A High-Performance, Integrated Powertrain Solution: The Key to EV Adoption

TEXAS INSTRUMENTS

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This paper examines the benefits of using an integrated powertrain solution to speed adoption of electric vehicles through power electronics. Implementation of wide band-gap semiconductor switches and isolated gate drivers are highlighted to illustrate the value of powertrain integration.

At a glance

Powertrain integration is crucial to enabling mass market adoption of electric vehicles.

1 Performance improvements: increasing power density

Isolated gate drivers with advanced diagnostics and protection features enable integration and lower cost.

2 Wide band-gap semiconductor devices: a disruptive technology in the automotive market

Using silicon carbide (SiC) and gallium nitride (GaN) for power switches enables higher efficiencies in electric vehicles.

3 An integrated powertrain solution at a system level

Lower costs and maximize board space with the powertrain system in one unit.

Automotive manufacturers are increasing the electrification of vehicle powertrains as more hybrid electric vehicles (HEVs) and electric vehicles (EVs) make their debut. Driven by regulations across the globe to curb carbon-dioxide emissions, sales are increasing annually at 20% to 25% [1] and are projected to represent 20% to 25% of vehicles sold by 2030 [2]. In addition, an increase in consumer acceptance for HEV/EVs has led to greater demand for energy-efficient, robust and compact systems with improved performance and longer driving ranges.

One of the biggest concerns in this space is how to make HEVs/EVs more affordable, in order to facilitate mass-market adoption and address the current lack of profitability for automakers. Today, the average price of a small- to mid-size EV is around $12,000 higher than a similar internal combustion engine vehicle [3].

At first, the price difference was thought to be solely attributable to battery costs. It is true that battery costs may drop significantly in the future. However, detailed business models recently indicated other options that can reduce costs [3] and accelerate the time in which original equipment manufacturers (OEMs) can make profitable HEV/EV sales. One option is design to cost (DTC), which focuses on powertrain integration where the power electronics components are positioned closer together, reducing the number of components and integrating them into fewer boxes.

In this white paper, I'll examine how applying DTC to power electronics can enable OEMs to achieve mass-market adoption. I'll begin by explaining why advances in power electronics were able to alleviate consumer "range anxiety" while striving for lower DTC in the powertrain system, and describe an integrated powertrain solution at a system level designed to approach DTC, with a particular emphasis on optimizing semiconductor integrated circuit (IC) and power device content.

Resolving range anxiety

Range anxiety has been the No. 1 concern of consumers when shopping for HEVs and EVs. In 2020, several EVs are expected to be released with ranges beyond 200 miles [4]. What these EV models have in common, even among different OEMs, is a from-the-ground-up powertrain platform design that optimizes battery stacking and packaging for high ranges. Higher battery stacks translate to higher voltages and higher horsepower.

Modern EVs typically have battery voltages around 400 V, but achieving greater horsepower requires increasing the battery voltage to 800 V, particularly in high-end EVs. Higher voltages translate to higher horsepower for the same amount of current. Optimization of the battery stacking and packaging enables compact spacing and lower DTC.

Also, higher voltages increase efficiency for the same amount of power because the lack of high current lowers thermal dissipation. Lower cabling diameters and lower weight in turn lowers DTC.

Performance improvements: increasing power density

The power efficiency and size of the powertrain system determines the performance of an HEV or EV. The ratio of power efficiency to overall size – also known as power density – is a key figure of merit in the power-management world. The goal is to achieve the highest level of power density. The EV industry is extending this goal to powertrain systems through integration – to achieve the highest efficiency in the most compact space. “Compact space” in this context implies smaller printed circuit board (PCB) space and casing material, also positively impacting DTC.

At the power electronics level, there have been significant changes in topologies/architectures, integrated IC solutions and semiconductor power switches in powertrain subsystems, including the onboard charger (OBC), DC/DC converter (high voltage to low voltage) and traction inverter. **Figure 1** shows a typical block diagram of a powertrain system in an HEV/EV.

Let’s discuss the impact of changes to semiconductor power switches and how to integrate the functionality required for an efficient power electronics architecture into an IC. This is the basis for an integrated powertrain solution at a system level.

