How semiconductors improve the efficiency of automotive combustion engines

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Introduction

In the last decade, the automotive industry has been reexamining vehicle propulsion systems with the goal of improving fuel efficiency and reducing greenhouse gas emissions. Government regulatory bodies—one of the key stakeholders of the industry ecosystem—have endorsed these efforts through ever-tightening regulations.

After years of system evolution and innovation, older concepts for improving efficiency and reducing exhaust have hit their limit. Just as steam power was the catalyst for the Industrial Revolution in the 19th century, semiconductors have revolutionized the 20th century. These innovations heavily affected the automotive industry and new innovations continue.

Reducing carbon dioxide (CO_2) emissions is the strongest force driving the automotive industry toward a sustainable future. **Figure 1** charts current and planned CO_2 emission limits for passenger vehicles.

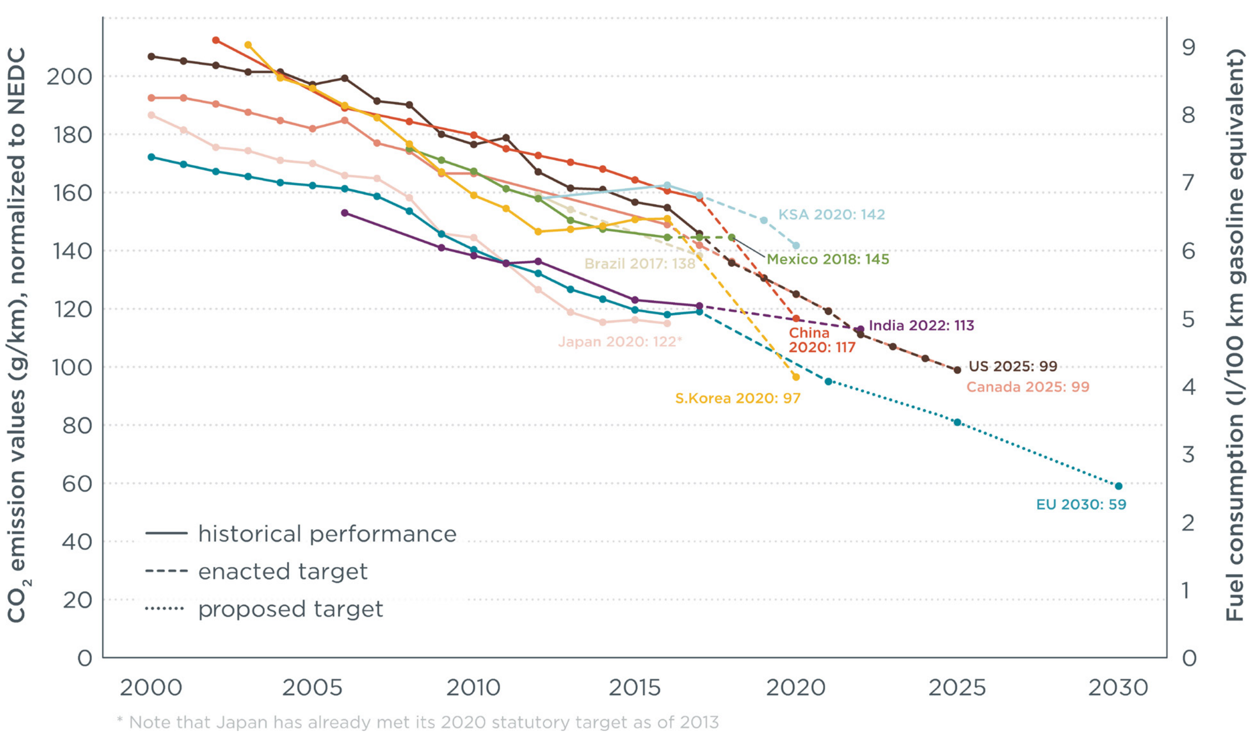

***Figure 1**. Comparison of global CO_2 emissions limits for new passenger vehicles (Source: International Council on Clean Transportation).*

CO_2, while not regulated as an air pollutant, is the transportation industry's primary contribution to climate change. In 2009, the European Commission set a 2015 target fleet average of 130 grams of CO_2 per kilometer (g/km). Automakers are allowed to unite to form a transparent pool for up to five years to achieve this target. By 2018, the average emissions from a new car were 120.4 g CO_2/km. The European Commission has since introduced a stricter, fleet-wide average emission target of 95 g/km CO_2 limit by 2021.

Improving efficiency with design

Stricter regulations mean that automakers and Tier-1 suppliers must be acutely aware of the effects their designs have on vehicle emissions. They must have fresh thinking and consider all of the trade-offs of a particular system or feature to know whether it helps meet the aggressive emissions goals. The key to solving many of these problems may be efficient semiconductors that improve efficiency and add intelligence to vehicles.

