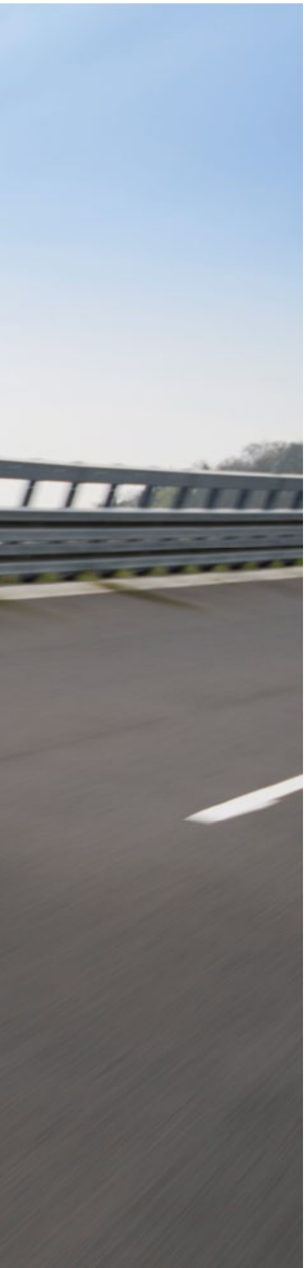
THE NETWORKED HYBRID CONCEPT FOR SPORTS CARS

Bosch Engineering GmbH has converted a sports car with a V12 internal combustion engine and manual six-speed transmission into a vehicle with an axle-split hybrid powertrain. By doing so, the Bosch subsidiary is demonstrating the potential of electrification for utilising cross-domain systems knowledge to reduce fuel consumption and CO_2 emissions, improve vehicle dynamics and performance, and expand customisation possibilities specifically in the sports car segment.



