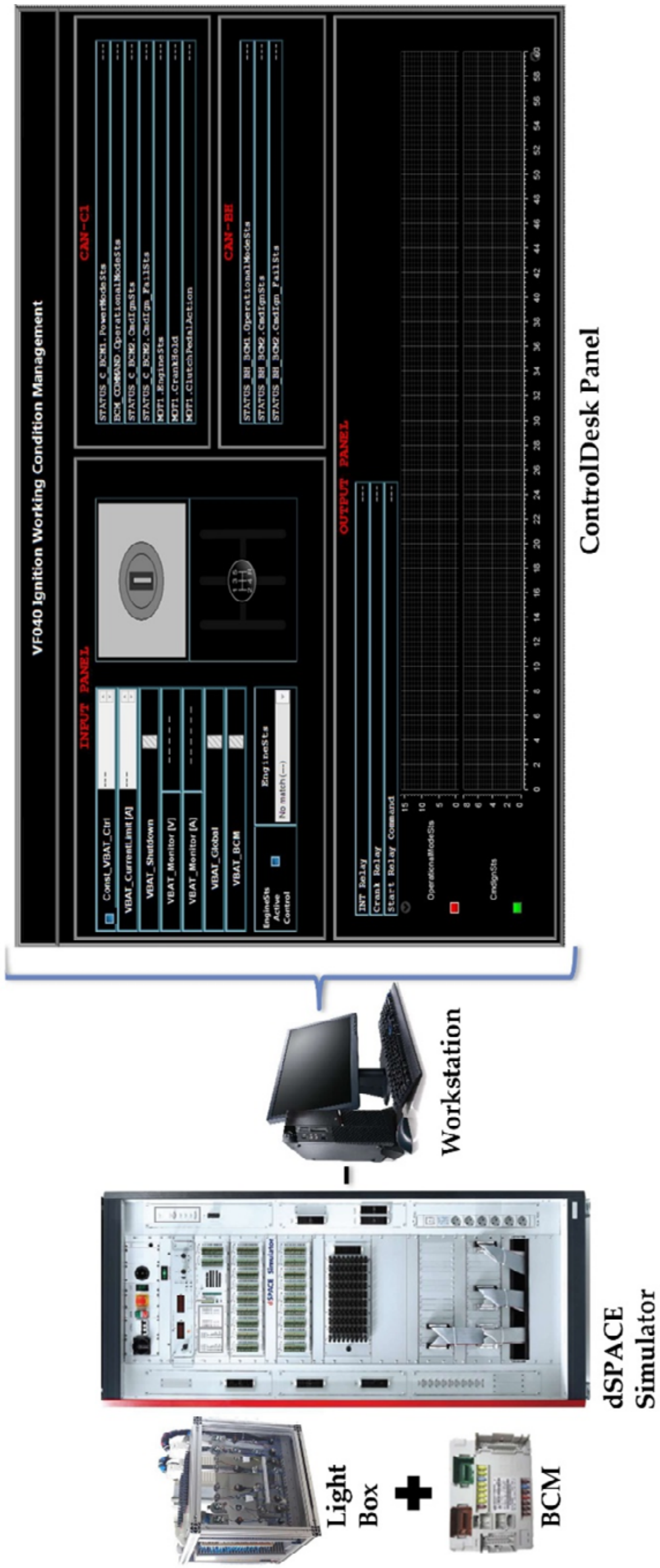

Fig. 16 Complete BCM HIL Test System

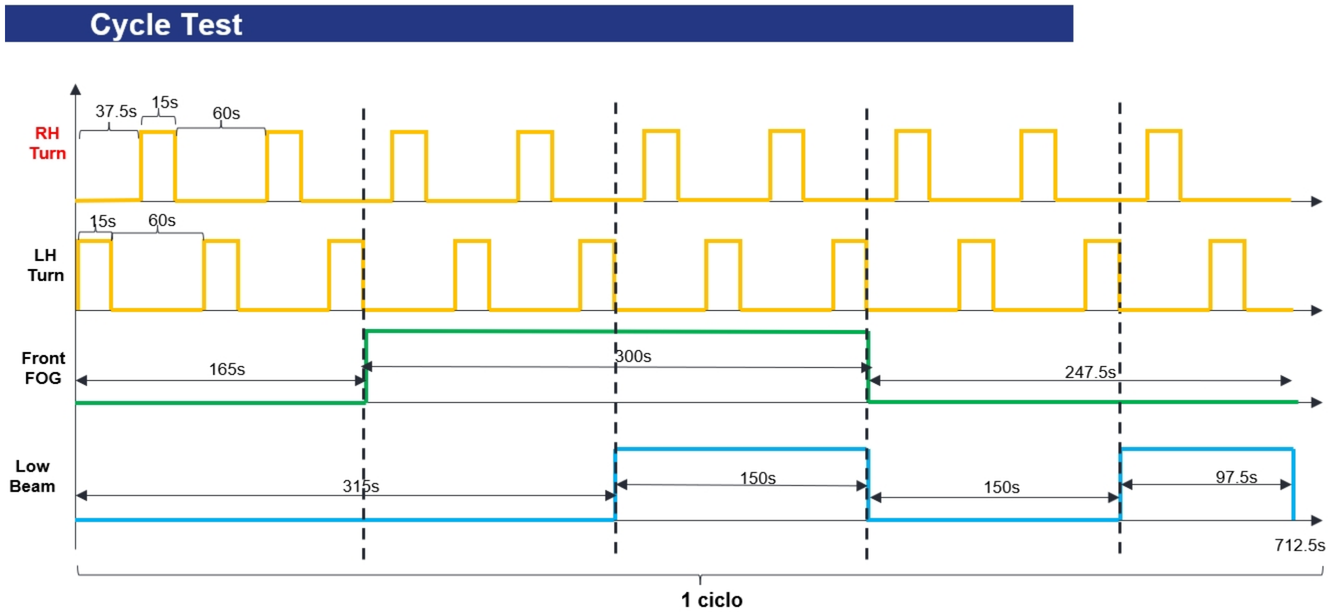

