Transportation I Volume 24

We get technical

Simplifying automotive connectivity

Smarter hardware validation for a smarter vehicle

Understanding thermal challenges in EV charging applications

Road-tested GMSL cameras drive into new markets

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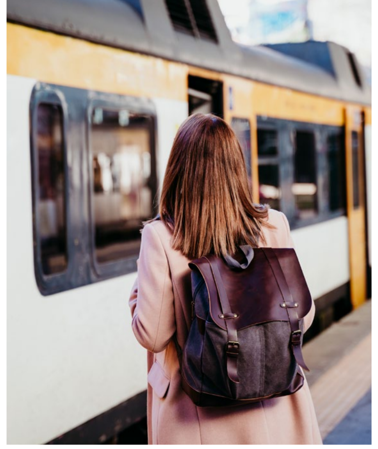

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Editor's note

Welcome to the DigiKey eMagazine Volume 24 – Transportation.

This edition will explore the transformative technologies shaping the future of transportation. As the industry accelerates toward smarter, safer, and more sustainable mobility, innovation continues to fuel every facet of development—from vehicle electrification to advanced sensing systems.

In this issue, we feature a compelling mix of expert insights and cutting-edge solutions. Molex introduces the MX-DaSH Wire-to-Wire Connector System, designed to meet the high-performance demands of next-generation vehicles. NI shares a modular approach to validation in Smarter Hardware Testing, bringing agility to the development of intelligent automotive systems.

Electric vehicles take center stage with articles on compact power supply designs using automotive-grade flyback transformers, and the critical role of thermal management in EV charging. We also delve into the nuances of voltage sensing, multiphase DC-DC converters, and circuit protection which are all vital to enhancing eMobility platforms.

Advancements in autonomy and safety are reflected in discussions around LiDAR components, GMSL camera technologies, and precision components for reliable aircraft navigation systems. Each article offers valuable perspectives for engineers and innovators navigating this dynamic sector.

Whether you're working on the latest EV powertrain, refining sensor technologies, or developing high-speed data links for automotive and aerospace applications, this issue offers practical insights and inspiration.

Thank you for joining us on this journey through the electrified, data-driven future of transportation.

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Simplifying automotive connectivity: Molex’s MX-DaSH solution for wiring harness consolidation

Vehicle harness complexity has grown tremendously due to the integration of advanced driver assistance systems (ADAS), infotainment networks, and autonomous driving technologies. In fact, the automotive wiring harness market is projected to hit $118.07 billion by 2033 . Modern luxury vehicles contain up to 5,000 meters of wiring with 150+ electronic control units requiring interconnection through approximately 700 separate connectors. This connectivity challenge produces more assembly bottlenecks and increasing failure points throughout electrical architectures that conventional solutions struggle to address effectively.

Molex’s approach to connectivity consolidation

Current automotive designs use multiple separate connectors for power, signal, and high-speed data transmission, which typically leads to complex wiring layouts that consume valuable space and increase manufacturing costs. For example, instrument panel and

Molex’s MX-DaSH (Molex Data-Signal Hybrid) Connector System. Image source: Molex

body control harnesses may require eight or more inline wire-to-board connectors, along with extensive copper wiring to interconnect various vehicle systems. This multi-connector approach tends to create assembly challenges, increasing potential failure modes, and complicating serviceability in the field.

Molex’s MX-DaSH (Data-Signal Hybrid) Wire-to-Wire Connectors address these challenges by combining power circuits, ground circuits, and high-speed data connections into one connector that replaces multiple standard connectors in vehicle applications. This consolidation approach directly targets the root causes of automotive wiring complexity and maintains the reliability and environmental performance standards required for harsh automotive environments.

Molex’s MX-DaSH (Molex Data-Signal Hybrid) Connector System. (Image source: Molex)

MX-DaSH makes it possible to bring down the number of inline, wire-to-board connectors for an instrument panel and body control harness from eight to two while removing up to six meters of copper wiring, depending on the specific vehicle model. This solution delivers benefits in weight reduction, cost savings and simplified assemblies without compromising electrical performance or environmental durability.

Advanced integration technology for automotive systems

The MX-DaSH’s design incorporates power, signal, and data connections using 0.50, 1.20, 1.50, 2.80, and 4.80mm terminals as well as High-Speed FAKRA Mini (HFM) modules for high-speed data transmission. This integration allows engineers to consolidate multiple connections within single connector platforms for a broad range of applications, e.g., autonomous driving modules, camera systems, GPS devices, and high-resolution displays.

Molex has designed this connector system to offer multiple options for wire-to-wire applications. The 31+1-Way connector system, for example, integrates 31 power and ground circuits with a high-speed data connection, which reduces packaging requirements by up to 30%. The system supports voltage levels up to a 250V maximum, with current capacity determined by terminal size and environmental conditions. Wire compatibility spans from 0.35 to 1.50mm² wire for 1.20mm terminals, 0.50 to 1.50mm² wire for 1.50mm terminals, and 2.00 to 2.50mm² wire for 2.80mm terminals, providing broad flexibility for automotive applications.

Key design features of the MX-DaSH connector system. Image source: Molex

Gateway modules take up extensive connector real estate, since standard architectures utilize separate interfaces for power, CAN networks, Ethernet connections, diagnostic systems, etc.

Durable environmental performance

The MX-DaSH offers reliable operation in harsh conditions via available T2/V1/S3-rated sealing and mat seal technology. Its environmental ratings align with automotive industry requirements for components exposed to extreme temperatures, vibration, and moisture ingress. Operating temperature range is from -40 to +120°C or -40 to +85°C depending on connector type, which is ideal for most under-hood and cabin applications. The mat seal can eliminate the need for individual cable seals, reducing overall package size and lowering the cost of connectors inside or outside the cabin. Sealing performance includes initial pressure ratings of 50 kPa min., 30 kPa min. after endurance testing, and IP69K compliance for high-pressure washing applications.

Reliable connectivity features for production environments

Automotive connector field failures often result from vibration-induced terminal withdrawal and assembly mis-mating during production. Molex's MX-DaSH Connector system achieves secure mating and connectivity using independent secondary lock (ISL), pin protection plate (PPP) and blade protection features. Up to six unique keyways are available to ensure proper orientation and prevent mis-mating, which minimizes assembly errors that can lead to costly rework or field issues. The terminal retention force with ISL is up to 100 N minimum retention, while mating and unmating forces is at a 70 N maximum.

Sealing Characteristics

How wet can it get?

USCAR Call Out	Requirement	Ingress Protection
S1 (Unsealed)	Passenger Compartment	IP40
S2 (Sealed)	Exposed to Water	IP62
S2.5 (Low Pressure Spray)	Risk of Direct Splash	IP65
S3 (High Pressure Spray)	High-Pressure Spray (Car Wash)	IP69K

- Key Connector Features
  - Custom Silicon based seal designs
  - Protected locations for interface and cable seals
  - Extensive validation testing

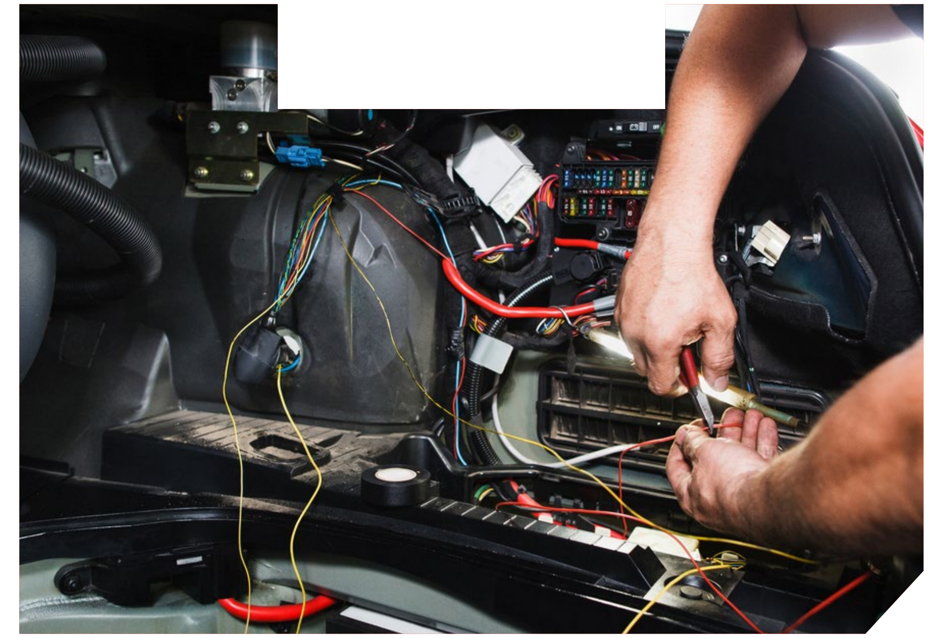
Key design features of the MX-DaSH connector system. Image source: Molex

Supporting zonal architectures

Leading automakers are transitioning from distributed ECU networks toward zonal systems that consolidate electronic control functions by physical location. This shift serves to minimize wiring complexity by centralizing processing power into fewer, more capable controllers that manage all electronic functions within their physical zone. Molex's MX-DaSH connector system supports this transition by providing high-density, multi-signal connectivity required for zonal controllers. Key applications include autonomous driving modules, camera systems, GPS and infotainment devices, LiDAR, high-resolution displays, and more.