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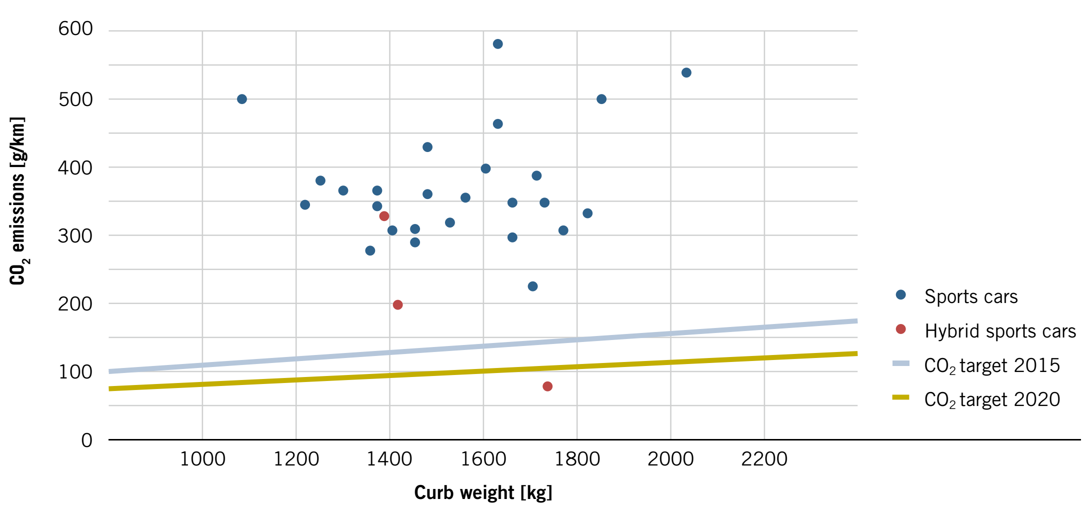
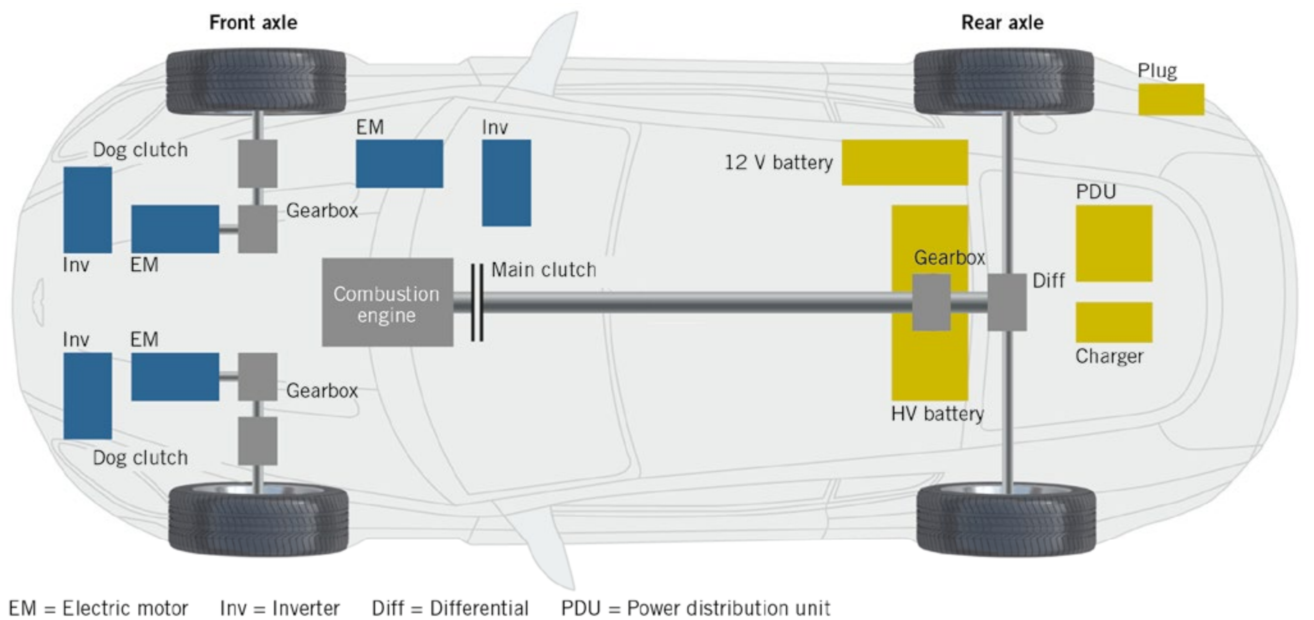
MOTIVATION

The latest emissions standards to be adopted, which set the limits for 2015 and 2020, require ambitious technical progress in reducing fuel consumption. This affects mid-range and premium vehicles as well as sports cars. In order to permanently reduce fleet emissions to meet the specified targets, modern vehicle development is focusing on sustainable system solutions. ❶ shows the weight-classified CO_2 emissions of sports cars with gasoline and hybrid powertrains currently available on the European market, alongside the emissions limits for 2015 and 2020. To get closer to these limits, sports car manufacturers are already employing classic engine-based CO_2 reduction strategies, including IC engine displacement downsizing, dethrottling, and cylinder deactivation. However, vehicles in the sports car segment will not reach the new emissions limits by IC (internal combustion) engine measures alone. In combination with other measures targeting other parts of the vehicle, powertrain electrification is a sustainable move with the potential to bring sports cars' CO_2 emissions below future statutory limits for the long term.

With its hybrid concept car, Bosch Engineering GmbH is demonstrating the benefits of electrifying high-performance sports cars in terms of fuel consumption and CO_2 reductions, improved vehicle dynamics, innovative HMI concepts, and personalised driving functions. In a matter of months, the Bosch subsidiary converted the DB9 with its IC engine and manual six-speed transmission into a car with an axle-split hybrid powertrain. To do this, 30 new components were integrated into the vehicle in the domains of powertrain, vehicle dynamics, body, and multimedia. These components were then networked with each other and with the base vehicle's systems, and new driving functions were developed. The networking concept and the new functions can be adapted in subsequent series-production projects to different manufacturers' brand concepts and their requirements with respect to the driveability, comfort, and dynamics of their vehicles.