Start-stop engines

One step is adding intelligence to vehicle systems, such as the common practice of dynamically adapting the configuration of a vehicle based on the driver's driving style. When start-stop systems were launched and became widespread in the mid-2010s, there was an initial challenge with stopping the internal combustion engine (ICE) from being shut off when it was inconvenient for drivers. In addition to the algorithm that detects the right moment for an ICE shutdown, it's now also possible to use microwave radar. This radar is typically a part of a vehicle's adaptive cruise control system. In a stop condition, such as when the car is standing still in traffic, the radar can detect movement of the car immediately ahead and turn the ICE back on. This will occur before the driver releases the brake or presses the clutch pedal, which are the typical triggers for restarting the engine in a start-stop system.

This Short-range radar (SRR) reference design uses the AWR1642 evaluation module. The design allows users to estimate and track the position and velocity of objects in its field of view up to 80 m.

Adaptive cruise control

The next generation of adaptive cruise control systems not only allows drivers to establish a pre-set distance with the vehicle immediately ahead, but also uses GPS coordinates with detailed maps to enable adaptive breaking. A vehicle with this type of system knows when it is approaching an intersection or highway exit in advance, and will optimize propulsion and minimize the amount of energy burned for braking. This system is often combined with a front camera-based signage detection system to provide the most up-to-date road information. The camera can detect anything from a stop sign to a speed limit sign and will inform drivers as well as internal control systems.

Our Automotive 1.3M-camera module reference design with OV10640, DS90UB913A and power over coax demonstrates a very small solution size for 1.3-MP automotive cameras.

Mirror replacement

Cameras aren't just for the front of vehicles; the concept of using cameras as a replacement for rearview mirrors has been around since the early 1990s. This concept completely eliminates mirrors, reducing the aerodynamic drag of a vehicle and improving its efficiency. Ultra-efficient plug-in hybrid electric vehicle (EV) concepts are a typical example of this concept. However, transportation regulations in many countries still require traditional rearview mirrors, even though the new camera-based technology is ready for mass deployment.

As the uses for automotive cameras increase, multiple cameras will require not only careful power-supply selection but also a camera hub as described in these resources.

- Automotive power design for front camera systems using single-core voltage application processors
- Automotive ADAS reference design for four camera hub with MIPI CSI-2 output.

Offloading the ICE

Removing the traditional ICE is an immediate step to fully electrified vehicles. The most progressive jump toward this reality is the introduction of 48-V automotive systems. The European automotive industry encourages 48-V technology because it sees it as the next evolution in onboard vehicle power: 48 V optimizes power distribution, reduces the cross-section of cables (and thus vehicle weight), enables mild hybrid EV (HEV) operation while keeping the voltage below hazardous levels, and keeps costs reasonable. Starter generators with torque-assist functionality offload the combustion engine and help reduce CO_2 emissions.

The industry's current strategy is to move power-hungry systems like starter generator units, air-conditioning compressors, active chassis systems, electric superchargers, turbochargers and regenerative braking to 48-V technology to reduce input currents, as shown in **Figure 2**.

As an example, the Bidirectional DC-DC Converter Reference Design for 12-V/48-V Automotive Systems transfers energy between the traditional 12-V battery and the 48-V battery depending on the operation mode. Other important vehicle systems are moving to 48-V technology as well, including heating, ventilation and air conditioning pumps or blowers; electric power steering; e-turbochargers; and various actuators. Advances in semiconductor development and more accurate sensors not only offload the combustion engine but also improve the efficiency

