WHITEPAPER

New drive solutions for modern BEVs

In-wheel motors and skateboards

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Table of contents

Most battery electric vehicles currently in use have primary and/or auxiliary e-axles that integrate the e-motor, transmission, and inverter. However, this results in lower efficiency due to losses at low speeds. New designs, such as the skateboard architecture, address this challenge, and enable cost-effective and efficient electric vehicles.

By Giovanni Parrino, Infineon Technologies

As part of the mobility transition, conventional internal combustion vehicles are being replaced by battery-only electric vehicles (BEVs). Currently, the most popular driving systems for BEVs are integrated drive modules, also known as e-axles. Unlike conventional axles, they integrate the electric motor, the inverter, and the transmission. Their thermal management also differs significantly from that of conventional axles.

One of the most critical systems in the e-axle is the traction inverter, as its specific characteristics have a strong influence on the overall performance and efficiency of the vehicle. The most common configuration today is a two-stage B6 configuration because it requires fewer switches and is easier to control. Depending on the different power classes and torque requirements of the vehicles, architectures are implemented with one or two e-axles with different characteristics:

- The primary e-axle is responsible for the vehicle motion and contributes most to the overall efficiency (Figures 1a and b), partly thanks to the regenerative braking. For this reason, the traction inverter is usually based on SiC MOSFETs (modules or discretes), as they offer about five percent longer range compared to conventional IGBTs, especially at partial load [1].

- The secondary e-axle helps to achieve the maximum torque and speed targets: Its operating time can even drop to as low as 10 percent (Figure 1c). In this case, the inverter operates in a narrow operating range and is mainly based on IGBTs, as they are less expensive and offer good performance in high power operation.

However, the secondary e-axle increases not only the performance but also the overall cost of the vehicle, which is why it is only used in higher power classes. Furthermore, a mechanical differential coupling is mounted on the additional e-axle, which provides a different torque for each wheel. This also increases mechanical maintenance and losses due to additional gears and transmission losses.

Alternative drivetrain architectures are shown in Figures 1d to h: In addition to the traditional single- or dual-axle options, a dedicated inverter could be provided for a single wheel, increasing the number of motors up to four. Controlling a single electric wheel motor by a dedicated inverter system makes it possible to simplify the system and achieve higher efficiency with lower maintenance compared to the differential approach.

Figure 1g shows one of the most popular concepts: a rear e-axle and two front in wheel motors. Due to advanced torque vectoring algorithms, it is mostly used for high-performance sports cars. The concept with four in-wheel motors (IWMs) (Figure 1h) is also ideal for achieving a natural AWD configuration.

1 In-Wheel Motors

By installing an electric motor in the wheel hub, each wheel can be driven directly without the need for a transmission. Until now, technological constraints have limited their widespread us. But now with increasing electrification and high demand for efficiency and space flexibility, wheel hub motors are on the rise. The architecture of an in-wheel motor is defined by the presence of independent corners corresponding to each individual wheel.

Three different setups are possible, depending on IWM requirements and technologies:

- Inboard configuration: The motor and inverter are in a central position on the chassis; the direct connection to the wheel is made via cardan shaft.
- Close-to-wheel configuration: The motor and the inverter are located on the chassis; the direct connection to the wheel is made via cardan shaft.
- In-wheel configuration: The most compact solution where the motor is embedded in the hub while the inverter can still be in the chassis or even integrated into the wheel hub.

IWMs improve handling and grip because advanced torque vectoring algorithms can be implemented for each wheel to reduce the turning radius to almost zero.
They also increase available space and provide better weight distribution between the front and rear axles for added stability and handling. However, the architecture shifts a significant amount of mass to the unsprung area, which affects handling and reliability by transmitting bumps or vibrations directly to the drive system. For this reason, the suspension may need to be redesigned. One way to reduce unsprung mass is to reduce or even eliminate the mechanical brakes on an axle, since braking power can usually be achieved through recuperation.

This new architecture concept could become the next breakthrough trend in electric drive design. But it has significant hardware and software-level implications and is currently only intended for specific use cases where design flexibility and high maneuverability are required, such as buses, vans, and people movers.