Key applications and benefits

Typical connector approaches force engineers to choose between functionality and complexity, as each new feature usually requires additional connection points and wiring segments. Molex's MX-DaSH breaks this compromise by consolidating electronic functions within single platforms.



Close-up of automotive components under the hood. Image source: Shutterstock

ADAS controllers must manage camera feeds, radar signals, LiDAR data, and GPS information while providing adequate power to multiple sensor units. Traditional approaches utilize separate connectors for each sensor type, which creates complex routing challenges and potential failure points. Here, MX-DaSH connectors can be used to combine power circuits for sensor activation with high-speed data connections for signal transmission to reduce harness complexity.

Infotainment and display systems require 4K resolution capabilities, multiple camera inputs, and high-bandwidth data transmission alongside power and control signals. The MX-DaSH system addresses these requirements by incorporating power and high-speed FAKRA Mini (HFM) data connections within single connectors, enabling engineers to reduce overall system complexity.

Gateway modules take up extensive connector real estate, since standard architectures utilize separate interfaces for power, CAN networks, Ethernet connections, diagnostic systems, etc. The MX-DaSH connector allows engineers to consolidate these systems into fewer connection points, simplifying both the module design and vehicle-level wiring harness architecture.

Overall, reducing the number of components can deliver multiple benefits beyond cost savings. Fewer components can lower bill of material (BOM) costs and make supplier management and inventory control more straightforward. Engineering teams can take advantage of this reduction by standardizing on fewer connector platforms, which enables volume purchasing agreements that further reduce costs. This strategy also creates opportunities for manufacturing automation.

Conclusion

The MX-DaSH Wire-to-Wire Connector System is a practical engineering solution to automotive connectivity, consolidating several connections with validated, automotive-grade packages. The complete MX-DaSH portfolio enables automotive designers to reimagine vehicle electronics by integrating more power and high-speed data transmissions within a single connector system to achieve considerable savings in size, space, cost and labor.

Suggested reading

1. Automotive Wiring Harness Market to Reach US$118.07 Billion by 2033 | Astute Analytica
2. Wiring harness development in today's automotive world

Smarter hardware validation for a smarter vehicle: a modular approach to automotive testing

As the automotive industry accelerates toward software-defined vehicles, zonal architectures, and increasingly complex electronic systems, the demands on validation and production testing are evolving just as rapidly. Hardware validation – once a straightforward process – is now a critical, multidimensional workflow that must keep pace with innovations in connectivity, autonomy, and electrification.

Designers are now exploring how a modern, modular test platform can address these challenges through three representative use cases: ECU testing with high-power precision instrumentation, camera validation with synchronized, software-defined vision modules, and electrified powertrain validation powered by intelligent test automation. NI's differentiated solutions (Figure 1) – including the PXIe-4151 power supply, PXIe-1487 vision module, and TestStand automation framework – demonstrate how smarter testing enables faster innovation, better product quality, and future-ready engineering teams.

Figure 1: NI's differentiated solutions – including the PXIe-4151 power supply, PXIe-1487 vision module, and TestStand automation framework – demonstrate how smarter testing enables faster innovation. (Image source: NI)

The new era of automotive innovation

The automotive landscape is undergoing a seismic shift. Vehicles are no longer defined solely by mechanical performance – they are becoming intelligent, connected, and software-defined. Zonal architectures are replacing traditional ECUs, consolidating control into powerful regional hubs. Advanced driver-assistance systems (ADAS) are pushing the boundaries of perception and decision-making (Figure 2). Additionally, electrification is transforming the very foundation of propulsion and energy management.

Figure 2: As the automotive industry accelerates toward software-defined vehicles, the demands on validation and production testing are evolving just as rapidly. Image source: NI

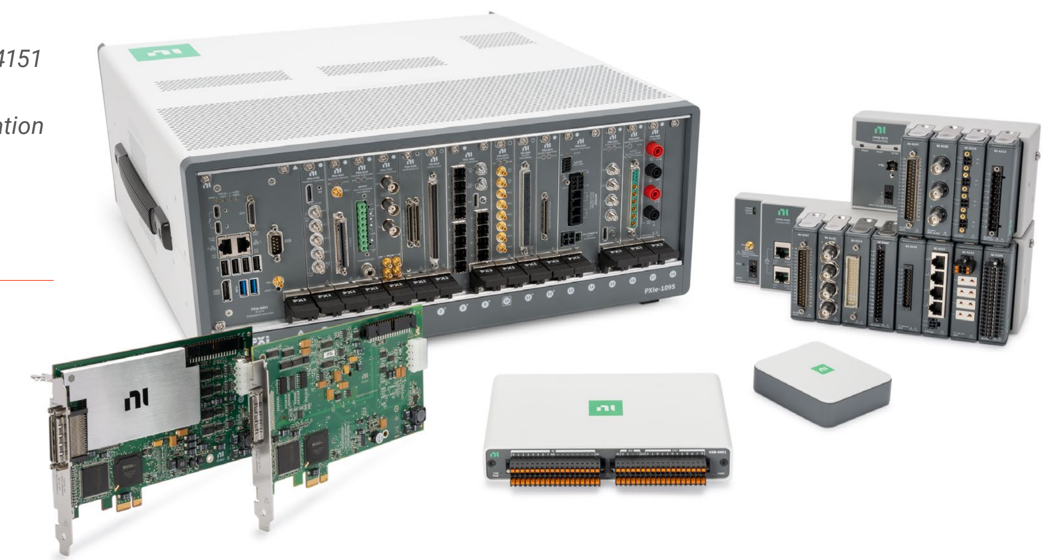


Figure 1: NI's differentiated Platform – including the PXIe-4151 power supply, PXIe-1487 vision module, and TestStand automation framework – demonstrate how smarter testing enables faster innovation. Image source: NI

These trends are driving a new level of complexity in vehicle systems – and with it, a new urgency in how we validate them. Hardware validation must evolve to keep pace with rapid development cycles, tighter integration between hardware and software, and the need for real-world simulation in the lab. PXIe Ethernet modules from NI play a critical role in this evolution, offering high-performance, time-synchronized network interfaces that support the latest automotive Ethernet standards and protocols. Their flexibility and precision make them essential tools for testing and validating next-generation vehicle architectures.

A modern workflow for hardware validation

Modern hardware validation is no longer a linear process. It's a dynamic, iterative workflow that spans requirements definition, test planning, system configuration using modular components, real-world simulation of sensors and networks, fault injection, data acquisition, and automation across teams and geographies.

This evolving workflow demands a platform that is flexible, scalable, and software-connected – one that can adapt to changing requirements without starting from scratch every time.

ECU testing with high-power precision

As zonal architectures consolidate functionality into fewer, more powerful ECUs, the demands on power delivery and validation increase. Engineers must simulate ECUs and real-world electrical conditions, inject faults, and monitor performance with high precision – while also validating communication across a wide range of in-vehicle networks.

