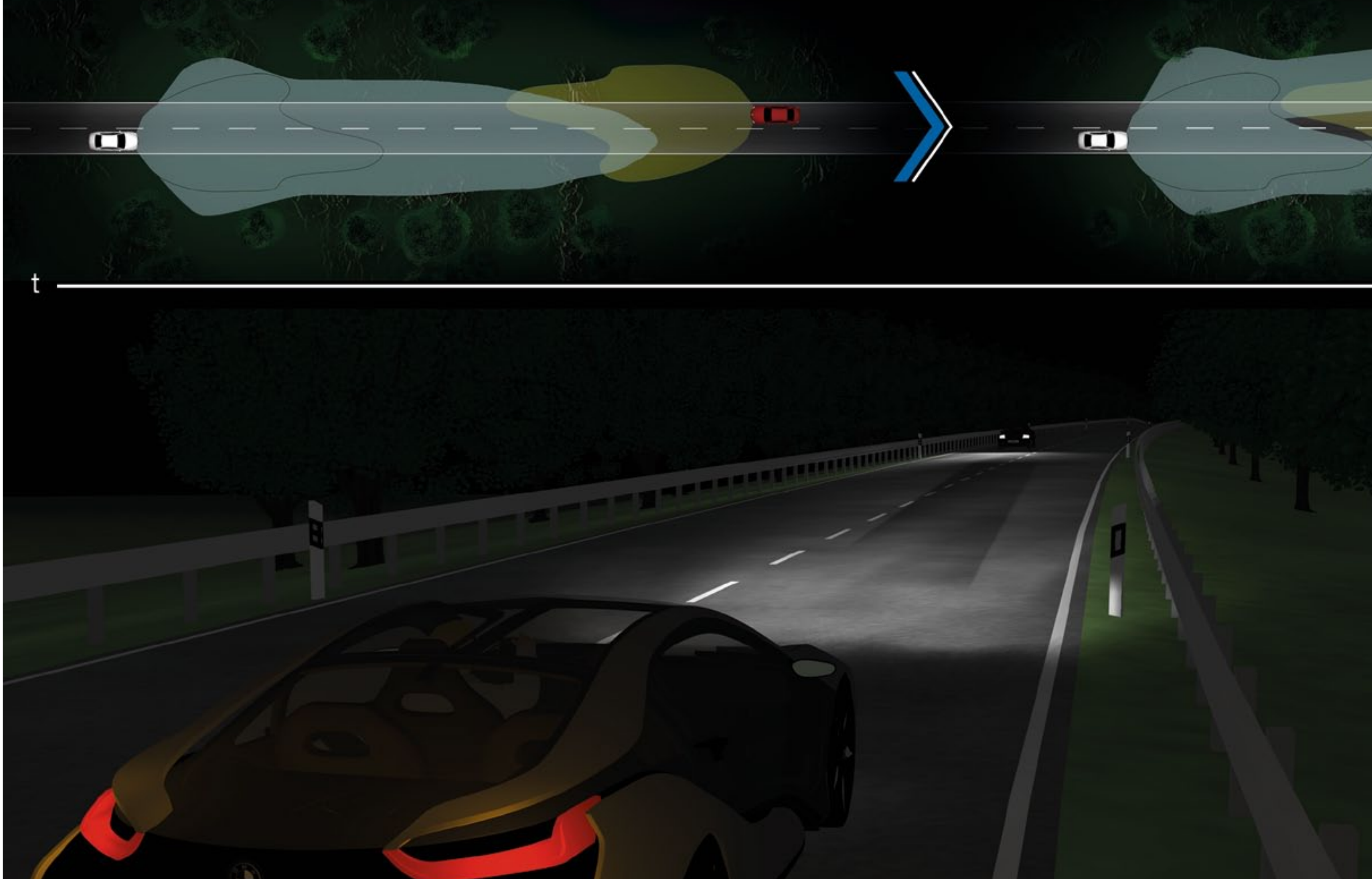
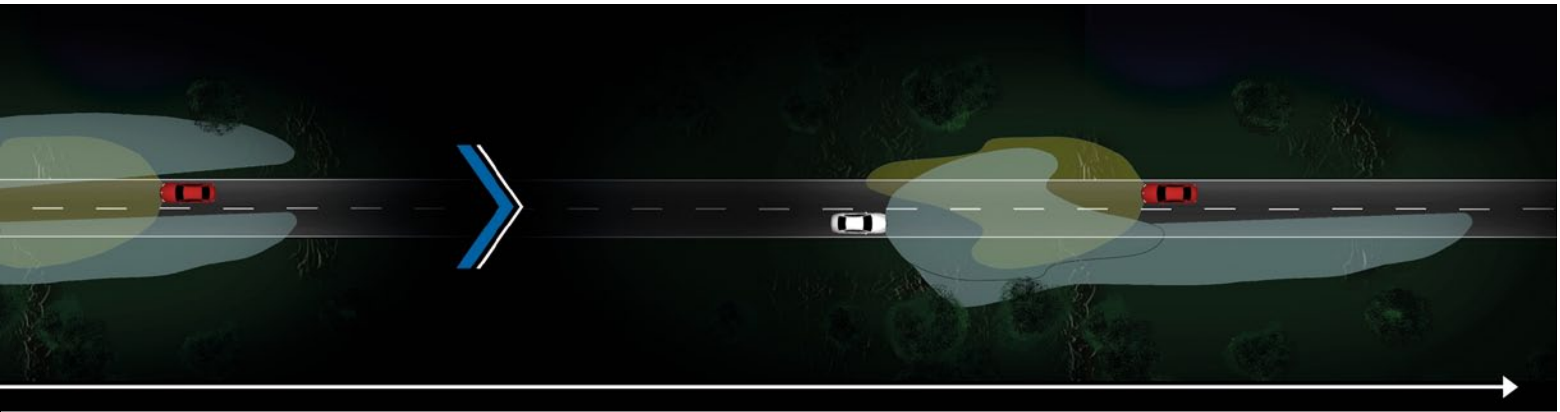