❶ Sports car emissions values



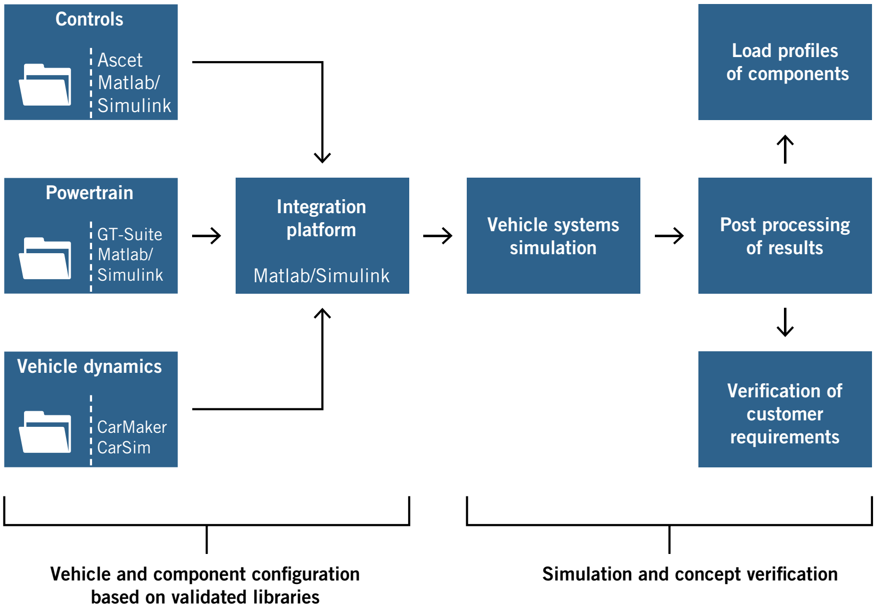
❷ Powertrain topology concept vehicle

HYBRID CONCEPT

Performance, efficiency, and vehicle dynamics are key factors in developing high-performance sports cars. When electrifying the powertrain, not only must no compromises be made in these crucial areas, it is also important for customer acceptance reasons to actually improve them via a suitable hybrid concept. Moreover, a hybrid powertrain should allow automakers to adapt the driving characteristics of their predominantly rear-wheel drive sports cars to specific brands to a great extent. To meet these requirements, the conventional powertrain of an Aston Martin DB9 was converted into an axle-split hybrid powertrain with two separate wheel-specific electric motors (Bosch SMG 180/120) on the front axle, ❷. A general advantage of this topology is that it makes it easier to integrate the requisite hybrid components into existing powertrain architectures based on conventional IC engines; the vehicles do not have to be developed from scratch. Installing two wheel-specific electric motors on the front axle also allows for additional vehicle dynamics functions, such as torque vectoring, integrated vehicle dynamics control, and temporary four wheel drive. In addition, the concept car was fitted with a third electric motor (Bosch SMG 138/80) on the drive belt, which facilitates both power-assisted steering and air conditioning by powering the belt drive at the IC engine. Both these functions were transplanted unmodified from the base vehicle. The third electric motor can also be operated as a generator in conjunction with a specially developed overrunning clutch on the crankshaft and supplies the vehicle's 12-V electrical system via an intermediate DC-to-DC converter. Three Bosch Invcon 2.3 power electronics units serve as central interfaces between the electric motors and the high-voltage battery.

