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CONNECTED, ELECTRIFIED: ELECTRONIC SYSTEMS IN A HYBRID CONCEPT CAR

In developing a hybrid concept car based on the Aston Martin DB9, Bosch Engineering has shown the potential that resides in the electrification of sports cars. As well as reduced fuel consumption and emissions, this includes enhanced driving dynamics and greater possibilities regarding vehicle customisation. The high degree of networking within the vehicle requires complex electrical and electronic systems and permits a large variety of driving functions. To ensure technical control of all this complexity and to make it come alive for drivers, high-performance on-board communications, energy, and high-voltage traction systems were developed by Bosch Engineering combined with an ergonomic driver interfaces concept.

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VEHICLE CONCEPT

In the past, observing EU5 and EU6 emissions limits was just one focus of vehicle development. The latest standards to be adopted have set the CO_2 emissions limits to be achieved by 2020, making the reduction of fuel consumption to meet these stricter limits a central concern when developing modern vehicles. Manufacturers of sports cars are not exempt from this challenge. In order to reduce CO_2 emissions, they are already using measures that target the combustion engine, such as downsising, dethrottling, and cylinder shutoff. These measures are complemented by others that focus on non-engine related ones, such as reducing rolling resistance, weight reduction of the vehicle, and optimising aerodynamics. Electrification of the powertrain is a sustainable move that makes it possible for vehicles to meet future CO_2 emissions standards over the long term.

In the case of high-performance sports cars, the primary objective to date has been achieving maximum engine performance while keeping the car as light as possible. Although integration of electrified drives into the cars means additional weight in the first instance, electrification provides opportunities for improved efficiency, driving performance, and driving enjoyment as well as greater customisation of sports cars, as described in ATZ 11/2014. This is made possible by increased networking and synergetic use of the powertrain, chassis, body, and multimedia, which have often been treated as completely separate domains during the development process. Networked vehicle systems open up new possibilities in the area of driving dynamics. For example, the torque from the additional electric drive enables greater vehicle acceleration, while new functions such as torque vectoring and integrated vehicle dynamics control are made possible in the first place. Moreover, innovative vehicle functions and customisability play a particularly important role in brand differentiation for many vehicle segments and especially for high-priced sports cars, whose end customers often have very specific requirements and preferences.

Manufacturers already offer adjustable chassis and a choice of various set driving modes, often in the form of internally coordinated vehicle configurations that influence several systems in the vehicle. If the driver chooses the eco or the sport mode, for instance, the transmission, steering, damping, and ESP are all adjusted, coordinated, and preconditioned accordingly. In order to fulfill customers' very diverse and challenging requirements, however, in the future it will be possible to further develop driving characteristics to include new customisable vehicle functions, allowing drivers to continue to choose a various set, internally coordinated configurations or to adjust them for every drive according to their personal preferences or outside conditions.

In addition to innovative and predictive hybrid strategies, this includes new functions that arise from the use of predictive navigation data (electronic horizon). The development of high-performance on-board energy and communications systems is a prerequisite for these complex electrical and electronic systems, with their great variety of distributed functions. Communication across different vehicle domains is the basis for reliable and efficient energy management.

