Automotive Electronic Olympics – Lighter, faster power.

How GaN is gaining speed

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A fast evolution

Cars are already high-tech computers, and increasingly use more electronics for the powertrain, safety systems and creature comforts that consumers expect. These systems tend to add weight in the face of fuel economy targets and powertrain electrification. One component that is critical for all electronics is a transistor, which is used to either amplify while being used as an analog device – and take a tiny electric current signal and control a much bigger current – or act as a switch – to turn electric current on and off. With the right blend of technical skills, that includes an understanding of transistor technology, detailed electronics and vehicle systems, the appropriate selection and control of this tiny device has the potential to make our "rolling computers" much more lightweight and fuel efficient, and improve technology integration.

Silicon, as the semiconductor on an integrated circuit chip, made California's Silicon Valley famous. Today, there are alternative transistor technologies that are advancing, including gallium nitride (GaN) and silicon carbide (SiC). It has become apparent that the high-tech industry drives technological changes and advances occur quickly, often faster than in the automotive industry. These new transistors are becoming more reliable and cost effective, to help improve electronic componentry across nearly all markets.

With an increase in switching frequency, the accuracy of the current control can be increased. Compare an experienced downhill skier to a fast-switching transistor. The faster the skier turns left to right, the more control the skier has on the downhill descent. Similarly, the faster the switching speed, the better an AC signal can be controlled. Further, the high switching speed enables passive filters to be designed with higher cut-off frequencies and lower ripple current requirements, which allow the system to use smaller inductors, transformers (in isolated DC/DC conversion) and capacitors. Just as a downhill skier has to be efficient with turns for high speed, at elevated frequency, the design of the transistor control algorithm and associated gate drive circuitry has to efficiently manage switching losses. This maximizes the capacity to conduct current by minimizing the device junction temperature.

For transistors to support advanced electrified innovations for emerging vehicle features, such as hybridization, electrification, entertainment, advanced driver assistance systems (ADAS) and connectivity – while lightweighting for fuel efficiency or range of travel on full battery charge – the increase in switching speed and reduction in size, weight and/or cooling requirements is paramount. Historically, the silicon transistor was the only reliable and cost-effective option available for use as a switch in power electronic product development. Silicon transistors continue to improve and have delivered many industry-first capabilities; however, as electronics continue to advance, limitations due to slower switching speeds affect the size and efficiency of many systems. The silicon device will continue to be a staple within power electronics for years to come, but judicious selection of the correct device and the correct technology is crucial, whether it be Si, GaN, SiC, or devices just coming out of research, such as diamond or Ga_2O_3.

Silicon, gallium nitride and silicon-carbide transistor technologies each possess unique attributes. To determine which technology best fits a specific application, it is important to understand the respective benefits and challenges of each, in the context of that application. Some key categories that should be closely analyzed to determine the optimal transistor technology,

Key factors to determine transistor technology use

- Application
- Voltage
- Switching speed
- Efficiency
- Thermal requirements
- Size
- Design manufacturability
- Cost

include application, voltage, switching speed, efficiency, thermal, size, design manufacturability and cost.

Recent advances for GaN transistors

When first introduced in 2009, GaN transistors faced a number of challenges, such as reliability, ease of use and maximum power – not to mention high cost and low availability. However, the industry has worked quickly to improve the GaN transistor. Today, the manufacturing process, which is similar to making a silicon transistor, has been refined to improve GaN transistor reliability. More powerful GaN transistors are becoming readily available, capable of handling the power requirements of electric vehicles and industrial motors, as well as consumer products like wireless chargers. The latest generation of GaN transistors has been developed to be robust, more cost competitive and compatible with the latest electronics manufacturing processes.

Because of its properties, GaN is able to achieve a much higher switching speed and delivers a number of benefits:

- Increased energy efficiency
- Reduced size, enabling smaller and lighter packaging.