CROSS-DOMAIN VEHICLE DEVELOPMENT

All the additional components together with their wirings made the concept car 280 kilograms heavier than the base vehicle, so the challenge when converting the powertrain was to observe the CO_2 limits despite the additional weight while also improving performance. Even though drive power was increased by 169 kW and the hybridisation delivers high torque, it is the extra weight along with the change in center of gravity and suspension characteristics that determine the sports car's handling. Consequently, the focus was on implementing a system design that incorporated all vehicle domains right from the start of the development process, so as to factor in the dependencies and interactions of the powertrain and vehicle-dynamics domains along with their respective subsystems. To use simulation to good effect in system design, Bosch Engineering developed a software platform that provides a fast and efficient comparison between different powertrain topologies with regard to fuel consumption, CO_2 emissions, and basic longitudinal dynamics performance. In order to include vehicle dynamics characteristics, corresponding sub-models were added to the simulation platform, ❸. The vehicle simulation also reproduces powertrain components' thermal behaviour, taking into consideration power losses from energy storage. By using cross-domain simulation, it was possible to simulate and evaluate the boundaries of dynamic performance over defined parameters while taking account of lateral dynamic performance and to compare them directly with those of the series production model [1]. The results showed the hybrid concept car consuming 50 % less fuel compared to the conventional powertrain. At the same time, there was a significant improvement in vehicle dynamics performance, measured by acceleration time, ❹. Initial validation results are confirming the simulation figures: in test drives, acceleration time from 0 to 100 km/h was reduced by 21 % and from 0 to 200 km/h by 19 %. More



❸ Simulation platform

results are to follow. In other vehicles, these values can vary depending on the capacity of the installed battery, the recovery capacity, and the operating strategy.

MECHANICAL INTEGRATION

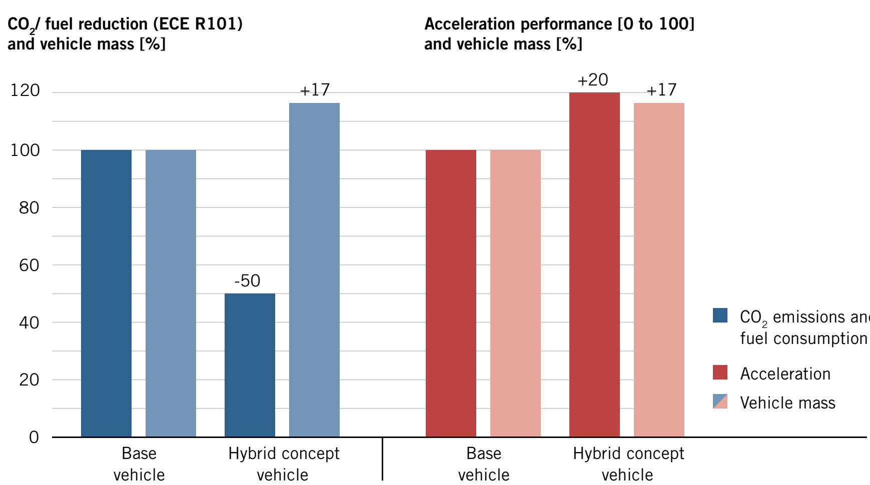
Mechanical integration of the car's 30 new components was carried out by Bosch Engineering at its Holzkirchen site near Munich. The engineers and developers converted the powertrain by installing the separate wheel-specific drives on the front axle and the third electric motor on the drive belt. To do this, they integrated a combination of available Bosch components, third-party provider components, and new, specially developed components into an overall system. All three of the car's electric motors and the power electronics are Bosch products. The commercially available, series-produced components from third-party providers are the charger, the charge plug, and the power distribution unit (PDU). A third-party provider's high-voltage battery was developed and built as a prototype following the specifications. For power transmission from the two drive shafts to the front wheels, Bosch Engineering developed and prototyped an adapted the suspension geometry. The team also developed a new gearbox with a disconnecting clutch to integrate the powertrain components into the base vehicle. For each front wheel, it connects the electric motors to the wheel with a gear ratio of approx 1 : 6 and a 90 ° rerouting for reasons of installation space. The scarcity of installation space available inside the unchanged base-vehicle body was the biggest challenge for the developers when it came to developing and integrating the gearbox. As a solution, they modified components such as the chassis frame in the engine compartment, adjusted the position of the engine, sub-frames, and further components (including in the steering), and manufactured new attachments. For the electrical powertrain components, Bosch Engineering developed an independent cooling circuit along with an additional autonomous cooling system for the high-voltage battery. The latter was integrated into the concept car instead of the fuel tank, and a prototype solution was also developed for the tank system together with its pumps, hoses, level sensors, and purging mechanisms, ❺ [2].