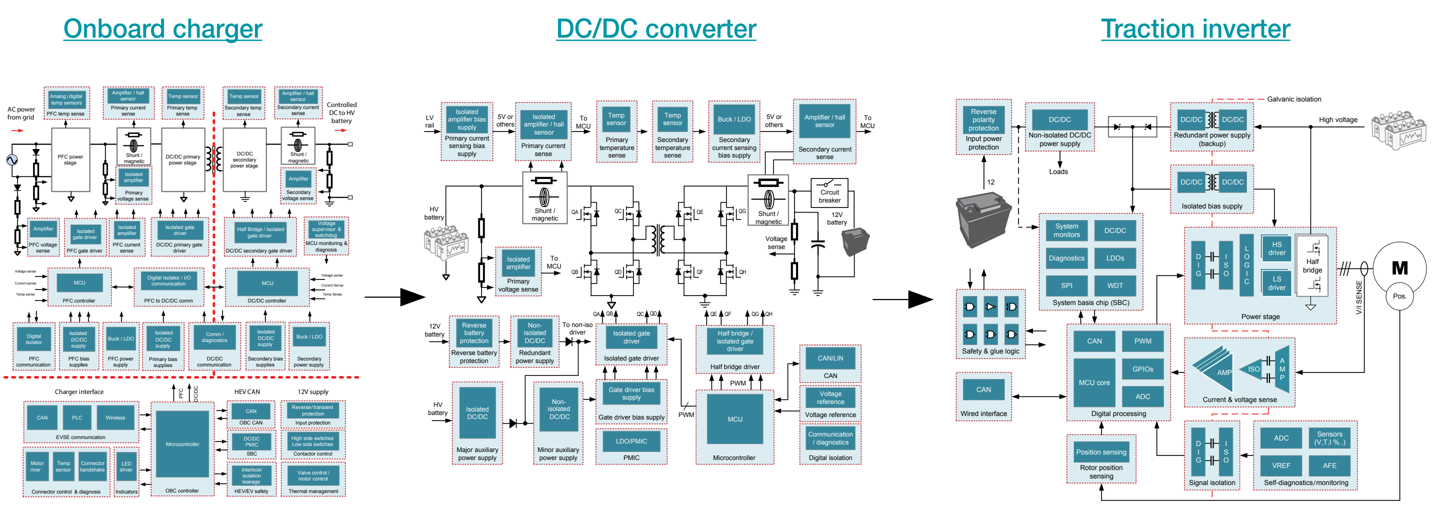


Figure 1*. Block diagram of a powertrain system in an HEV/EV.*

Wide band-gap semiconductor devices: a disruptive technology in the automotive market

Power electronics play a critical role in attempting to meet demanding power-density requirements. Power semiconductor devices inside power electronics must have these attributes:

- Lower power losses.
- High-frequency operation.
- Higher junction temperatures.
- High-voltage operation.
- Increased heat dissipation.

The incorporation of advanced high-voltage devices such as wide band-gap semiconductors using SiC and GaN for power switches makes it possible for HEVs/EVs to achieve higher efficiencies compared to traditional silicon-based power switches such as power silicon metal-oxide semiconductor field-effect transistors (MOSFETs) and insulated gate bipolar transistors (IGBTs).

As power levels rise, power silicon MOSFET or IGBT thermal management becomes challenging, due to the limitation in their maximum operating temperature, known as allowable junction temperature. This limitation requires the addition of cooling components, such as large copper blocks with water jackets, in the powertrain system – especially in a traction inverter where the power levels can rise higher than 100 kW. Adding cooling components impacts vehicle size, weight and cost. Conversely, SiC has a much higher allowable junction temperature. Additionally, the thermal conductivity of SiC is two to three times higher than silicon [4]. The combination of the high junction temperature and high thermal conductivity in SiC makes it an attractive candidate for powertrain systems, as it eliminates the need for big copper blocks and water jackets. Using GaN in OBCs and DC/DC converters can also enable a significant reduction in passive elements, such as magnetics and capacitors, because of its ability to switch in the hundreds of kilohertz to megahertz range.