The NI PXIe-4151 power supply is

purposely built for this challenge. Delivering up to 300 W of power in only two PXI slots, combined with SourceAdapt customizable transient response technology and precision current/voltage sourcing, it enables accurate simulation of dynamic power conditions, fault injection for robustness testing, and real-time monitoring of ECU behavior under load.

What sets NI's platform apart is its ability to combine high-power delivery with a comprehensive suite of automotive communication interfaces. From Automotive Ethernet, CAN, LIN, and FlexRay to video interfaces and a variety of digital and analog I/O, engineers can validate not only the electrical performance of ECUs but also their ability to communicate reliably across complex vehicle networks.

Its integration into a PXI-based test system allows for synchronized operation with other instruments, enabling comprehensive validation of power, communication, and functional behavior – all in one platform.

Camera testing for ADAS and vision systems

ADAS systems rely on a fusion of sensors – radar, LiDAR, and especially cameras – to perceive the environment and make split-second decisions. Validating these systems requires more than checking image quality; it demands precise synchronization, fault injection, and real-time analysis under simulated conditions.

The NI PXIe-1487 vision module (Figure 3) is a software-defined, FPGA-based solution designed for high-performance image generation and acquisition. It supports synchronized, deterministic testing with PXI-based timing and triggering, customizable automation via FPGA programmability, and integrated power and data through Power over Coax (PoC). Its scalable architecture supports high-channel-count systems, delivering

Figure 3: NI PXIe-1487
Image source: NI

the control, precision, and flexibility needed for superior test coverage.

Battery and powertrain validation for electrified vehicles

Electrification is reshaping the vehicle architecture – from propulsion to energy storage to thermal management. Validating these systems requires more than just long-duration testing and high-voltage safety; it demands a flexible, high-performance platform capable of adapting to evolving battery technologies and test strategies.

For battery modules and packs, the NI BTS-16110 is a purpose-built solution that delivers the power, precision, and configurability needed for advanced validation. Designed with an open, software-defined architecture, the BTS-16110 supports seamless integration into custom workflows and enables engineers to precisely monitor real-world charge/discharge cycles, thermal stress conditions, and fault scenarios with confidence. It is typically paired with the HPS-17000, a high-power system that extends the platform's capabilities for demanding pack-level testing, offering scalable current and voltage ranges to match evolving EV requirements.

Together, the BTS-16110 and HPS-17000 form a powerful foundation for battery validation, enabling scalable test stations, precise control, and deep integration with lab automation and data systems. Their compatibility with NI's broader ecosystem – including SystemLink for lab management and PAtools for battery test automation – ensures that battery validation is not only accurate and repeatable but also scalable across test benches and global teams.

Whether validating a next-gen EV platform or optimizing energy efficiency in hybrid systems, this open, modular approach provides the performance and flexibility needed to accelerate innovation in electrified mobility.

The NI advantage: a platform that is scalable (Figure 4)

At the heart of these use cases is a common foundation: NI's PXI-based modular platform. It brings together data acquisition, signal conditioning, real-time simulation, and multi-protocol communication in a single, scalable system. Combined with software toolkits like LabVIEW+ Suite and SystemLink, it enables rapid development and reuse of test logic, seamless integration across domains, centralized data management, and scalable deployment across global teams (Figure 5).

A key part of this platform advantage is TestStand, NI's powerful test management software. TestStand enables teams to scale from single-DUT validation to high-throughput, multi-DUT configurations – supporting up to six DUTs in parallel with efficient resource sharing. Its built-in execution models, including Batch Mode and Parallel Mode, allow engineers to coordinate test sequences, manage shared instrumentation, and optimize throughput without sacrificing traceability or test coverage.

NI is also driving innovation by enabling AI-powered capabilities in

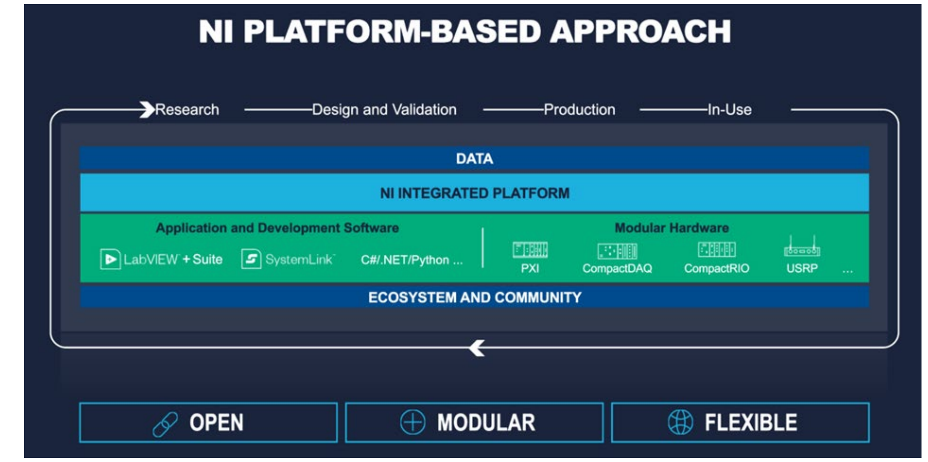


Figure 4: A scalable platform that grows when required. Image source: NI

TestStand. With new features like natural language processing and intelligent sequence generation, users can now transform requirements written in Excel directly into automated test sequences. This AI integration reduces development time, minimizes manual errors, and helps teams move from specification to execution faster than ever before.

This platform approach ensures that test systems can evolve alongside products – without costly rework or reinvention. Whether building a new lab or scaling an existing one, NI's open, software-connected platform enables the flexibility and control to test smarter.

Enabling innovation through smarter testing

As vehicles become more intelligent, electrified, and software-defined, the systems used to test them must evolve in parallel. Smarter hardware validation is not just about verifying functionality – it's about enabling innovation, accelerating development, and ensuring quality at every stage.

With NI's modular platform, differentiated instrumentation, and intelligent automation tools, engineering teams can meet today's challenges – and tomorrow's – with confidence.

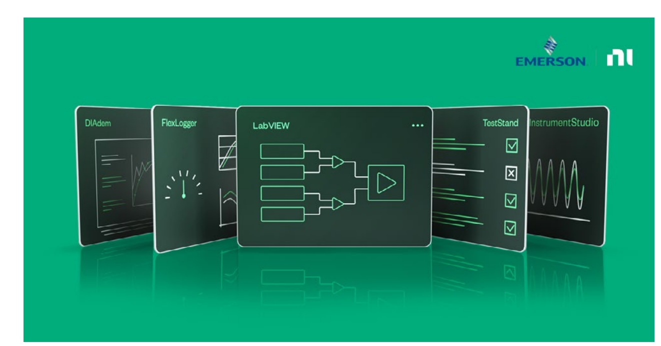


Figure 5: Whether building a new lab or scaling an existing one, NI's open, software-connected platform gives the flexibility and control to test smarter. Image source: NI

Use an automotive-grade flyback transformer for compact EV power supply designs

Written by Art Pini

The electrical and electronic power needs of innovative automotive designs can be summarized as follows: increased power, improved efficiency, reduced space requirements, and enhanced reliability. In the case of electric vehicles (EVs), efficiency is crucial in helping to alleviate 'range anxiety' for users. The combination of requirements in the context of EVs translates to compact and lightweight power solutions for standby and auxiliary power sources. Smaller power supplies introduce additional challenges, including the need for greater isolation to prevent electrical breakdowns between closely spaced components and reduced electromagnetic interference (EMI).

Flyback power converters are commonly used in various low-power EV applications, including generating auxiliary power, battery management, and gate-drive power. They offer simpler designs with fewer components, which reduce size, increase reliability, and lower costs. The heart of any flyback power supply is the flyback transformer, which is generally among one of the largest components required to support high voltage isolation.

This article describes how flyback converters operate, the effects of inductive and capacitive parasitics, and the importance of component size and signal isolation. It then introduces a flyback transformer from Bourns and shows how it can help address numerous automotive power challenges.

The flyback converter

Flyback converters are noted for their simple, minimal component design, for power levels up to 100W. At the heart of these designs is a flyback transformer, which provides both power transfer and isolation between the primary and secondary sides of the converter circuit (Figure 1, top). The converter can step up or down the voltage of a DC power source based on the flyback transformer configuration. In addition to the flyback transformer, the circuit requires a primary-side switch (SW), typically a MOSFET, and a secondary rectifier/filter.