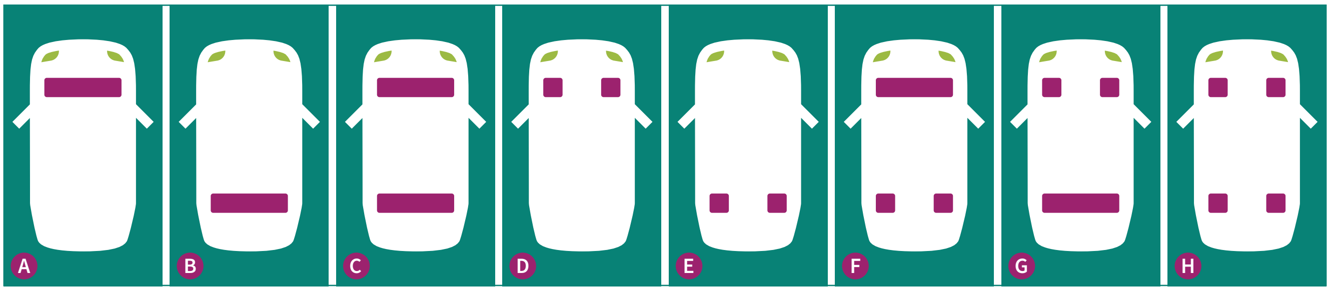

Figure 1 Possible engine configurations in a passenger car. © Infineon

2 What's inside an IWM?

To achieve higher mechanical robustness in the architecture, three-phase brushless radial flux motors are sometimes chosen instead of axial flux machines, usually driven by a standard two-stage inverter. For micromobility, a classic 48 V solution is usually sufficient to deliver about 20 kW per wheel with low-voltage MOSFETs in the drive inverter. The design of such an air-cooled system is quite challenging because once the vehicle stops after a high-load condition, there would be no air flow, a critical thermal condition for the inverter devices. For higher power classes, liquid cooling is mandatory, but integrating the cooling circuit into the hub places additional demands on the final mechanical design.

The maximum power for commercial vehicles is higher than 100 kW per active wheel. For higher power applications, the most common battery voltage class is around 400 V, which is compatible with standard BEV chargers already available today. Architectures with higher battery voltages of up to 800 V are useful for heavy-duty commercial vehicle applications, but otherwise offer few additional benefits. The switching voltage class ranges from 650 V to 750 V, for which efficient SiC MOSFET technology is usually preferred over IGBTs to reduce power dissipation. In addition, a package with low thermal resistance and low inductance is required to minimize power dissipation. Therefore, a double-sided cooling package is useful, such as the Infineon HybridPACK™ DSC with CoolSiC™ G2 (Figure 2).

Figure 2 With HybridPACK DSC based on CoolSiC G2 technology, high power density can be achieved. © Infineon2

3 The advantage of the skateboard architecture

IWMs are the starting point for adapting the value chain, enabling new business models for the entire field of electromobility. The “rolling chassis” or skateboard architecture offers greater freedom in vehicle design and use. Typically, conventional platforms are customized by the respective car manufacturers as a modular system to meet the respective requirements and the responsibility for applications such as braking, and drive systems lies with the car manufacturers. In contrast, a skateboard architecture is independent of the development work of the respective OEM. Instead, the focus is on the electric drive concepts developed by the system integrator, which include the wheels and the flat battery pack. Modular designs from skateboard suppliers provide a high degree of flexibility, which is important to meet different vehicle layout requirements. The introduction of standard modules available to multiple customers will also have a positive impact on maintenance and service.