The GaN transistor capabilities open the door to reengineer products and technologies. This technology is currently being considered across many different electronic industries. For example, information technology companies are turning to GaN for use in data center power supply. In these applications, the benefits of GaN transistors support the transition from 12V to 48V power architecture, to improve power supply efficiency and save energy where power consumption is a growing concern. Interestingly, this same transition in power from 12V to 48V is emerging within automotive electric system architectures to support increased electrification within the vehicle. The automotive industry may experience benefits from economies of scale, in terms of cost and availability, as data centers adopt this technology.

Experience and creativity needed to reimagine advancing technology

The alternative SiC and GaN transistor technologies are not 'plug and play'. The first step is to evaluate which technology is right for the specific application, and then get the design right. For example, to achieve the optimum benefits of the GaN transistors, vehicle system and component designers will need to rethink automotive systems and subsystems to deliver improved efficiencies with smaller packaging. A fundamental understanding of the nuances of GaN chemistry and transistor technology within a circuit, combined with the empirical knowledge of fully integrated vehicle system design, help speed development and maximize the performance. In other words, it takes an understanding of the full system to get the benefits out of sub-components in the electric design with new transistor technology.

There are a number of applications where the use of GaN transistors has the potential to improve performance and reliably deliver the expected benefits:

The appropriate selection of transistor technology has the potential to make our cars more lightweight and fuel efficient with improved technology integration

300-600V to 12V DC/DC converters for electric and hybrid electric vehicles

A DC/DC converter is used to convert direct current from one voltage level to another. The converter is an integral part of an electric or hybrid electric vehicle, leveraging the battery energy to power system electronics. The GaN transistor's increased switch frequency can allow new designs with the potential to reduce the size and weight of the DC/DC converter by up to 50 percent. This, in turn, allows for greater vehicle system design flexibility and overall vehicle weight reduction that ultimately improves fuel economy.

AC/DC and DC/AC converters for charging electric and hybrid electric vehicles

When charging an electric vehicle at home or with other power sources, an AC/DC converter is required to convert the AC power from the source to DC power, which can be stored in the vehicle's battery. With GaN transistors, the switching frequency is increased, driving down the DC ripple current. This enables designers to use a smaller DC capacitance, resulting in a smaller and lighter charger, which improves the installation process and the appearance. Additionally, because of improved energy efficiency, the vehicle can charge more quickly.