The operating cycle begins when SW is turned on by placing Vgs in a high state (Figure 1, bottom). The switch closes, and the voltage

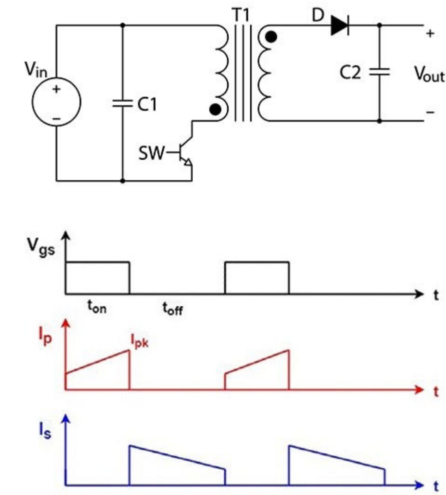


Figure 1: Shown is a simplified schematic of a flyback converter's basic elements (top) and the significant operational waveforms (bottom). Image source: Bourns Inc.

applied across the inductor is a step function. The inductor opposes any instantaneous change in the current and serves to integrate the applied step voltage. This results in a ramp function, and the current in the primary winding of the flyback transformer increases linearly due to the effect of primary inductance. The transformer secondary has no current flow because the rectifier diode (D) is reverse-biased, and an air gap in the flyback transformer's magnetic core prevents saturation as the transformer's magnetic field increases.

When the switch is turned off, achieved by returning Vgs to the low state, the energy stored in the transformer's magnetic field is transferred to the secondary through the now forward-biased diode, charging the output capacitor (C2). The secondary current falls linearly until the energy from the magnetic field is depleted or the switch is turned on again, beginning the next cycle.

A typical transformer, as found in a linear power supply, continuously transfers energy from the primary winding to the secondary winding. The flyback transformer's operation is more similar to that of a pair of coupled inductors in that it does not transfer energy continuously during the operating cycle. However, like a transformer, the output voltage can be adjusted by varying the turns ratio between the primary and secondary windings. The flyback transformer also provides galvanic isolation between the primary and secondary windings. Additionally, it supports multiple secondary windings, allowing numerous output voltages from the converter.

Parasitic effects in flyback converters

Typical of electronic circuits, flyback converters suffer unwanted effects due to parasitic inductances and capacitances (Figure 2).

The magnetizing inductance (Lm) is the main inductive property that determines the energy storage of the flyback transformer. Also associated with the transformer is a parasitic leakage inductance (Llk), which is in series with the switch. When the switch is opened, it tries to maintain the primary current and raises the voltage across the switch. Most flyback converters employ clamp circuits or snubbers to protect the switch from this transient voltage. This effect also increases magnetic field radiation and impacts EMI. Board trace inductance (Ltr) adds to these effects.

Transformer designers make every effort to minimize leakage inductance. The principal method is to increase the coupling between the primary and secondary windings. This is accomplished by minimizing the separation between the windings and also by interleaving them.

The distributed capacitances include the primary capacitance (Cp), interwinding capacitance (Cps), secondary capacitance (Cs), FET output capacitance (Co),

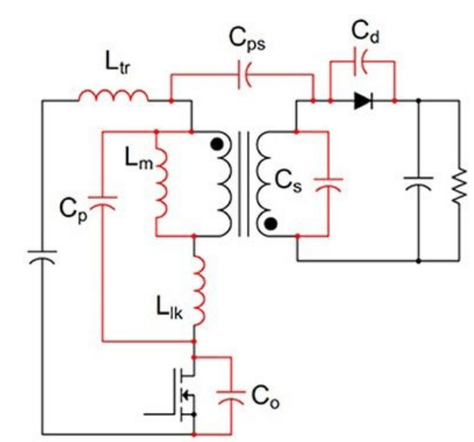


Figure 2: Shown is a schematic diagram of a flyback converter that highlights in red the parasitic capacitances and inductances associated with converter components. Image source: Bourns Inc.

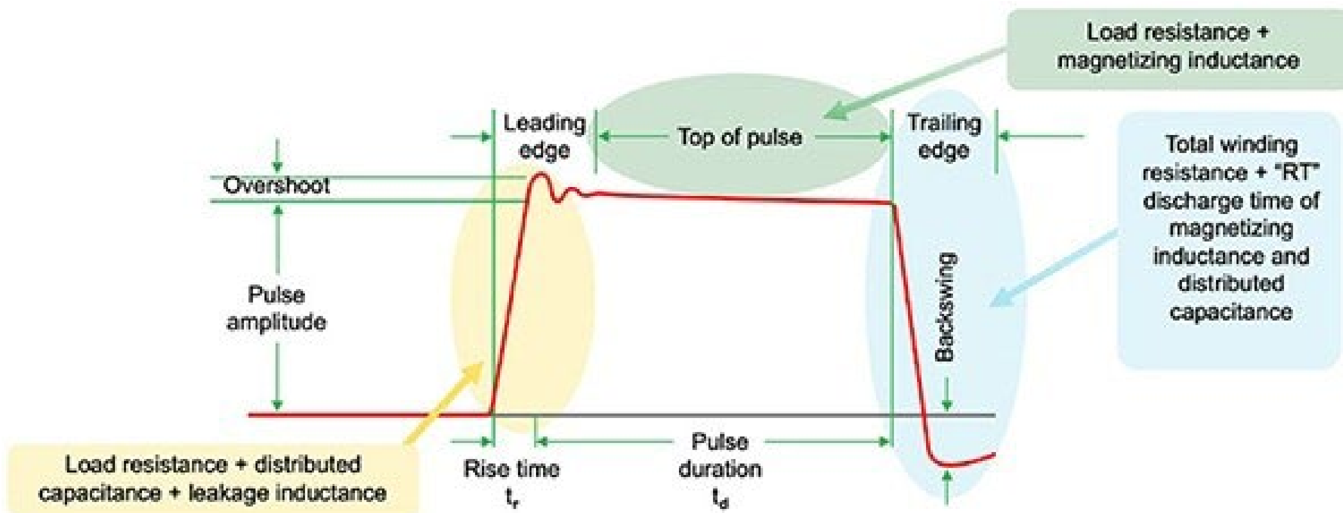


Figure 3: Shown are the effects of capacitive and inductive parasitic elements on the switching waveform. Image source: Bourns Inc.

and secondary diode capacitance (Cd). These capacitances interact with the inductances to reduce the integrity of the converter signal waveforms (Figure 3).

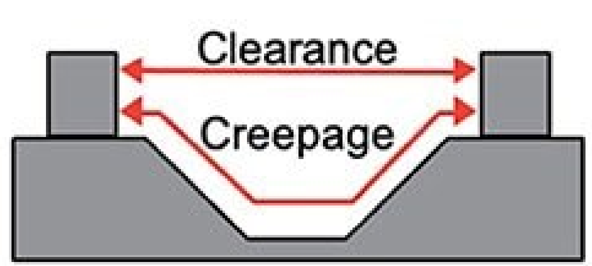
The switching waveform ideally would be a rectangular pulse with no overshoot or undershoot. The fast transition times of this rectangular pulse guarantee that the voltage waveform is at zero before the current increases. In reality, the effects of parasitic capacitances and inductances slow the transition times and cause overshoot, undershoot, and ringing. In addition, slower rise and fall times increase the converter's switching losses due to the overlap of the non-zero primary voltage and current waveforms. This overlap dissipates power as switching losses in the FET switch, thereby lowering the converter's efficiency. The noticeable droop in the pulse top is due to the load resistance and magnetizing inductance.

When designing a flyback transformer, significant effort must be made to keep the self-resonant frequencies away from the converter's switching frequencies, and keeping the wiring between the switch and the flyback transformer as short as possible helps minimize parasitic capacitance. Additionally, the interwinding capacitance provides a path for coupling the high-frequency components of the primary signal to the output. The greater the interwinding capacitance, the greater the converter's conducted EMI emissions. Optimal performance requires a design trade-off, as closer coupling of the windings decreases the leakage inductance but also increases the interwinding capacitance. This is where the experience of the transformer designer matters.