Besides converting the powertrain, the developers in Holzkirchen also integrated the components of the new HMI concept with its 7-inch head unit, 12-inch instrument cluster with fully digital display, and 10-inch tablet computer, as well as the control unit and networking architecture behind the user interface. As regards vehicle dynamics, the base vehicle's existing brake system was replaced with a Bosch ESP system in order to implement – in combination with the separate wheel-specific drives on the front axle – new torque vectoring functions and integrated vehicle dynamics control.

To enable the conversion of the concept car to be accomplished within just ten months, a total of 75 developers and engineers worked together in a simultaneous engineering team at two locations.

OPERATING STRATEGY AND MODULAR HYBRID PLATFORM

The operating strategy for the concept car was developed with numerous different driving modes in order to meet customer demand for the greatest possible



❹ Simulation results

❺ Mechanical integration

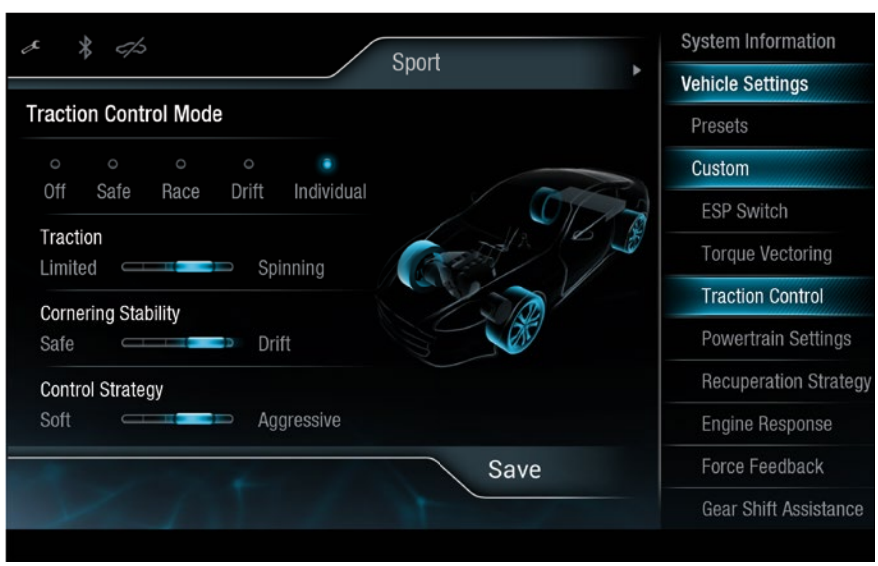
degree of vehicle personalisation. In addition to fully IC engine and fully electric modes, various hybrid forms are also possible. The standard hybrid mode, which is called Hybrid Eco, prioritises efficiency and low fuel consumption. In Hybrid Sport mode, by contrast, drive torque distribution is designed for sportier, more agile driving. The IC-engine is activated at all times and the boost function is used for support at certain times, such as when overtaking or when starting the vehicle. The Hybrid Race mode was developed for use on closed racing circuits. If, in addition to standard information such as vehicle model, battery state of charge, recovery potential, and the power of the electric motors, information is available on the routes of the circuits, the operating strategy calculates an optimum boost strategy to minimise lap times. The Custom hybrid mode allows drivers to select their personal preferences for all personalisable characteristics. They can also save their preferred configurations and access them at any time.

In addition, the concept car includes various functions that allow drivers to personalise the vehicle's driving behaviour to meet their personal preferences. This includes the ability to set a custom recuperation level as soon as the driver's foot lifts from the accelerator. To this end, a force feedback pedal has been integrated into the vehicle, whereby an electric motor generates a resistance force that presses against the driver's foot. When driving in all-electric mode, for example, drivers can be notified via a signal in the pedal as soon as the electric motors have reached maximum output. This enables drivers to instinctively recognise that the IC engine will be activated if they do not ease up on the accelerator. In other words, they can directly influence changes in the operating modes of the hybrid system. In addition, drivers can determine the pedal's feedback by means of various fixed settings, including a "kick-down mode" and various profiles with constant force balance [3].