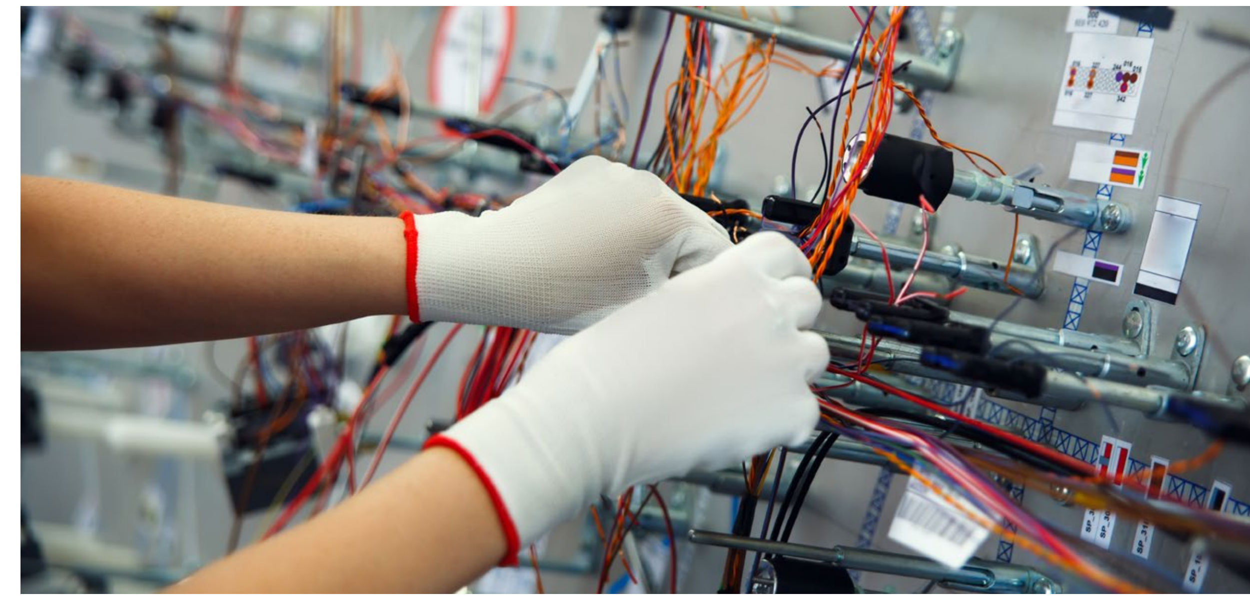
Active safety/autonomous vehicles

LIDAR (Light Distancing and Ranging) is a remote sensing technology currently being used for active safety and autonomous driving technologies. Its speed and accuracy in detecting objects on and around the vehicle are critical for passenger and pedestrian safety.

A GaN transistor can deliver a faster response time, which improves resolution for LIDAR in mapping the surrounding area. This, in turn, will improve the accuracy of the data, ultimately improving technology.

Audio amplifiers

By implementing GaN transistors in Class-D audio amplifiers, the critical performance factors for distortion (sound quality) are improved. Also, heatsinks can be eliminated, which reduces the size and cost.



As cars use more electronics, these systems tend to add weight

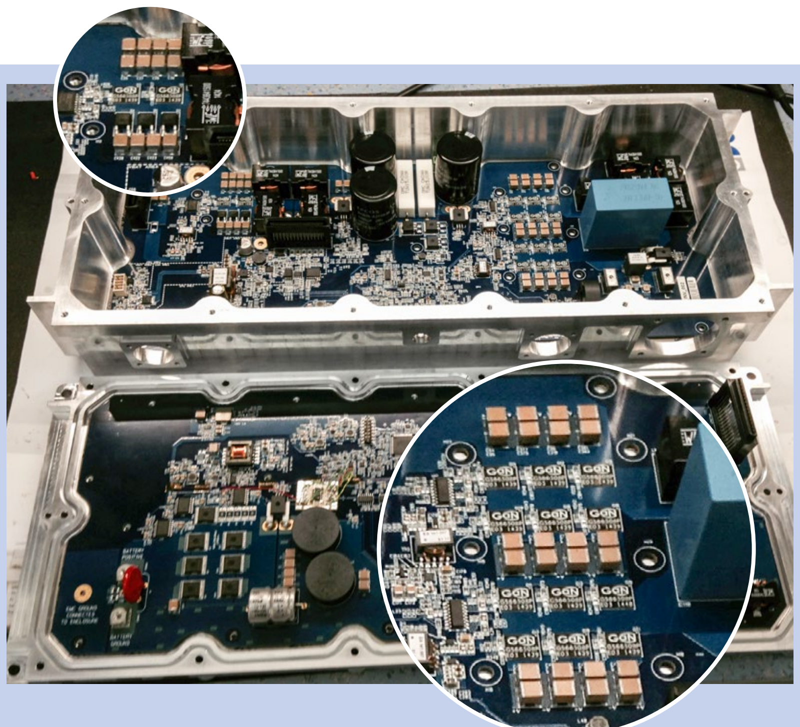
48V motor drive for mild hybrid and regenerative stop/start

As the automotive industry continues to develop technologies to reduce fuel consumption and emissions, mild hybrid systems such as start/stop have become an increasingly popular solution. With the ability to improve fuel economy by up to 15 percent, depending on the driving scenario, experts predict that by 2020 more than 55 percent of vehicles sold in the US will use start/stop.

With the use of GaN transistors, engineers are able to redesign the electrical infrastructure from 12V to 48V, as well as the motor to reduce the overall size by up to five times, improve efficiency and increase the motor's capability to drive a large number of devices in parallel, which reduces cabling and conduction losses.

Throughout all of these transportation-based examples, the GaN transistor can support improvements that are critical to the mobility industry as it works to develop vehicles that meet legislative and consumer requirements. With the right expertise, knowledge and experience, companies can continue to innovate and deliver advanced technology within the transportation industry.