Size reduction and signal isolation

Components intended for automotive applications should be as small as possible. The physical size of a component is determined by the materials' characteristics and the physics of the part's function. In the case of the flyback transformer, the spacing of conductors has to be sufficient to handle the peak working voltages and the voltage testing required for standards certification. The key specifications associated with voltage breakdown are clearance and creepage (Figure 4).

Figure 4: Clearance and creepage are specifications that describe the minimum distances between adjacent conductors needed to prevent electrical breakdown and arcing. Image source: Bourns Inc.



The Bourns HVMA03F40C-ST10S is particularly well-suited to helping designers meet EV power requirements

Clearance is the shortest distance between two conductive paths in the air, and creepage is the shortest distance between two conductive paths along the surface of an insulating material. These distances are crucial in preventing arcing and maintaining electrical isolation.

Flyback transformer meets EV requirements

The Bourns HVMA03F40C-ST10S (Figure 5) flyback transformer is automotive-qualified and designed to operate at switching frequencies from 100 to 400kHz, and is rated to handle up to 3W.

This flyback transformer is an automotive-grade, AEC-Q200-compliant component rated to operate over a temperature range of -40 to +155°C (including self-temperature rise). It is an eight-pad surface-mount device with an exceptionally compact footprint of 9.5 × 10.3mm, with a height of 13mm. Designed to operate with a primary drive of 6V to 27V, its dual secondary windings produce a nominal output of 14V.

The primary winding (between pins 1 and 2) offers a main inductance of 40 microhenries (mH) with a leakage inductance of only 1.1mH and a series resistance of 1.0 ohms (Ω). The principal secondary (between pins 6 and 7) has a series DC resistance of 1.0 Ω. The auxiliary output (between pins 3 and 4) has a series resistance of 1.4Ω. The transformer is set for unity gain with a turns ratio of 1:1:1.

Rated to handle a working voltage up to 900V, its voltage isolation is 4,000VAC. Despite the high voltage rating, the transformer has a rated creepage distance of 10mm and a clearance distance of 6mm.

This flyback transformer is suitable for automotive applications, such as transistor gate-drive power supplies, battery management circuits, or an isolated power source between independent power circuits in EVs. It is compatible with many flyback controller integrated circuits operating at a fixed switch frequency with pulse width modulation, or with fixed pulse width and variable frequency control.

Conclusion

The Bourns HVMA03F40C-ST10S is particularly well-suited to helping designers meet EV power requirements. It is AEC-Q200 compliant and features a compact form factor, compliance with clearance and creepage specifications, and a rating of 3W over a wide temperature range.

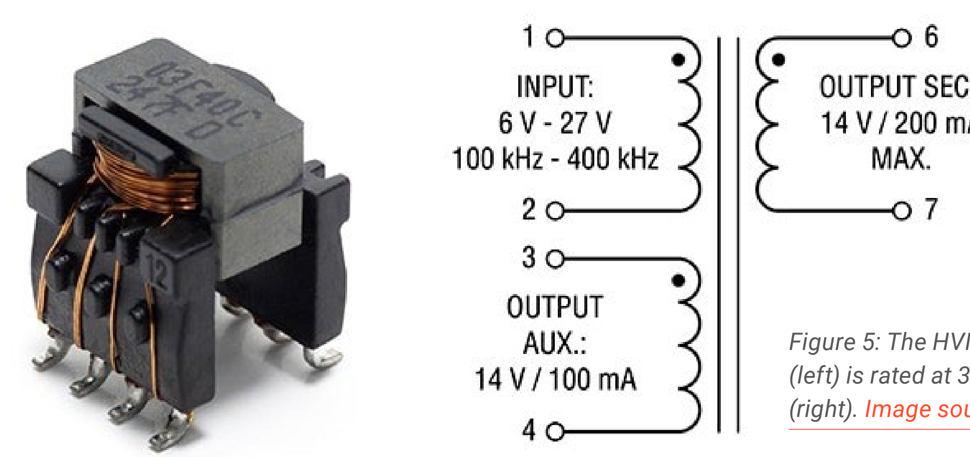


Figure 5: The HVMA03F40C-ST10S flyback transformer (left) is rated at 3W and features dual output windings (right). Image source: Bourns Inc.

Understanding thermal challenges in EV charging applications

Written by Jeff Smoot, VP of Apps Engineering and Motion Control at Same Sky

While the concept of electric vehicles (EVs) has been around for as long as gasoline vehicles, it's only in recent years that they've gained widespread acceptance. This surge in popularity can be attributed to significant advancements in EV technology coupled with substantial governmental backing.

For instance, the European Union's decision to ban internal combustion vehicles by 2035 and mandate fast EV charging stations every 60 kilometers by 2025 serves as a clear testament to this anticipated surge in demand.

As EVs emerge as the dominant mode of transportation, factors such as battery range and even quicker charging rates will play pivotal roles in sustaining the global economy. Enhancements in EV charging infrastructure will necessitate advancements across various domains, with thermal management standing out as a key area requiring technological evolution.

AC and DC EV chargers – what's the difference?

As the demand for quicker charging solutions intensifies, there have been both incremental and transformative shifts in approach. One notable change is the increasing adoption of DC chargers – a term that may initially seem ambiguous given that all battery systems inherently operate on DC electricity. However, the crucial distinction lies in where the conversion from AC to DC occurs within these systems.

The conventional AC charger, typically encountered in residential settings, primarily serves as a sophisticated interface responsible for communication, filtering, and regulating the flow of AC power to the vehicle. Subsequently, an onboard DC charger within the vehicle rectifies this power and charges the batteries. In contrast, a DC charger undertakes rectification prior to delivering power to the vehicle, transmitting it as a high-voltage DC source.

The primary advantage of DC chargers lies in their ability to eliminate many constraints related to weight and size by relocating the power conditioning components from the EV to an external structure.

By shedding weight and size constraints, DC chargers can seamlessly incorporate additional components to enhance both their

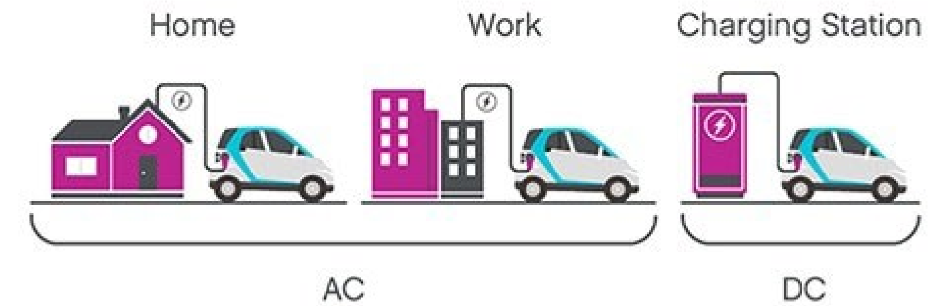


Figure 1: DC chargers exhibit notably accelerated charging rates, albeit with heightened complexity and increased heat generation. Image source: Same Sky

current throughput and operating voltage. These chargers leverage state-of-the-art semiconductor devices for rectifying power, alongside filters and power resistors, all of which generate substantial heat during operation. While the contributions of filters and resistors to heat dissipation are noteworthy, the predominant heat emitter in an EV charging system is the Insulated Gate Bipolar Transistor (IGBT), a semiconductor device that has witnessed increased adoption in recent decades. This robust component has unlocked numerous possibilities in the charging domain, yet ensuring its adequate cooling remains a significant concern.

Tackling heat challenges

An Insulated-Gate Bipolar Transistor, or IGBT, essentially serves as a hybrid between a Field-Effect Transistor (FET) and a Bipolar Junction Transistor (BJT). Renowned for their capacity to endure high voltages, minimal on-resistance, rapid switching rates, and remarkable thermal resilience, IGBTs find optimal utility in high-power scenarios such as EV chargers.

In EV charging circuits, where IGBTs serve as rectifiers or inverters, their frequent switching operations lead to the generation of significant heat. Presently, the foremost thermal challenge pertains to the substantial escalation in heat dissipation associated with IGBTs. Over the past three decades, heat dissipation has soared more than tenfold, from 1.2 to 12.5kW, with projections indicating further increases. Figure 2 illustrates this trend in terms of power per unit surface area.