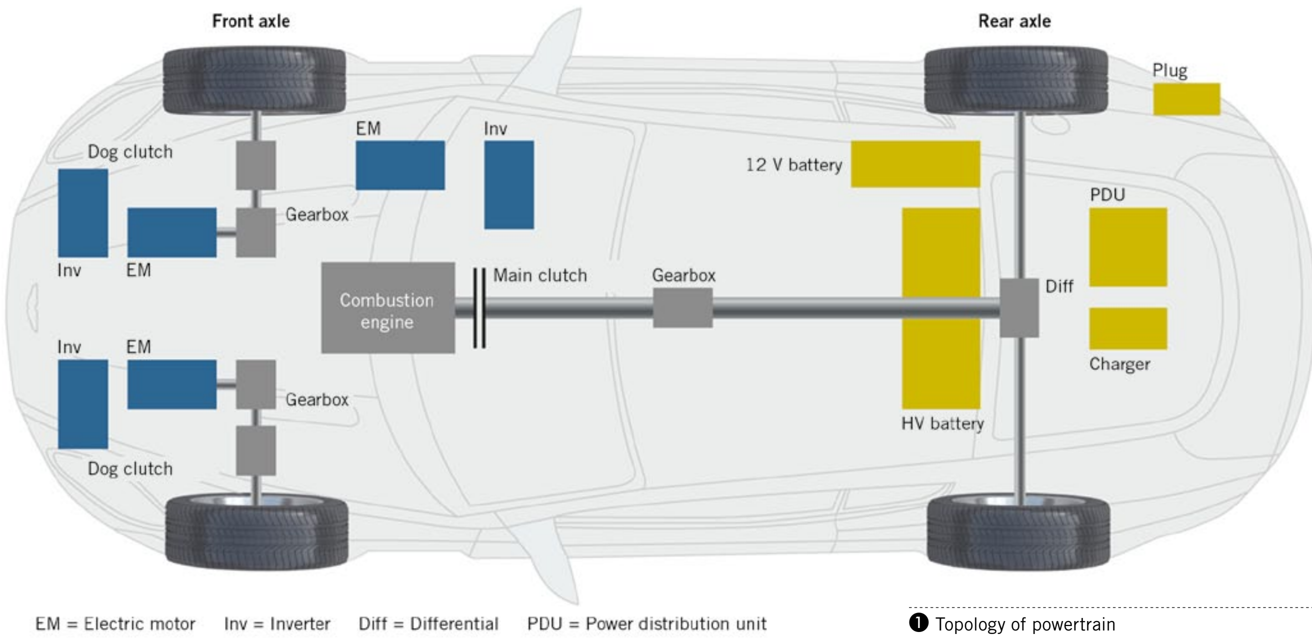
VEHICLE DEVELOPMENT

Vehicle manufacturers design and develop new vehicle functions to fit their brand philosophy. Bosch Engineering GmbH developed the hybrid concept car, ❶, to demonstrate new driving functions as well as the potential of networked systems across the different domains of a sports car. The vehicle functions in the concept car can be adjusted and experienced by drivers within their operational limits and can be adapted and customised for individual customers in series production projects.

At the start of the development process, target functionalities were systematically defined to apply across vehicle domains and their individual requirements were specified at the vehicle level. The goal of development was to build an integrated system architecture based on the defined functional requirements. The implementation of the networking and communication concept came from the functional requirements. Performance of the overall system was always prioritised over the performance of individual subsystems and components. This recognises the key role played by an overall vehicle system design that takes into account from the very beginning the dependencies and interactions between the domains of powertrain, driving dynamics, multimedia, and body along with their respective subsystems in successful vehicle development.

Among the new vehicle functions are the following:

: customisable hybrid strategies with adjustable driving modes for comfort, sporty, and energy-efficient driving
: integrated vehicle dynamics control with adjustable modes for comfort and agile driving as well as driving on closed-course racetracks
: torque vectoring and customisable four-wheel drive functions
: driving functions with dynamic force feedback pedal
: driving functions by networking with predictive navigation data (electronic horizon)



❶ Topology of powertrain

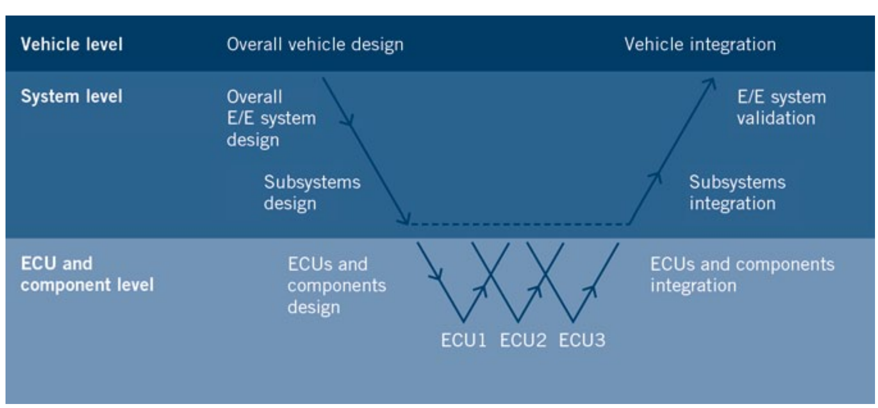
: driving functions via connection to external digital infrastructure and cloud-based data platforms.

In addition to the requirements of the individual functions, the engineers also defined the requirements for their technical implementation in a future-ready E/E system. The first question they explored in this regard was whether a centralised or decentralised ECU architecture would be most suitable. Defining the ECU architecture was therefore the primary step in the development of the vehicle's E/E architecture and a fixed part of the requirements specifications for the individual ECUs.