REDUCED VALIDATION EFFORT FOR DYNAMIC LIGHT FUNCTIONS

Increasingly advanced driver assistance functions and their integration result in higher complexity of the systems and their validation. This also applies to dynamic light functions which provide situation-dependent headlight adjustment consisting of adaptive headlight, headlight leveling and (glare-free) high-beam assistance. The required road tests can often be performed only at night. BMW AG and IPG Automotive are developing a problem-solving approach here which makes it possible to significantly reduce the validation effort and to manage the requirements for safety-related functions associated with ISO 26262. It combines in-development testing and the standardised Functional Mock-up Interface (FMI) with the methods of virtual test driving.



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MOTIVATION

Advanced driver assistance systems (ADAS) provide a significant increase in comfort and safety. In many cases, a single vehicle contains several assistance systems, with the number of safety-relevant control systems constantly rising. From an overall perspective, it must be assured that all driver assistance systems – individually as well as in the way they interact – deliver reliable and faultless functionality for any driver or in any driving situation worldwide. This results in higher development and testing requirements, which becomes evident when validating dynamic light functions as well.

New light functions are specified based on models and checked using simple test cases with Model-in-the-Loop (MiL) simulations. Subsequently, C Code is generated from the specification models and integrated into the electronic control unit (ECU) software as an Autosar software component. Approval is provided through Hardware-in-the-Loop (HiL) testing based on real-world measurement data or synthetic stimuli.

Finally, the desired functionality is tested and evaluated only at a late stage of the development process, namely in the completed vehicle. Software-in-the-Loop (SiL) simulations provide the developers with evaluated concept design decisions at an earlier stage. The stimuli are based on recorded test drives or manually generated scenarios. This process, up to now, has been subject to various restrictions:

- In the case of modified controller software open-loop tests are reusable only to a limited extent.
- If additional evaluation scenarios emerge during the analysis of the interaction of the controller and the plant, they have to be recorded again in real vehicle tests. Furthermore, the tests required for these scenarios can be neither reproduced nor performed for all conceivable variants.
- The transfer to different vehicle configurations or new vehicle variants is only partially possible. Due to the limited availability of prototype vehicles in the respective development stages only a small number of tests are possible in many cases.