To put this into perspective, contemporary CPUs achieve power levels around 0.18kW, corresponding to a modest 7kW/cm2. The staggering disparity underscores the formidable thermal management hurdles facing IGBTs in high-power applications.

Two contributing factors play significant roles in enhancing the cooling of IGBTs. Firstly, the surface area of IGBTs is approximately twice that of CPUs. Secondly, IGBTs can withstand higher operating temperatures, reaching up to +170°C, whereas modern CPUs typically operate at only +105°C.

The most effective method for managing thermal conditions involves employing a combination of heatsinks and forced air. Semiconductor devices, such as IGBTs, generally exhibit extremely low thermal resistance internally, while the thermal resistance between the device and the surrounding air is comparatively high. Incorporating a heatsink substantially increases the available surface area for dissipating heat into the ambient air, thereby reducing thermal resistance. Additionally, directing airflow over the heatsink further enhances its efficacy. Given that the device-air interface represents the most significant thermal resistance in the system, minimizing it is crucial. The advantage of this straightforward approach lies in the reliability of passive heatsinks and the well-established technology of fans.

Same Sky has customized heatsinks specifically for EV charging applications, with dimensions of up to 950 x 350 x 75mm. These heatsinks are capable of passively handling less demanding requirements or actively managing more demanding scenarios with forced air.

In addition to air cooling methods, liquid cooling offers an alternative for dissipating heat from high-power components like IGBTs. Water-cooling systems are attractive due to their ability to achieve the lowest thermal resistances. However, they come with higher costs and increased complexity compared to air cooling solutions. It's also worth noting that even in water-cooling setups, heatsinks and fans are still essential components for effective heat removal from the system.

Considering the associated costs and complexities, direct cooling of IGBTs using heatsinks and fans remains the preferred approach. Ongoing research efforts are focused on enhancing air cooling technologies specifically tailored for IGBT applications. This active research aims to optimize heat dissipation while minimizing costs and system complexities associated with liquid cooling methods.

Figure 2: The power density of IGBTs has experienced significant advancements.
Image source: Same Sky

Figure 3: Utilizing heatsinks and fans represents a highly effective thermal management solution for IGBTs.
Image source: Same Sky

Thermal system design considerations

The effectiveness of any cooling system heavily relies on the strategic placement of components to optimize airflow and enhance heat distribution. Insufficient spacing between components can impede airflow and limit the size of heatsinks that can be utilized. Therefore, it's crucial to strategically position critical heat-generating components throughout the entire system to facilitate efficient cooling.

In addition to component placement, the positioning of thermal sensors is equally vital. In large-scale systems like DC EV chargers, real-time temperature monitoring facilitated by control systems plays a crucial role in active thermal management. Automatic adjustments in cooling mechanisms based on temperature readings can optimize system performance and prevent overheating by regulating current output or adjusting fan speeds. However, the accuracy of these automatic adjustments is contingent upon the quality and precision of the temperature sensors. Poor placement of sensors can lead to inaccurate temperature readings, resulting in ineffective system responses. Therefore, careful consideration must be given to the placement of thermal sensors to ensure the accuracy and reliability of temperature monitoring and control.

Environmental factors

EV charging stations are frequently deployed in outdoor environments, subject to diverse weather conditions. Therefore, designing weather-resistant enclosures with proper ventilation and protection against elements, such as rain and extreme temperatures, is imperative to uphold optimal thermal performance. It's crucial to ensure that airflow paths and venting systems are engineered to prevent water ingress while maintaining unobstructed airflow.

Among external factors, solar heating from direct sunlight poses a significant challenge, leading to a considerable increase in the internal ambient temperature of the charger enclosure. While this

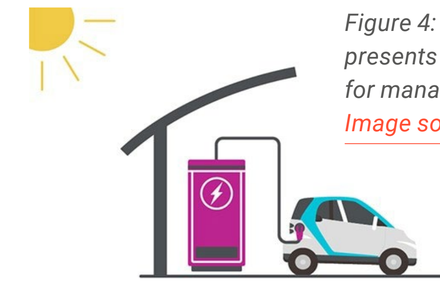


Figure 4: Shielding chargers from direct sunlight presents a cost-effective and efficient strategy for managing thermal conditions.
Image source: Same Sky

presents a legitimate concern, the most efficient solution is relatively straightforward. Implementing well-designed shading structures with sufficient airflow between the shading and the charging unit effectively mitigates solar heating, thereby maintaining lower ambient temperatures within the charger enclosure.

What's next?

In recent years, there has been a remarkable surge in the worldwide adoption of electric vehicles, with demand showing consistent and significant growth across various technological fronts. As the number of EVs on the road continues to escalate, the proliferation of charging infrastructure is expected to expand in lockstep. The effective operation and efficiency of chargers are paramount to the development of this burgeoning charging infrastructure. Cost-efficiency is also a critical factor, as the speed at which individuals and businesses integrate these chargers into their homes and establishments is contingent upon affordability.

Anticipating the continuous growth of EVs and chargers, one must acknowledge the evolving nature of the underlying technologies. This entails considering potential advancements in charging power and capacity, evolving software and hardware standards, and allowing room for unforeseen innovations. This proactive approach ensures that thermal management systems can adapt to evolving demands over time.

At their core, electric vehicle chargers share similar thermal management concerns with other dense, high-power electronic devices. However, the power density of the Insulated-Gate Bipolar Transistors (IGBTs) utilized in EV chargers, coupled with the escalating demands placed on them, presents a unique challenge. As charging speeds and battery capacities continue to rise, the imperative to develop chargers effectively and safely becomes increasingly stringent, demanding more from thermal management designers and engineers than ever before.

Same Sky offers a comprehensive range of thermal management components, coupled with industry-leading thermal design services, to support the evolving needs of the electric vehicle charging ecosystem.

Understanding the role of drivers, switches, and laser diodes for effective LiDAR performance

Written by Bill Schweber

Light detection and ranging (LiDAR) systems have become the preferred method for enabling an automobile, an automated guided vehicle (AGV), or even a robotic vacuum to 'see' its surroundings. Drones and higher-flying aircraft also use LiDAR to navigate and map terrain at greater distances.

Though LiDAR has been well studied, designers must exercise great care when selecting key components such as the gate driver, the gate-switch FET, and the laser diode necessary to create the optical pulses.

This article provides an overview of LiDAR. It then presents examples of the critical electro-optical components and shows how they work together to generate the necessary pulses.

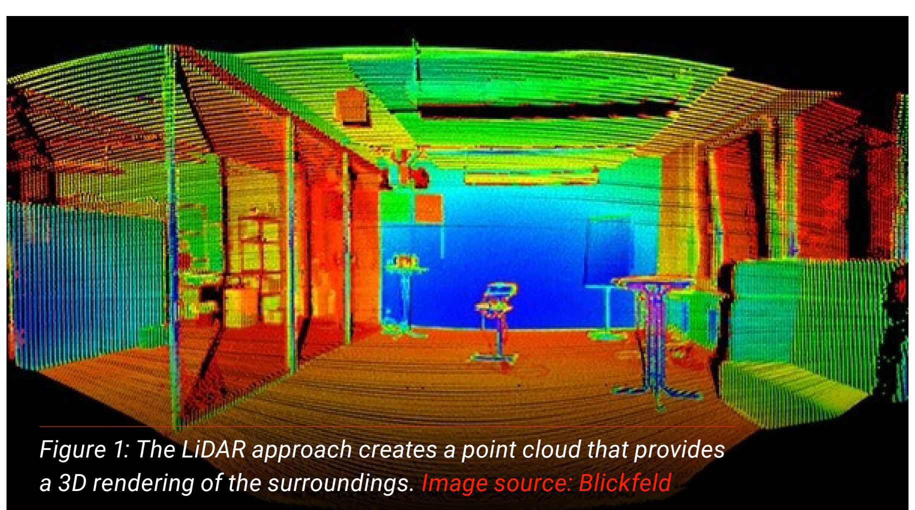


Figure 1: The LiDAR approach creates a point cloud that provides a 3D rendering of the surroundings. Image source: Blickfeld

How LiDAR works

LiDAR operates by sending out a continuous stream of short, moderate-power optical pulses and then capturing their reflections. It measures time-of-flight (ToF) to create a point cloud of the surroundings that presents a three-dimensional (3D) perspective (Figure 1). Many systems use multiple laser diodes in a matrix for broader area coverage.