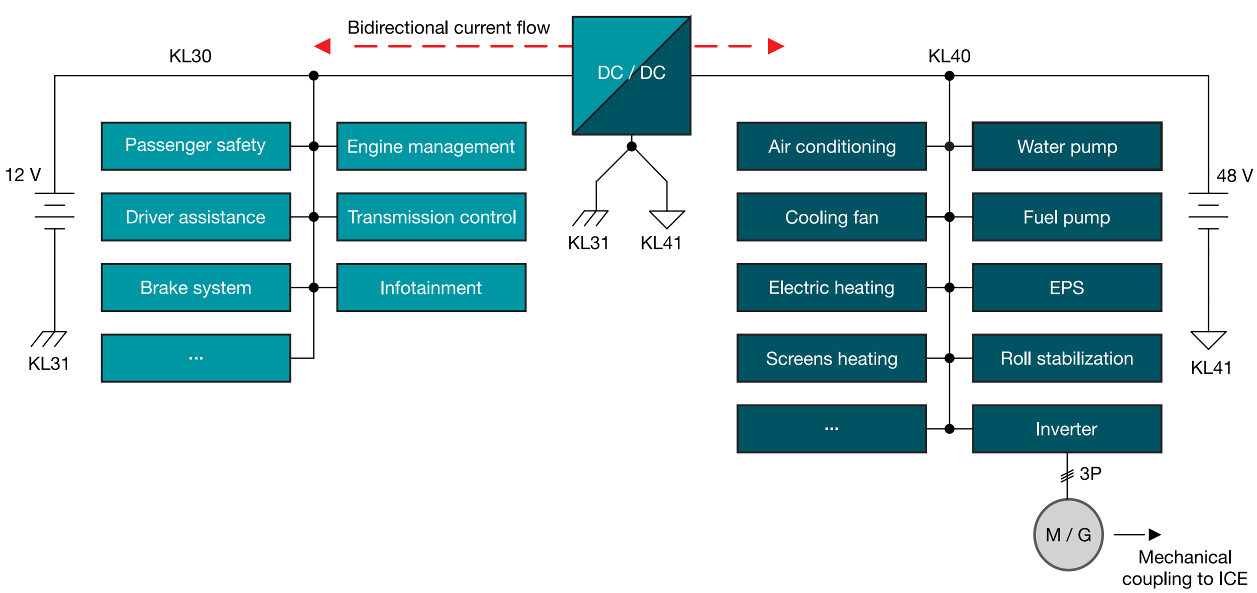

Figure 2*. A typical 48-V automotive system used in an HEV.*

of the combustion process itself. Using integrated signal conditioners enables more precise and compensated measurements.

A typical example of a smart application of signal conditioners is our **Automotive shunt-based ±500A precision current sensing reference design**. Automotive engineers can now achieve accuracy of ±0.2% over a temperature range from –40° to 125°C.

Semiconductor switching components play an important role in the gradual electrification of vehicle systems. Insulated-gate bipolar transistors (IGBTs) are affordable and a proven solution. New technologies using wide-bandgap semiconductors such as silicon carbide (SiC) or gallium nitride (GaN) are finding their way into automotive applications too. SiC and GaN benefit from high voltage and fast operation compared to IGBTs, which themselves enable improved efficiency, reduced size and (eventually) even reduced cost of the overall system.

Using high voltages for in-vehicle power requires careful basic and functional isolation to prevent electric hazards or system performance degradation. Developers can typically choose from digital and analog isolators based on capacitive technology integrated at the silicon level. Silicon dioxide (SiO_2) is the most stable dielectric over temperature and moisture, withstanding electric strength 500 to 800 V/µm. The capacitive isolation barrier is not subject to aging (like its optical counterpart) and provides extraordinary electromagnetic (EM) immunity, with lower EM emissions than transformer-based solutions.

Sometimes, passing an analog signal through the isolation barrier is convenient such as current or voltage measurement circuitry in traction inverters, which can use isolated sigma-delta modulators and isolation amplifiers for this purpose.

Capacitive isolation technology can also deliver benefits to gate drivers. Single-channel isolated gate drivers can be used in high-voltage traction inverters, onboard chargers or DC/DC converters. Another example could be dual-channel isolated gate drivers that are able to drive a complete high-voltage half bridge. They fit applications with space constraints such as belt starter generators.

From an embedded processor standpoint, EVs can benefit from **microcontrollers (MCUs)** that offer real-time control solutions for efficient power conversion and high-performance motor control, or functional safety MCUs that help meet strict industry standards for safety-critical automotive applications.

Temperature sensors also play an important role in automotive systems. Long-term temperature monitoring can help predict failures caused by aging components. It is important to have accurate, repeatable results with sufficient resolution. Although traditional negative temperature coefficient (NTC) or positive temperature coefficient sensors (PTC) are cost-effective, they require a stable excitation voltage (or current), must have a narrow tolerance range, and can’t typically match the complete analog-to-digital converter range without additional circuitry. For applications where safety and robustness are a concern, additional voltage comparators can sense the output of a temperature sensor in order to provide an over-temperature signal independent of the MCU.

Conclusion

Automakers and Tier 1 suppliers who look at technology agnostically are pushing hard to gain as much efficiency as possible from traditional ICEs. Advanced semiconductor technologies are enabling new developments in automotive efficiency by offering integrated circuit solutions for every electronic system in vehicles today, along with extensive development support in the form of reference designs with proven circuits and extensive test data, evaluation modules, and tools to simplify development and help speed time to market.

References

1. Environmental Protection Agency, "Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks," EPA420-F-08-024, October 2008.
2. European Commission, "Reducing CO_2 emissions from passenger cars," Climate Action report.