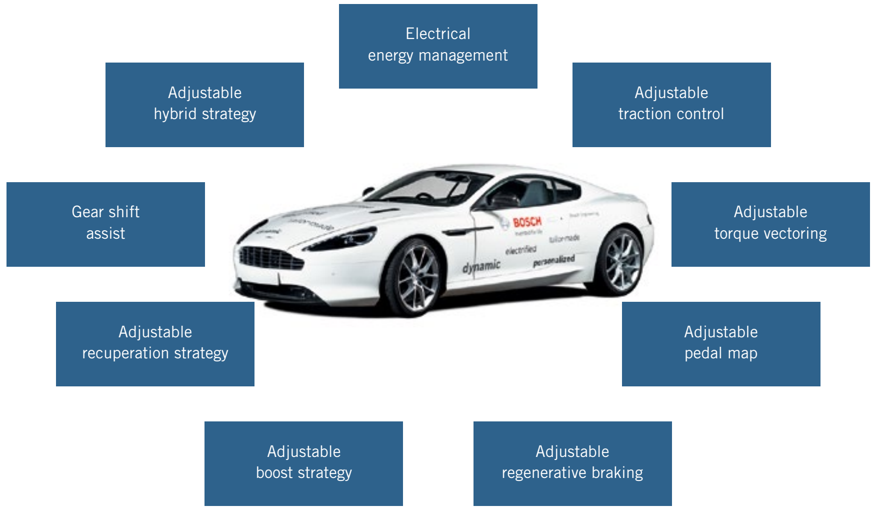
The Bosch Engineering simulation platform, which was already introduced at the systems development stage for the vehicle, was also used for development of the operating strategy and the driving modes and functions. For example, it simulated certification driving cycles such as the NEDC for the EU market and FTP75/US06 for the U.S. market. To provide more efficient support for the development of hybrid and all-electric powertrains for small-scale series customers in future, Bosch Engineering has developed a modular hybrid software platform. With this software, users can quickly and efficiently adapt a self-developed platform operating strategy to a variety of powertrain topologies. To do this, the software platform integrates the electric motors contained in the respective topology on the one hand and the interfaces of numerous control units – including from the driving dynamics, body, and multimedia domains – on the other. The vehicle's thermal system is also integrated into the development process for the operating strategy, along with the respective temperatures of the IC engine, electric motors, and catalytic converter, the battery's state of charge, and the specific torque of the electric motors.

VEHICLE DYNAMICS

A big advantage of the concept car's hybrid powertrain topology is the power it gives drivers to influence driving dynamics. This power is exercised via the two new wheel-specific electric motors in conjunction with the newly integrated ESP system. The integrated vehicle dynamics control function, developed and



❻ Graphical user interface of the tablet-PC for vehicle dynamics adjustments patented by Bosch Engineering, connects these actuators with each other. In this topology, the function can achieve software-based improvements in vehicle dynamics behaviour that not even chassis adjustments could deliver. The wheel-specific electric motors on the front axle are networked with the IC engine and wheel-specific braking to optimise lateral dynamics. As a result, the application of integrated vehicle dynamics control in this vehicle comprises three pre-set driving programs as well as a freely adjustable mode, which satisfies customers' need to be able to personalise the vehicle as much as possible [4]. In addition to integrated vehicle dynamics control, the concept car can also implement torque vectoring and temporary four-wheel drive functions.