The application determines the performance of a LiDAR system. A system used for a slow-moving, area-constrained robotic vacuum or an AGV has much looser range and angular resolution requirements than one used in a car, which must contend with faster speeds and respond to vehicles, cyclists, or pedestrians. The numbers often cited as top-level performance objectives for automotive applications are an effective range of 100 to 200m and an angular resolution of 0.1°.

A two-axis electromechanical galvanometer scans the laser flashes across the image area to achieve a precise point cloud. Since the LiDAR system measures ToF for each emitted pulse and its associated return, it can create a 3D image with the depth perspective necessary for vehicles to navigate their surroundings accurately.

The electro-optical path at LiDAR's core

A complete LiDAR system, such as the one used in an AGV, requires a diverse set of interconnected optical, analog, processor, and mechanical blocks. At the system's core is the electro-optical path, which comprises a laser-based optical source and a co-located optical receiver (Figure 2).

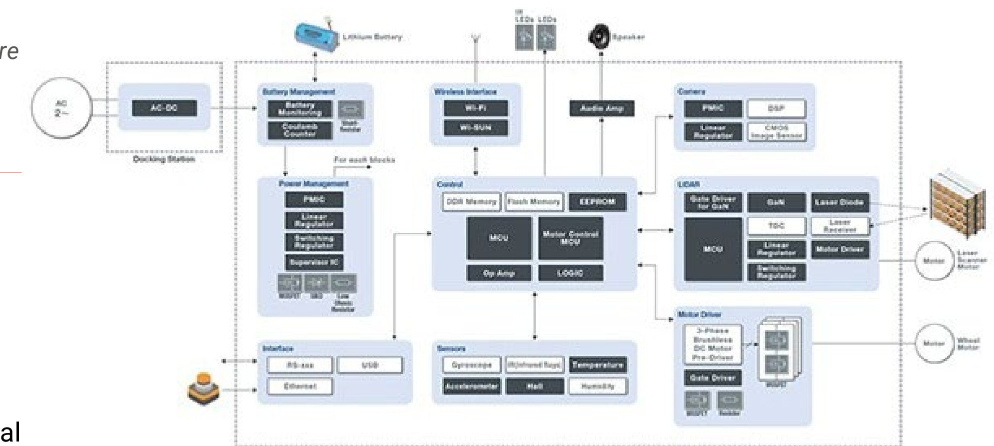


Figure 2: The electro-optic signal path and associated components are the heart of a LiDAR system (right side, middle row). Image source: ROHM

The signal path of the source that creates the stream of optical pulses is controlled by a dedicated microcontroller unit (MCU), which determines the desired optical pulse repetition rate and width. The source path has three key functional elements:

- The gate driver provides high-speed pulses with fast rise and fall times to turn the gate switch on and off
- The gate-switch FET turns crisply on and off to control the laser diode's current flow
- The laser diode creates independent, non-overlapping optical pulses at the required wavelength

Selecting and integrating these components requires an understanding of electrical issues, as well as optical characteristics such as field of view, laser diode power and wavelength angular sensitivity, and optical signal-to-noise ratio (SNR). Advanced software algorithms can overcome some limitations in the electro-optical signal paths and challenges in the sensed setting. However, it is prudent engineering to choose components optimized for LiDAR rather than assume these algorithms can compensate for shortcomings.

A look at a representative component for each of these functions illustrates how LiDAR-optimized devices address the many challenges:

The gate driver

The ROHM Semiconductor BD2311NVX-LBE2 (Figure 3) is a single-channel, ultra-fast GaN gate driver well-suited for industrial applications such as AGVs. It provides the necessary combination of drive current and voltage. It comes in a 6-pin package measuring just 2.0 × 2.0 × 0.6mm, and can source up to 5.4A of output current with a supply voltage range of 4.5 to 5.5V.

The BD2311NVX-LBE2 can drive GaN high electron-mobility transistors (HEMTs) and other switching devices with narrow output pulses, thus contributing to LiDAR's long range and high accuracy. These pulse-related parameters include a minimum input pulse width of 1.25 nanoseconds (ns), a typical rise time of 0.65ns, and a typical fall time of 0.70ns, all with a 220 picofarad (pF) load. The turn-on and turn-off delay times are 3.4 and 3.0ns, respectively.

The gate-switch FET

The output of the gate driver connects to the control input of the current-control switch device. This

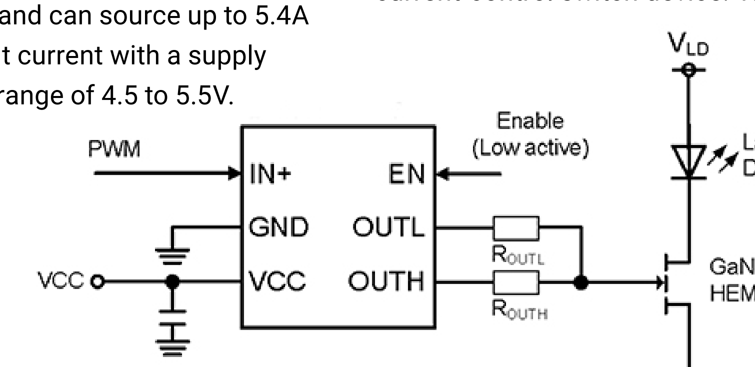


Figure 3: The BD2311NVX-LBE2 single-channel gate driver provides the necessary combination of drive current and voltage to precisely control a LiDAR gate switch. Image source: ROHM

device must rapidly switch between on and off states as directed by the gate driver and handle relatively large current values, typically 50 to 100A.

The required level of performance is available using devices such as EPC's EPC2252, an automotive-qualified (AEC-Q101) N-channel, enhancement-mode GaN power transistor. It features exceptionally high electron mobility and a low temperature coefficient for a very low on-resistance (RDS(ON)), while its lateral device structure and majority carrier diode provide an exceptionally low total gate charge (QG) and zero source-drain recovery charge (QRR). The result is a device that can handle tasks where very high switching frequency and low on-time are beneficial, and where on-state losses dominate.

The EPC2252's 80V drain-source voltage (VDS), 11 milliohms (mΩ) (maximum) RDS(ON), and continuous drain current (ID) of

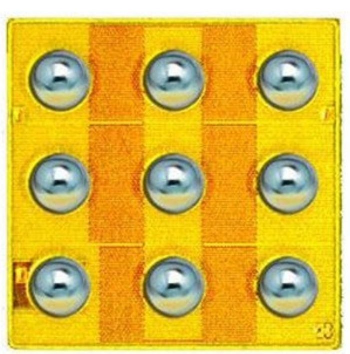


Figure 4: The EPC2252 GaN power transistor provides the needed current switching for high-current laser diodes in a package measuring 1.5 × 1.5mm. Image source: EPC

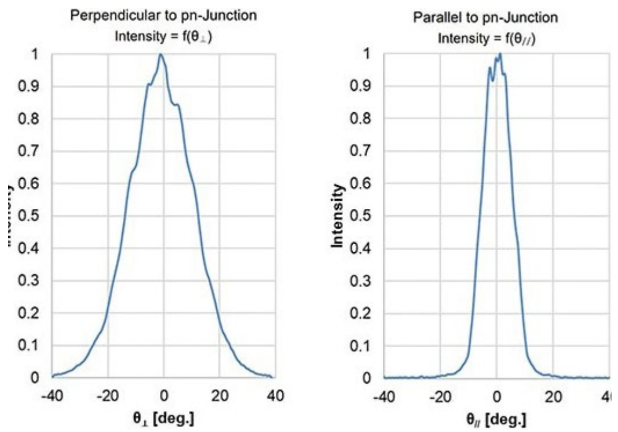


Figure 5: The RLD90QZW3-00A pulsed laser diode has typical beam divergence values of 25° in the perpendicular plane (left) and 12° in its parallel plane (right). Image source: ROHM

8.2A only tell part of the story. It is easy to use, requires an on-state gate drive of only 5V, 0V for the off state, and does not need a negative voltage. This simplifies both driver and supply rail considerations.