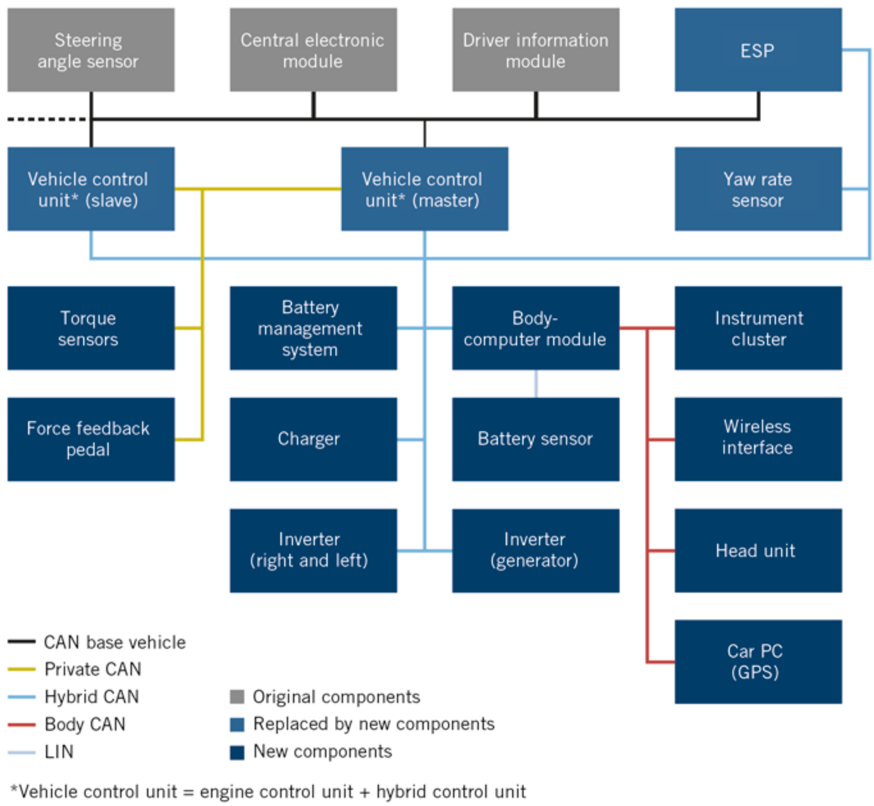
Once the technical requirements and the fundamental ECU and HMI architecture had been defined, the engineers turned their attention to the complete on-board power supply system, including the high-voltage traction system and the regular low-voltage system, and came up with a terminal control concept. Subsequently, they fleshed out ECU communication, working out details such as the frequency at which signals are exchanged between control units. In addition, they simulated ECU communication in advance in order to determine data communication utilisation, taking into account both the communication requirements of the base vehicle and communication involving the new components integrated into the vehicle. Next, the engineers specified the various bus systems, such as CAN and LIN, to be used for communication. To fully exploit the networking potential in the future, the design makes it possible to use the high-performance, high-speed Ethernet bus system.

E/E SYSTEM

The integrated development of the system architecture is most reflected in the vehicle's electrical and electronic (E/E) system, ❷. When developing an E/E system and defining its requirements, the first thing engineers must consider is what would make an optimum system from the perspectives of the different development areas (low-voltage on-board supply, mechanical integration, electrical integration, electromagnetic compatibility) before going on to lay down evaluation criteria and weight them from the perspective of the overall vehicle system. A particular challenge faced by the engineers when developing the E/E system was how to expand an existing system architecture consisting of the on-board communication and energy systems without applying extensive changes to the control units and components of the base vehicle. Comprehensive system simulations were one of the tools the engineers used to evaluate the various possible approaches for resolving this challenge. The simulations allowed them to analyse the effects of the expanded and adapted subsystems and components at the level of the overall vehicle.