Automated full vehicle simulations enable driving scenario tests with SiL simulations. This could reduce the workload of the HiL test rig resource and allow valid statements about a new function to be made at a significantly earlier stage.

STANDARDISED INTEGRATION

Software can easily and conveniently be integrated into a full vehicle simulation by means of the new Functional Mock-up Interface (FMI) [1]. C Code, in a standardised form, is executed here as Functional Mock-Up Units (FMU) in an integration platform. FMUs consist of the software libraries compiled for the respective target systems and an interface description. The XML-based description file encompasses all inputs and outputs of the software component as well as encoding parameters. Due to the high abstraction level of the FMI and low requirements for the execution environment FMUs can be used across the entire development cycle: from MiL and SiL to HiL as well as test rig simulations [2].

For software functions already available as Autosar software components, it is possible to automatically derive the FMUs. FMUs can also be generated manually, e.g. by means of a wrapper-generator script in Python [3]. This allows the addition of further functionality, such as the conversion of floating-point to fixedpoint numbers, as used in embedded controllers. The generation of FMUs is described in detail in [4].

INTEGRATION AND TEST PLATFORM IN COMBINATION WITH XIL

In addition to the universal usability of the FMUs, the availability of a seamless integration and testing platform is an essential element of the development method presented here. For this purpose, the CarMaker open integration and test platform has been equipped with the X-in-the-Loop (XiL) development method [5]. This integration platform enables the integration of FMUs as models, ECU software or real-world vehicle components into a virtual prototype by mouse click [6]. Due to this virtual integration new functions can be studied in the full vehicle during the development process, ❶.

Furthermore, CarMaker as a test platform features a maneuver description oriented towards real-world road tests. Complex open- and closed-loop tests are executed as maneuver instructions. In the same way, scenarios for testing the dynamic light functions are created as maneuver catalogues. Subsequently, the effects of the tested functions on the performance of the full vehicle are analysed through virtual test driving so that design decisions are evaluated in the context of realistic driving situations as early as in the concept design stage.

This is where the advantages of virtual test driving come into effect, with the test scenarios and test results being reproducible. Furthermore, a centrally provided maneuver catalogue can be universally applied across various domains in vehicle development. This catalogue is extended as required in order to comprehensively validate the concept design as well as the implementation of ECU software.

USE IN THE PROCESS – DYNAMIC LIGHT FUNCTIONS

The combination of FMI and CarMaker provides consistency with respect to function models and/or software functions as well as controller distance content and maneuver descriptions. The example of the dynamic light functions illustrates how current demands on an efficient development process can be satisfied this way.