Fig. 17 ON-OFF Test Cycle Validation Results

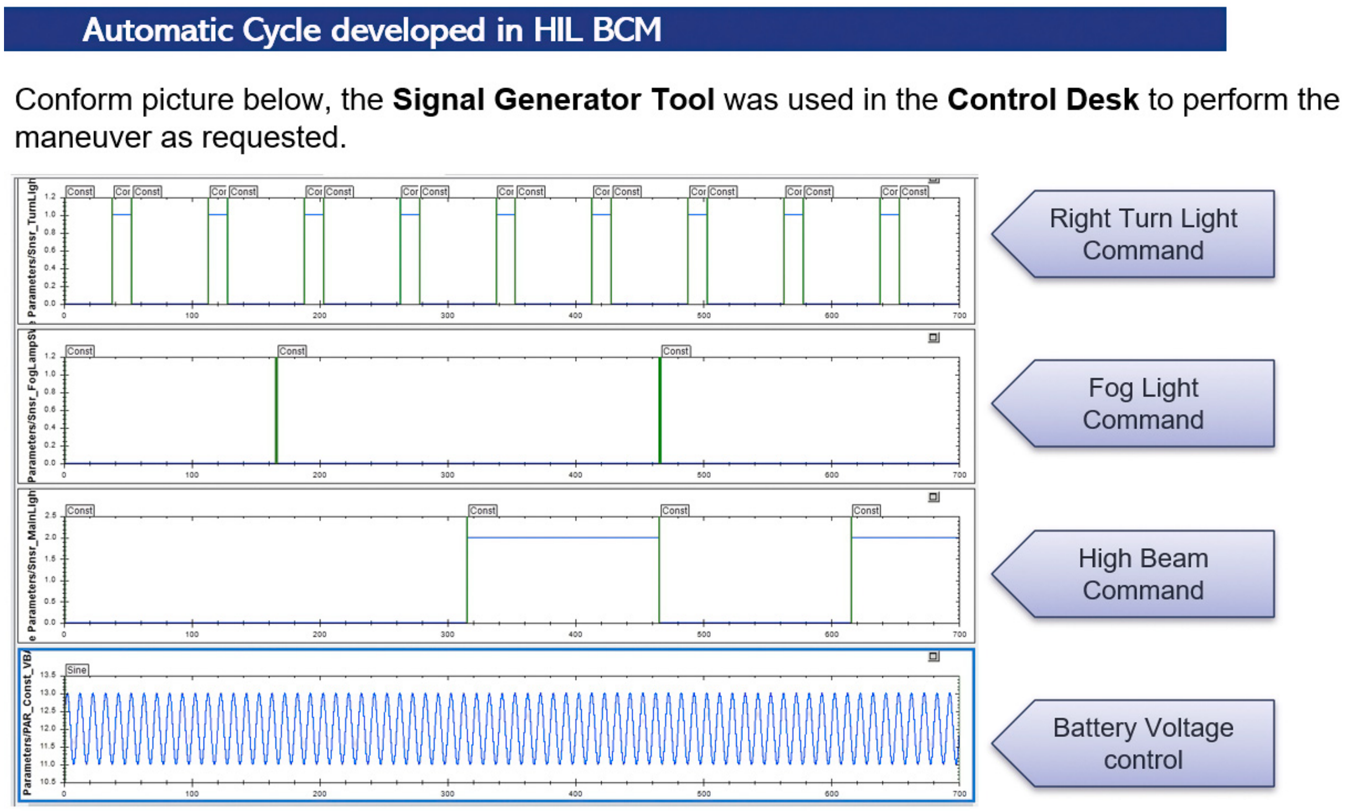

Fig. 18 Results of the load state validation during the test.