❷ E/E system integration process



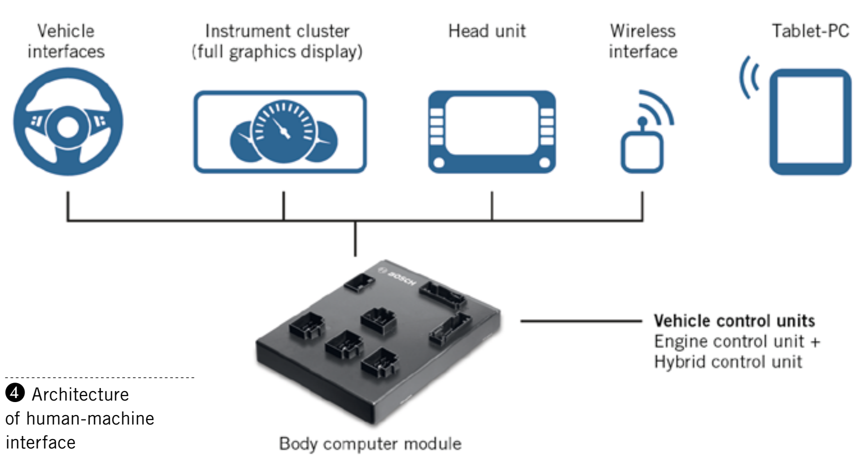
❸ On-board communications system

As a result of the new vehicle states (e.g. charging mode, electric/hybrid driving mode) and driving functions, the requirements for the wake-up and sleep concept have changed. It was important for existing functions not to be affected by these changes. The engineers analysed the transitions between the specific vehicle states and defined them at the overall vehicle level for the individual subsystems and components. They took into account both ECU-specific requirements and requirements at the functional level, such as for the electrical energy management system. The wake-up and sleep concept was used as the basis for defining the terminal concept.

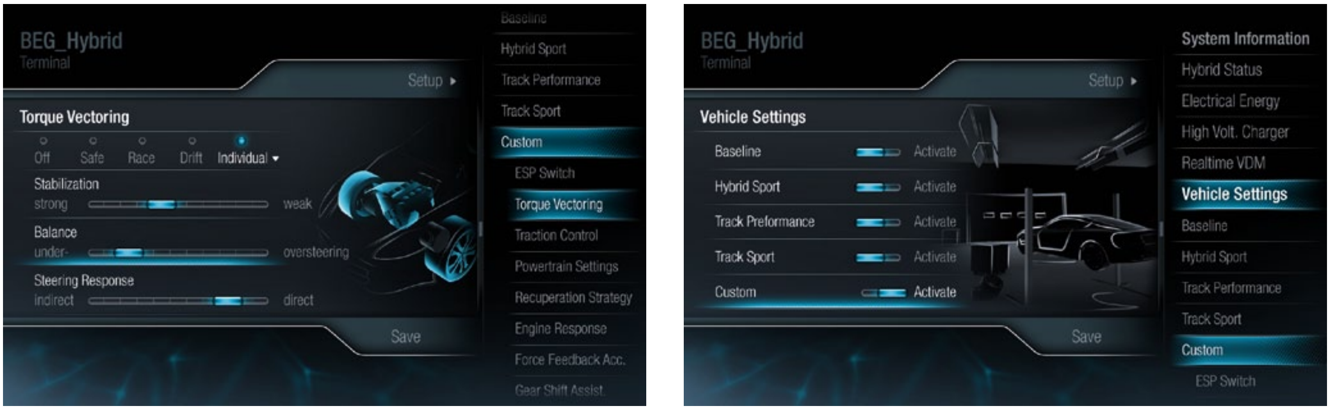
The wiring harness was developed on the basis of the new electrical system architecture. Its purpose in the vehicle is to ensure that all electrical components are efficiently and reliably supplied with energy. Due to the growing number of electrical systems and components in vehicles, wiring harness development is playing an increasingly important role in terms of overall vehicle development. When designing the wiring harness for the hybrid concept car, the engineers took into account the following criteria: installation space, packaging (dimensioning and positioning of the components and electrical wires), ambient conditions, component-specific requirements, partitioning and distribution concepts, and electromagnetic compatibility. Wiring harness development is an important factor in using the available installation space in the car efficiently and ensuring optimum energy distribution. Following analysis of the energy distribution in the base Aston Martin DB9 car, the engineers developed an energy supply concept for the newly installed components. They started out with a rough architecture and then filled in the details in an iterative process that involved weighing up the different contributing factors. Finally, they dimensioned the wire cross-sections, fuses, and connectors and documented them in corresponding plans, which then formed the basis for the wiring harness configuration and subsequent installation in the car.

Development of the high-voltage traction system is influenced by numerous factors, of which interdependencies between installation space, cable routes, and electromagnetic compatibility are among the most important. In addition, safety-relevant systems such as isolation monitoring and the high-voltage interlock system for monitoring the high-voltage connectors have to be defined, developed, and integrated into the system. Consequently, the corresponding error responses were defined at the overall vehicle level. These requirements influence further cross-domain functions and how they communicate in the system; driver visualisation is also affected.

A key component of the E/E system, the on-board communications system ensures secure and reliable data exchange between a vehicle's electronic systems. During the development process for the concept car, the communications requirements were identified both within individual domains and across domain boundaries, and a new communications concept was created on this basis. In order to implement the new vehicle functions, additional communication buses were defined and the capabilities of the



❹ Architecture of human-machine interface



❺ Graphical user interface tablet PC

existing bus systems were expanded. The amount of additional data transmitted over existing bus systems was kept to a minimum so as to avoid overloading the communication buses in the base car.