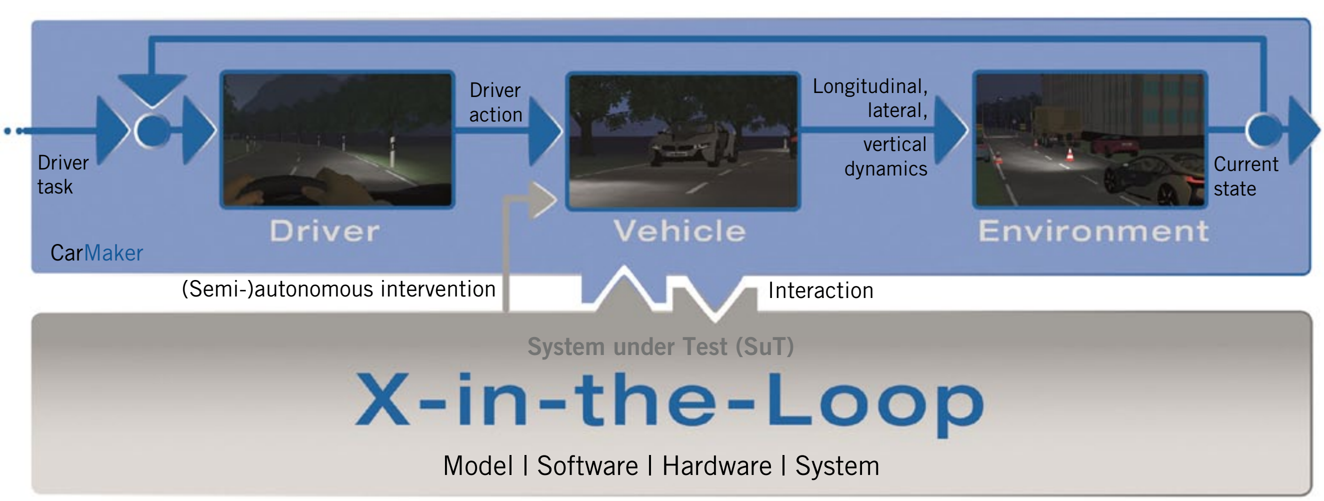
USE IN THE PROCESS – MODEL-IN-THE-LOOP

Using the MiL method, function specifications are developed further and made assessable. The fact that functions can be tangibly experienced not only supports the decisions regarding their use but also permits innovations to reach production-level maturity. In the dynamic light functions project, CarMaker for Simulink is used. Here CarMaker with its full functionality is combined with the advantages of Simulink: fast modeling of new functions or stability statements for controllers. Alternatively, an FMU can be generated via relevant extensions from the Simulink model and integrated into the full virtual vehicle.

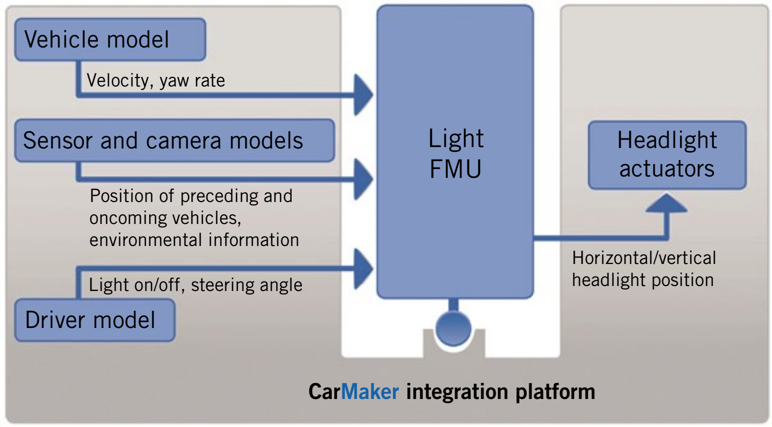
During the virtual test drive the available sensor models forward information about light sources of stationary or moving vehicles to the function model. In turn, the function transfers the calculated light distribution to the headlights in CarMaker for Simulink so that the light distribution can be immediately experienced in the 3D animation. During this process the function responds to signals from the realm of vehicle dynamics, sensors and camera systems as well as driver inputs (e.g. steering angle, manual headlight adjustment).

USE IN THE PROCESS – SOFTWARE-IN-THE-LOOP

The functions checked in the MiL simulations are compiled with model-based tool chains or written directly in C Code. Following the approval test, the Autosar-conformant ECU code is available for the HiL rig test. The challenge posed by SiL simulations lies in comprehensively testing the software component with respect to the implemented sub-functions. For this purpose, available test cases from the MiL simulations can simply be adopted and extended, e.g. for degradation, runtime or over-run tests. In this case, too, the FMI standard decisively contributes to the fast integration of the



❶ XiL and CarMaker: System and functions can be integrated into a full virtual vehicle and consistently be studied in virtual test driving; in addition to a powerful vehicle and driver model, an environment simulation with a sufficient level of realism is available here – consisting of the road, traffic, sensors, cameras, etc.



❷ Function models and software components are integrated into the virtual prototype as FMUs

software component, as the FMU is linked to the full vehicle by the same signals that were already used in the MiL simulations, ❷.

USE IN THE PROCESS – HARDWARE-IN-THE-LOOP

Aside from their use in the SiL test, FMUs can serve as substitutes for – so far – non-existent ECUs in distributed systems alongside existing real-world ECUs. Thus, FMUs make early complete-system simulations possible.