Several automakers are already incorporating wide band-gap solutions into their HEV/EV powertrain designs to achieve higher horsepower and higher efficiency, along with increased battery voltages. In addition, it is possible to lower DTC from wide band-gap solutions through improved thermal management and size-reduction benefits. Even though wide band-gap switches are expensive today, the cost will decline over time. At a system level, eliminating or minimizing the mechanical blocks for cooling and the amount of material for passive elements and casing realizes the lower DTC.

Isolated gate-driver ICs to operate the power switches

Powertrain system architectures require an isolated gate driver to drive the power switches efficiently. Isolated gate drivers convert pulse-width modulation signals from the controller into gate pulses for the power switches to turn on or off. Because of the high voltages associated with the battery, galvanic isolation is necessary between the controller (the primary side) and the power switch (the secondary side).

Galvanic isolation is a technique to isolate functional sections of electrical systems to prevent direct current or uncontrolled transient current from flowing in between them. Data and energy does need to pass through this galvanic isolation barrier, however. Capacitive isolation is a key isolation technology that has digital circuits for encoding and decoding incoming signals to pass through the isolation barrier [5, 6].

Capacitive isolation is the preferred choice for implementing an isolation barrier in isolated gate drivers due to its high data rate and high noise immunity (also called common-mode transient immunity [CMTI] above 150 V/ns) and can help realize the potential switching capability of wide band-gap solutions. Powertrains experience high levels of noise and vibration. Therefore, having a gate driver with CMTI is preferable. In addition, isolated gate drivers reduce PCB space, vehicle cost and weight through the elimination of pulse transformers or external discrete isolators.

Isolated gate-driver integration: a key aspect of system-level functional safety and lower DTC

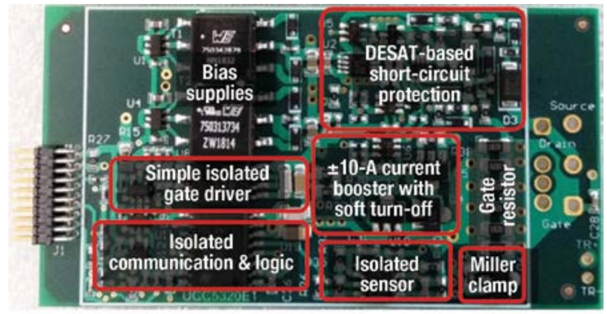
At a system level, when viewed as a black box, there are three semiconductor components for powertrain systems: the digital controller (microcontroller), isolated gate driver and power semiconductor.

Besides requiring key functionalities for high-efficiency systems, isolated gate drivers have recently become a primary component because of the increasing need for powertrain system diagnostics and protection developed at the highest functional safety levels. Monitoring and protection needs to occur intelligently, and integrating these features in the gate driver is becoming a popular solution.

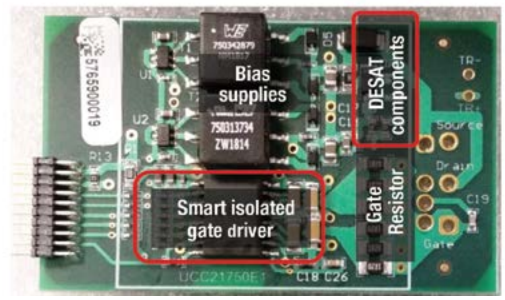
The failure-in-time (FIT) rate is considered a key metric toward achieving the highest levels of automotive safety integrity. For example, the FIT rate should be lower than 10 in order to achieve an ASIL D-compliant system; such an ASIL level is very common in traction inverters. A traction inverter spins the motor, which in turn moves the wheels of the vehicle. Similar ASIL requirements (typically ASIL B or ASIL C) are now becoming a requirement for OBCs and DC/DC converters as well.

In order to achieve the lowest possible FIT rates, all of the features for diagnostics and protection that would traditionally be positioned discretely in the system are now being integrated into the isolated gate driver, as shown in **Figure 2.** This directly enables a lower DTC, as it significantly reduces the number of components and PCB space. TI has recently introduced the UCC5870-Q1, which offers an advanced level of diagnostics and protection. The device provides a dramatic benefit in component reduction, enabling lower DTC and the ability to achieve the desired ASIL level, as shown in **Figure 3** for the traction inverter system.