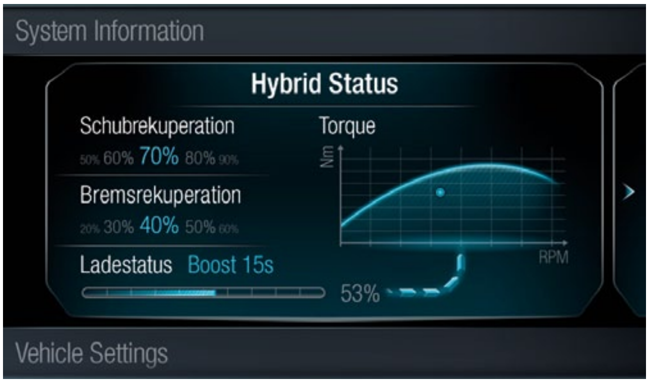
Two new busses were added to the base car, a hybrid CAN and a second body CAN. The hybrid CAN connects the components of the electric powertrain, such as the vehicle control units, inverter, battery management system, and charger. The body CAN networks the HMI concept control units, such as the Bosch fully digital instrument cluster, the wireless gateway as an interface for a tablet computer, the head-unit display, and the car PC. The body computer module is designed as a gateway between the two new hybrid and body busses. In addition, the gateway is used as a central HMI coordinator in order to coordinate the driver's commands and feedback from the domains and allow them to be visualised in a uniform format, ❸.

CONTROL AND DISPLAY CONCEPT

The diverse range of customisable 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 hybrid concept car, the engineers developed a control and display concept with a uniform visualisation design containing an instrument cluster, a head unit, and a tablet computer as output media, ❹. The head unit and instrument cluster in the base vehicle were replaced by new ones, whereas the tablet computer was a new addition. The parameters of the available vehicle functions are customised using the tablet computer and the buttons and switches in the car interior. So as not to change the esthetics of the vehicle interior all too much, it was decided not to fit additional switches and controls. This is realised via the tablet computer, ❺, which is connected to the body computer via Bluetooth, an important new interface with the driver. An advantage of having a tablet computer as an input medium is that it allows users to thoroughly customise the wide range of vehicle functions offline, away from the vehicle, and at their leisure. Only a limited, carefully chosen range of vehicle functions can be controlled from the tablet computer while the car is in motion so that drivers are not overwhelmed by a barrage of additional information. Drivers can fine-tune the settings of features relevant to driving dynamics – such as torque vectoring, recuperative braking, and the accelerator performance curve – while driving without taking their hands off the steering wheel. The feedback given to drivers

❻ Graphical user interface instrument cluster



❼ Graphical user interface head unit

❽ Body computer module

about the settings they have chosen takes the form of visual, tactile, and acoustic signals.

The instrument cluster with its fully programmable graphical display, ❻, was designed to show drivers only driving-relevant vehicle information, warnings, and safety-relevant changes to customisable functions while they are driving. In this customisable hybrid car, displays and information for drivers change frequently, which could quickly become very distracting for drivers. To prevent this from happening, all the information to be displayed was compiled in a priorities model. The display of temporary messages and information was carefully sequenced due to a priorisation concept to ensure that there is not too much information appearance on the instrument cluster and that drivers are not distracted. The head unit, ❼, is used for visualising information specific to the hybrid powertrain. In addition, the dynamic force-feedback accelerator pedal provides tactile feedback on the hybrid strategy, while further rockers and steering-wheel buttons allow functions to be selected and parameters adjusted while driving. The interfaces are controlled centrally via the body computer, ❽, which is connected to the vehicle systems across all domains, including the hybrid control unit, the battery management system, the inverter, the electric motors, the ESP, and the navigation system. Drivers also have the option of connecting to cloud-based data platforms and downloading individual driving profiles and real-time information about the driving environment and synchronising it with the vehicle [1].

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 vehicle dynamics, multimedia, and customisation.

Mastering this new and additional complexity requires domain-independent 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 by means of new functions and innovative control and display concepts.

REFERENCE

[1] Bihr, B.; Freudenstein, S.; Hofmann, H.; Pieraccini, G.: Performance and efficiency – technical solutions for high-performance sports cars to achieve future CO_2 limits. 14th Stuttgart International Symposium for Automotive and Engine Technology, 2014

THANKS

Bosch Engineering GmbH developed the concept sports car with hybrid powertrain as a demonstration vehicle. It does not form part of any preparations for series production by Aston Martin. Bosch Engineering expresses its gratitude to Aston Martin Lagonda Limited, which provided the Aston Martin DB9 that served as the base vehicle, for the support provided to this unusual project.