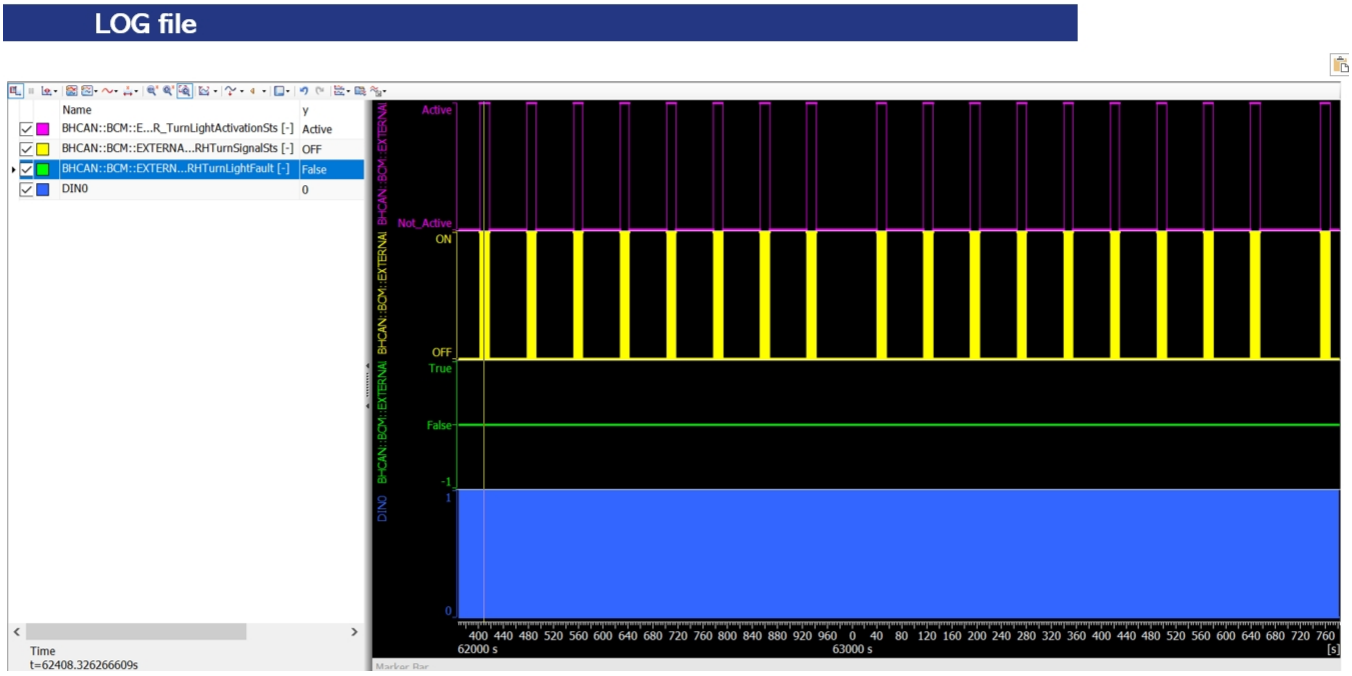

Fig. 19 Results of the ON-OFF repetition validation in critical state

Fig. 20 Results of the loads' operation compliance validation

VII. Conclusion and Discussion

The digital age has affected the automotive market positively, raising customer expectations for safer and more specialized vehicles. This has created challenges for the industry to produce the market need, encouraging the use of virtual testing, consequently, xIL. As a result, the complexity of vehicle production has affected not only engineering teams but all technological sectors. Therefore, changing testing methodology can provide innovations by increasing product quality and decreasing production time and cost. In this context, this work presented a case study to optimize the tests performed with the central BCM and the actual internal/external light of the vehicle using HIL. Aa load box was developed where case studies were carried out that defined each stage of the research of creation, structure, assembly, and validation.

Tests were performed for lamp actuation, fault insertion, and integration with other power plants or functions. The comparison of test times using a systemic bench versus a component HIL showed the HIL to be more efficient, allowing the automation of tests and simulation of power plants not present on the test bench; on the other hand, it was not possible to perform the same tests on the bench. However, its Development is a direct application to the BCM ECU, and the vehicle light loads are only a part of all the tests that are performed in the validation of the vehicle throughout the development process.

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