Power stage using a simple isolated gate driver



Power stage using a smart isolated gate driver



Integrated features of smart isolated gate drivers enable:

- Significant system cost reduction
- 2 times PCB area reduction

Figure 2. *Benefits of integration.*

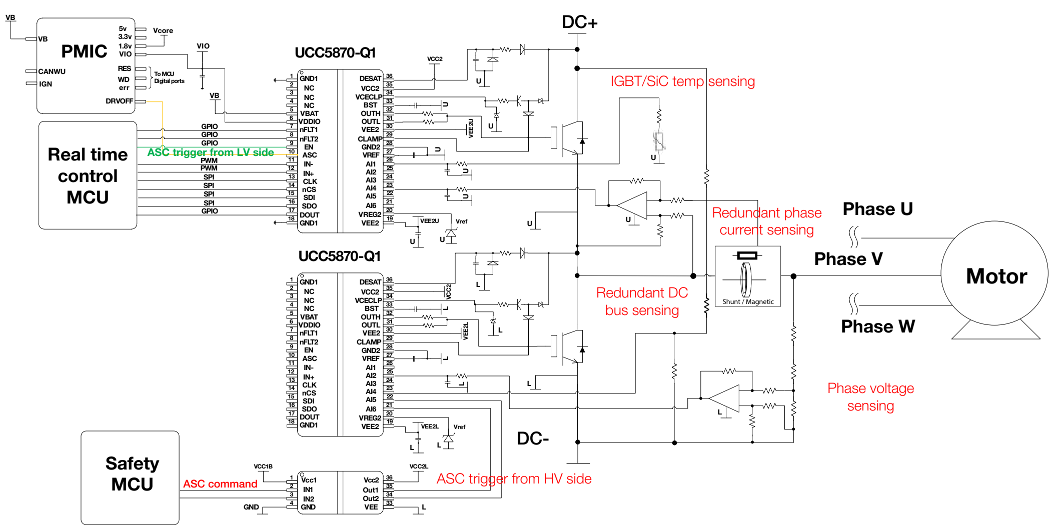


Figure 3 *Benefits of the UCC5870-Q1.*

Another idea involves the development of an integrated transformer bias supply IC that can further significantly lower DTC, which are applicable to traction inverters, OBCs and DC/DC converters.

An integrated powertrain solution at a system level

The focus over the years has centered on integration, DTC reduction and power-density improvements of individual subsystems in powertrains. OEMs are taking this to the next level to further lower costs by integrating the whole powertrain system into one unit, similar to the system-on-chip concept in the IC industry. To date, the first step has been combining either the OBC and DC/DC subsystems into one box, and the traction inverter and DC/DC subsystems into one box. New platforms combine all three subsystems into one box. Regardless of the configuration, the integrated powertrain concept can significantly reduce the overall weight of the powertrain system, increase the power-to-weight ratio, eliminate cabling among the subsystems, and achieve DTC goals. Studies and prototypes have reduced costs by as much as 15% [7]. In addition to gate-driver integration at the semiconductor component level, sharing MCUs among these subsystems further lowers the total cost of the powertrain system.

Powertrain integration reduces the assembly cost and build as well as the time to validate, thereby lowering the overall cost of ownership and time to market for OEMs. One trade-off, however, is the lack of flexibility of original design manufacturing sourcing.

Conclusion

The HEV and EV market is growing rapidly, and appears to be recovering from initial customer skepticism by achieving longer driving ranges and high performance. The future growth of this market hinges on cost reduction in order to make HEVs and EVs affordable for consumers and profitable for OEMs.

The DTC model includes efforts to reduce cost in the power electronics of powertrain subsystems. In addition to wide band-gap power switches such as SiC and GaN, isolated gate drivers have emerged as a key component that enables OEMs to reduce costs through component integration and achieve high functional safety levels. The UCC5870-Q1, TI's newly released gate driver, provides such a solution.

Taking this integration concept to the next level is the emerging trend that combines OBCs, DC/DC converters and traction inverters into one solution, which both reduces costs and benefits the power-to-weight ratio.

Additional resources

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