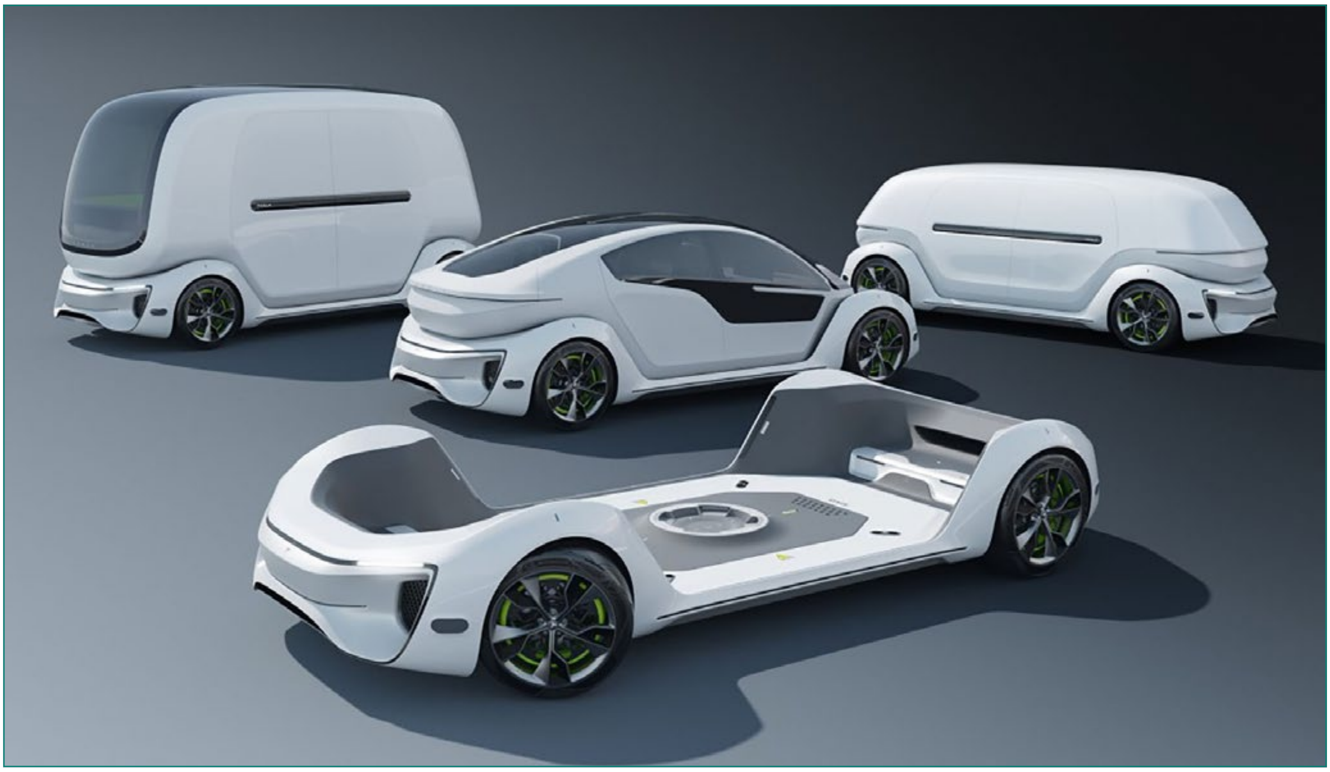

Figure 3 Example of different use cases for the same skateboard architecture. © Elaphe

All major vehicle motion tasks such as suspension, steering, propulsion, and braking are not assigned to specific areas, but are handled by the intelligent actuators in the “corners”. Thus, the skateboard integrator provides all vehicle motion (VMO) features and characteristics, including the drive motor, brake, damping and steering to a complete, rideable base platform. These designs behave differently than standard platforms in terms of safety and impact performance, which is why some skateboard manufacturers offer to qualify the battery pack. The car manufacturer is then only responsible for the final calibration and application. As a result, even software and delivery service manufacturers without an actual automotive background can build their own vehicle as an OEM without having to worry about the electric drivetrain. Additionally, much-needed vehicles could be brought to market more easily to fill some gaps in future mobility.

By-wire technology, such as steer-by-wire, which controls drive functions without a direct mechanical connection to the user, is also a special feature of skateboard concepts: This is supported above all by the push toward autonomous driving up to level 5.

The change in the supply and thought chain will also have a major impact on the standard E/E (electrical/electronic) architecture in vehicles and leads to new safety requirements. A central vehicle control unit (VCU) will request torque for each wheel individually to control the overall vehicle dynamics and determine the driving style. For this, the AURIX™ TC3x and upcoming TC4x families from Infineon with their OPTIREG™ PMICs offer an excellent combination of performance, functional safety, and protection, allowing control of vehicle movement to be taken at tactical and strategic levels.

4 Functional safety in a skateboard architecture

Drive systems must prevent incorrect or unintended torque from being transmitted to a wheel at all times and under any conditions. If a random fault occurs on a single inverter in a single e-axle architecture, it can transition to the so-called safe state within the fault tolerance time interval (FTTI) – for instance 100 ms. Depending on the exact conditions under which the fault occurred and the functional safety strategies of the system integrator, this safe state can be a freewheel (motor windings “open”) or an active short circuit.

An advantage of the four IWM skateboard architecture is the inherent redundancy in the event of a single drive failure: The affected system and the system in the same axis are put into the same safe state by the safety software in the FTTI. With the other IWMs still operational, the vehicle can drive home or to the nearest garage with reduced power.

Furthermore, the volume in the wheel hub is limited, so the mechanical brakes and their cooling should be accommodated in one of the axles. In this case, strong regenerative braking by the electric motors would come into play, reducing the unsprung masses in the wheels, as well as the cost of the drive concept. However, regenerative braking alone is not sufficient for emergencies, so mechanical brakes will still be implemented in at least one of the axles.

Usually, functional safety goals cannot be achieved with a single device. For this reason, Infineon combines tailor-made products for traction inverters that enable a strong safety concept while reducing development effort. For the implementation of safe skateboard architectures, developers can choose from a powerful series of current sensors (TLE947x), a new generation of isolated high-voltage drivers EiceDRIVER 1EDI30xx, and the AURIX TC3x and TC4x families with proprietary PMICs. In addition, the Infineon chipset offers the key features of an ASIL-compliant inverter design with the smallest PCB footprint and parts count.

Summary

The various electric vehicle architectures, particularly skateboard designs with up to four in-wheel motors, offer an unprecedented level of modularity and flexibility. In addition, the skateboard approach is seen as a potential evolution of OEM platform design, which has implications for the traditional supply chain, system responsibilities, and relationships between the car manufacturer and system integrators. These linkages have implications for functional safety goals and concepts, resulting in the skateboard architecture and hardware and software designs being adapted accordingly.

References

[1] Ajay Poonjal Pai; et al: Efficiency Investigation of Full-SiC versus Si-based Automotive Inverter Power Modules at Equal Commutation Speed. VDE

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