❼ Overview of tunable functions

PERSONALISATION CONCEPT

A variety of personalisation strategies that allow drivers to influence vehicles' driving behaviour are already on the market – especially in the premium segment. For this purpose, automakers often offer fixed, internally coordinated vehicle configurations that affect several systems in the vehicle. If drivers choose eco or sport mode, for example, the gearbox, steering, damping, and ESP are all set, coordinated, and preconditioned accordingly. Drivers are often unaware of the specific settings made for the systems and they cannot control these settings individually. The hybrid concept car's personalisation concept gives drivers control over these settings. As a result, they can use the capacity and performance provided by the vehicle systems to their full potential.

First of all, drivers can activate or deactivate all personalisable functions by selecting various user profiles. A distinction is made here between two categories of driver: those who want to use predefined vehicle setups as before and those who want to adjust individual driving functions precisely to reflect their personal preferences. In the area of driving dynamics, this means that drivers can make their own individual settings for features such as the control threshold for traction control, steering behaviour, cornering stability, and the accelerator performance curve. Drivers who do not want to make detailed settings for personalisable functions can continue to select predefined driving dynamics setups. However, the concept also gives them the option of continuously adjusting driving characteristics such as over- and understeer via intuitive, easy-to-use digital controllers, ❻. The integrated vehicle dynamics control then translates the driver's commands into action by setting the available actuators and functions in optimum configurations to deliver the desired driving behaviour. In the concept car, the new personalisation concept was implemented for driving dynamics functions and hybrid powertrain functions, ❼.

HMI CONCEPT AND E/E SYSTEM

The diverse range of personalisable vehicle functions in the concept car requires ergonomic control and display concepts with HMIs that are easy to operate and that provide an intuitive experience. It is through these interfaces that the complex technical interrelationships are communicated to drivers, so it is vital that they enable clear, easy-to-understand driver-vehicle interaction. For the concept car, the team developed an operating and display concept with a uniform visualisation design containing a 12-inch fully digital instrument cluster, a 7-inch head unit, and a 10-inch tablet computer as output media. Feedback to drivers takes the form of visual, tactile, and acoustic signals. In addition to the visible components in the vehicle's interior, the underlying control unit architecture and the E/E system were also newly developed and integrated. The interfaces are controlled via a body computer module, a central, domain-independent control unit; this in turn is connected to the vehicle systems in all domains, such as the hybrid ECU, the battery management system, the inverters and the electric motors, the ESP, and the navigation system. Consequently, the concept car's electrical and electronic systems illustrate the integrated development of the system architecture particularly well.

A particular challenge when developing the concept car's E/E system was how to expand an existing architecture consisting of the on-board communication and energy systems without making extensive alterations to the control units and components of the base vehicle. It was important here for the changes not to impair existing functions. Comprehensive cross-system simulations were one of the tools used to evaluate the various possible approaches for resolving this challenge. These simulations made it possible to analyse the effects of the expanded and adapted subsystems and components at the level of the overall vehicle [5].

Beyond its system boundaries, the concept car is also connected to digital infrastructure and cloud-enabled data platforms. On the one hand, this lets drivers implement additional driving functions by integrating predictive navigation data (electronic horizon), including predictive hybrid strategies that adapt to the route ahead and real-time synchronisation with traffic data.

On the other hand, drivers can also download individual driving profiles, vehicle setups, and functions via cloud-enabled data portals. Telemetry data about laps driven on racing tracks can be evaluated online and exchanged with other drivers. This external connectivity allows automakers to offer additional software functions, setting them even further apart from the competition.

SUMMARY

Efficient, high-performance, customisable, and networked: electrifying the powertrain of sports cars is more than just a means of slashing emissions to comfortably meet future statutory limits. It also opens up new brand differentiation possibilities for vehicle manufacturers in the areas of driving dynamics, multimedia, and personalisation.

Mastering this additional complexity requires overarching systems knowledge about the interplay between the different energy storage and powertrain systems and the vehicle domains of powertrain, vehicle dynamics, body, and multimedia. In addition, intelligent functional and software development can resolve the challenges of electrification. Innovative control and display concepts help drivers to manage the increased complexity and give them a completely new driving experience. What is more, the technology gives manufacturers the power to create distinctive unique selling points.

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