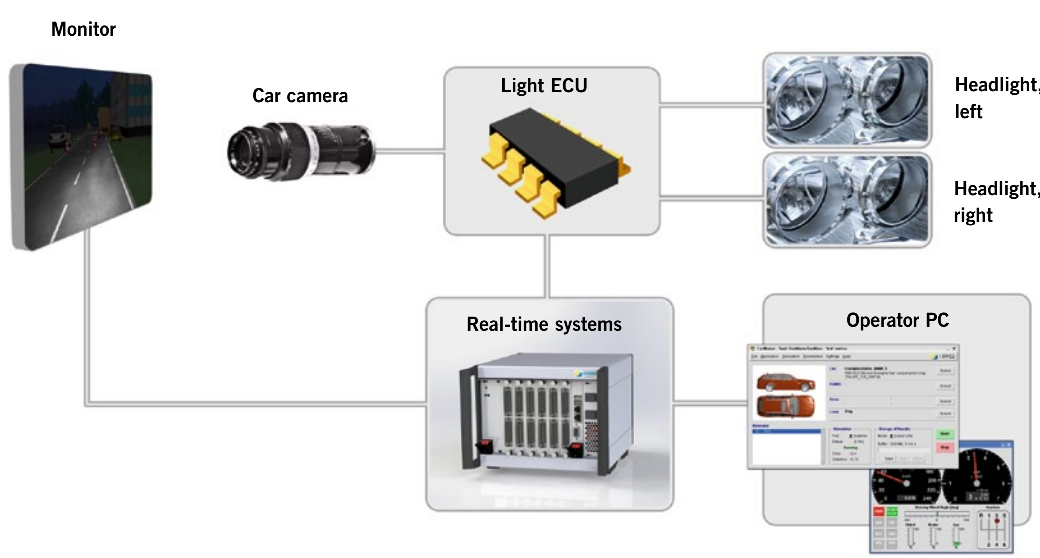
HiL simulations, just like the integration and test platforms, are applied to approve ECUs for use in the vehicle. The smooth operation of an ECU typically requires a so-called residual bus simulation. The relevant signals may be static but they may also be dynamically fed in by CarMaker, depending on the property to be tested. Furthermore, the test cases generated for MiL / SiL simulations can be reused and extended, e.g. for communication tests with other ECUs.

The establishment of a link with the real-world camera ECU extends this HiL set-up. With currently available monitor technology the filming of driving scenes by a camera may not always be a viable solution. Instead, the camera function receives a video data stream directly from the simulation [7]. Consequently, the sensor portion of the camera is disregarded. The camera function forwards the generated list of objects to the light ECU to calculate the light distributions. These light distributions are then directly displayed on the monitor, ❸. This sub-system may be varied according to the availability of real components. Apart from that, the use of FMUs instead of the camera function or the headlight actuators is certainly just as conceivable.

❹ compares a still from a real-world video recording (below) [8] and the corresponding simulated driving situation (above). The darkened area vis-à-vis the oncoming vehicle is clearly discernible. On the left-hand side, the headlight has been dimmed while on the right-hand side the headlight shines past the oncoming vehicle.

SUMMARY AND OUTLOOK

By combining in-process development testing, the Functional Mock-up Interface (FMI) and the seamless integration and test platform the current development process can be redesigned in a more efficient way. Furthermore, the gap in the SiL area is closed. With this development environment, the control loops “vehicle on the road” and “camera-detected light sources” can not only be analysed at the required level of detail but also extended step by step, for instance by additionally taking into consideration the position of the headlight actuators as well as the simulated illumination by the headlights. Subsequently, the utilisation of the test system will be evaluated in the light-testing facilities for illumination studies



❸ Set-up of an HiL test rig for the event chain test: operation terminal and HiL system, real-world or simulated control panels, light ECU, headlights with electric motors, camera for filming the monitor; the ECU software in the camera is fed by a video data stream as needed involving different vehicle models. Furthermore, a reduction of the test effort relating to the large number of variants can be achieved by using the Design of Experiments method in combination with conclusive real-world road tests [9]. For this purpose, the most critical and extreme parameters possible within the range of variants that is to be validated are subjected to real-world road testing and simultaneously simulated in virtual test driving. The assumptions serving as a basis for these tests can be further specified and adjusted by targeted test drives. With the conclusiveness of virtual test driving constantly improving thanks to improved data, real-world road tests could become increasingly more dispensable. This harbors further potential for reducing the validation effort in the future.

❹ Comparison of the light function: video (below) with glare-free high beam and its simulation (above)

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