Delta-Q's charger for low-voltage EVs uses GaN to fit significantly more power into the same size unit, with no need for a cooling fan



Case study

Military vehicle gets lighter with a GaN-based inverter

A manufacturer of military vehicles requested the development of an inverter to improve efficiency output and eliminate cooling, within the package for an electric military commercial vehicle application.

Armed with knowledge and experience in electric vehicle and inverter development, as well as the benefits of GaN transistor technology, engineers were able to develop a 2kW inverter that transitioned 400V DC to 12V AC. Because of the ability of the GaN transistor to deliver more power efficiently, experts were able to redesign the electrical architecture of the inverter to deliver very high efficiency of more than 97.5 percent (the efficiency percentage is typically in the low 90s), reduce the overall size (50% reduction) and employ passive cooling. Liquid cooling for the electronics requires additional cooling plates for the inverter and hoses from the radiator for this device. Through passive cooling, engineers were able to eliminate these components, reducing the weight and avoiding reliability issues relating to liquid cooling.

Applications for other transistor technologies

In some cases, GaN technology is a very viable solution for improved designs, but there are other transistor technologies that should be considered based on application requirements. Industries are also investigating SiC transistors to improve efficiency. Before the introduction of GaN transistors, it was once thought that SiC transistors would replace silicon due to their improved switching speed and resilience to external factors.

In comparison to silicon transistors, SiC transistors require about three times as much energy to reach the conduction band, which allows them to withstand higher voltages and temperatures. SiC transistors are ideal for high-voltage applications that are above 1.2 kV, such as marine vessels or rail systems.

Fine-tuned design can change the game

Active safety, autonomous drive and electrified powertrain continue to gain momentum and drive the growth of electronics within the mobility industry. In order to accommodate this increased integration of electronics, the industry must transition to systems with higher voltages to deliver more power, which, in turn, drives the development of new components and systems that support them. While many of these ground-breaking feature innovations are widely discussed and publicized, the tiny GaN transistor is one key enabler, hidden deep within the vehicle, that has the potential to significantly alter the design of many electronic systems. In this case, smaller is better.

Going back to the downhill skiing analogy, GaN devices can be compared to skis that are tuned for difficult ski conditions. In order to get the most out of the skis, the skier must be knowledgeable and experienced in using them properly, and achieve expert performance on the black diamond hill. More efficient, smaller electrical systems will require a system-level understanding, coupled with specialized experience of handling these transistor technologies in electronics design, to deliver the maximum performance available.

Component and vehicle manufacturers can leverage third-party resources that have in-depth knowledge of a given automobile's architecture, experience in new innovative technology development and a fundamental understanding of the impact of transistor technology to innovate and drive a game change for future cars.

Engineering teams have an exciting opportunity to better understand and use new transistor technologies in the research and design phase of products, to develop systems that will deliver accident- and emission-free driving. A tiny little device has the potential for a big impact.

Why Ricardo?

Ricardo is a global strategic, technical and environmental consultancy. It is also a specialist niche manufacturer of high-performance products. The company employs more than 2,900 professional engineers, consultants and scientists committed to delivering outstanding projects focused on class-leading innovation in our core product areas of engine, transmission, vehicle, hybrid and electrical systems, environmental forecasting and impact analysis.

With long experience and deep knowledge of full-vehicle systems, Ricardo has been working with GaN transistors to develop component designs and system integration to leverage the technology's benefits from design through production. As the preferred design house for GaN Systems, Ricardo understands the benefits of GaN transistor chemistry, and takes a holistic view to intelligently and effectively designing products that address challenges for transportation and energy.

Ricardo's services cover a range of market sectors, including passenger car, commercial vehicle, rail, defense, motorsport, motorcycle, off-highway, marine, clean energy and power generation and government. Clients include the world's major transportation original equipment manufacturers, supply chain organizations, energy companies, financial institutions and government agencies.

Services include:

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