Due to its design and die arrangement, the gate switch can handle an ID of 80A at 125°C (TPULSE of 10 microseconds (μs)) and is packaged as a passivated die measuring 1.5 × 1.5mm with nine contact solder bumps (Figure 4). Reduced package-and-die parasitics, such as an input capacitance (CISS) of 440pF (typical), support high-speed pulse performance with fast transitions.

The laser diode

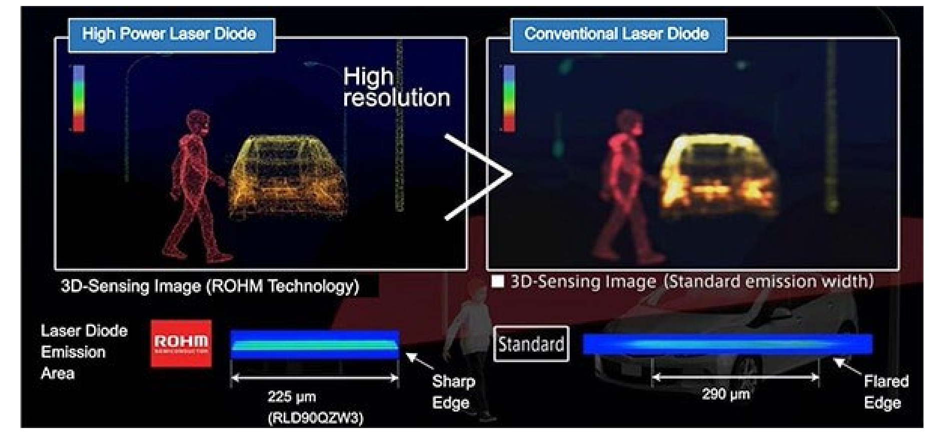
This is the final component in the optical path and functions as an electro-optical transducer. Unlike cameras, which are passive devices, laser diodes are active sources and emit optical radiation, which is deemed harmful to human eyes under some conditions. The maximum allowed intensity is defined by standards such as EN 60825-1:2014, 'Safety of Laser Products'.

The safety rating of a LiDAR system depends on its power, divergence angle, pulse duration, exposure direction, and wavelength. Most systems use a 905 nanometer (nm) or 1550nm wavelength, each offering acceptable efficiency and wavelength compatibility between the laser and a suitable photodiode. Generally, a 1550nm laser can safely emit more power than a 905nm laser before it is deemed unsafe. However, 905nm lasers are popular because they are more cost-effective.

For a 905nm wavelength, the ROHM RLD90QZW3-00A is a pulsed laser diode optimized for LiDAR applications. It supports 75W output at a forward current (IF) of 23A and provides superior performance across three parameters: beam width (divergence), beam wavelength narrowness, and beam stability.

Beam divergence defines the spread of the beam due to diffraction. The RLD90QZW3-00A

Figure 6: The stability and consistency of the RLD90QZW3-00A pulsed laser diode output yields an improved SNR and point cloud resolution. Image source: ROHM



specifies typical values of 25° in the perpendicular plane (θ⊥) and 12° in its parallel plane (θ//) (Figure 5). Its laser output temperature stability is 0.15nm per degree Celsius (nm/°C).

The narrow light-emission width and stability of this laser diode's output wavelength are also critical to enhanced system performance, as they allow the use of narrow-wavelength optical bandpass filters. ROHM states that this diode's 225 micrometer (μm) range is 22% smaller than available competitive devices, thus supporting higher resolution and a wider sensing range with high beam sharpness, narrow emissivity, and high optical density.

These two factors improve the optical SNR, enabling accurate sensing and assessment of objects at an extended distance. A comparative point-cloud image shows the positive impact of these tight and stable specifications on resolution (Figure 6).

Conclusion

LiDAR is widely used to capture 3D perspectives of surroundings and map terrains. At the core of the LiDAR system are the electronic and electro-optical components that integrate the complex capabilities needed for a viable system. For the optical-source functions, the gate driver, gate-switch FET, and laser diode must be compatible with respect to voltage, current, speed, and stability to ensure optimal performance.

Related LiDAR content

1. Ensure LiDAR Automotive Distance Sensor Precision With the Right TIA
2. An Understanding of How LiDAR Works Shows the Importance of Careful TIA and Comparator Selection
3. Simplifying Time-of-Flight Distance Measurements
4. Get Started Quickly With 3D Time-of-Flight Applications
5. Quick Guide to GaN FETs for LiDAR in Autonomous Vehicles
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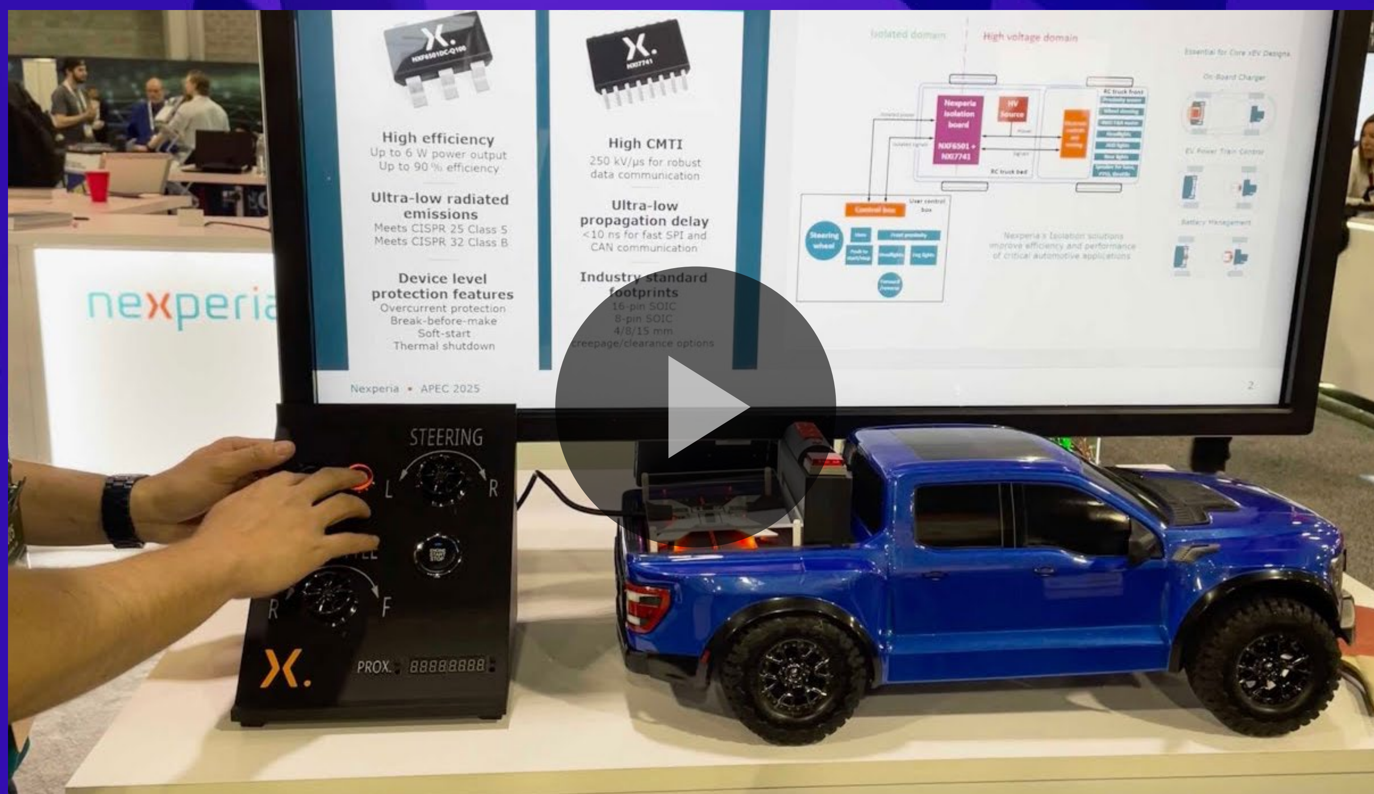
Video spotlight



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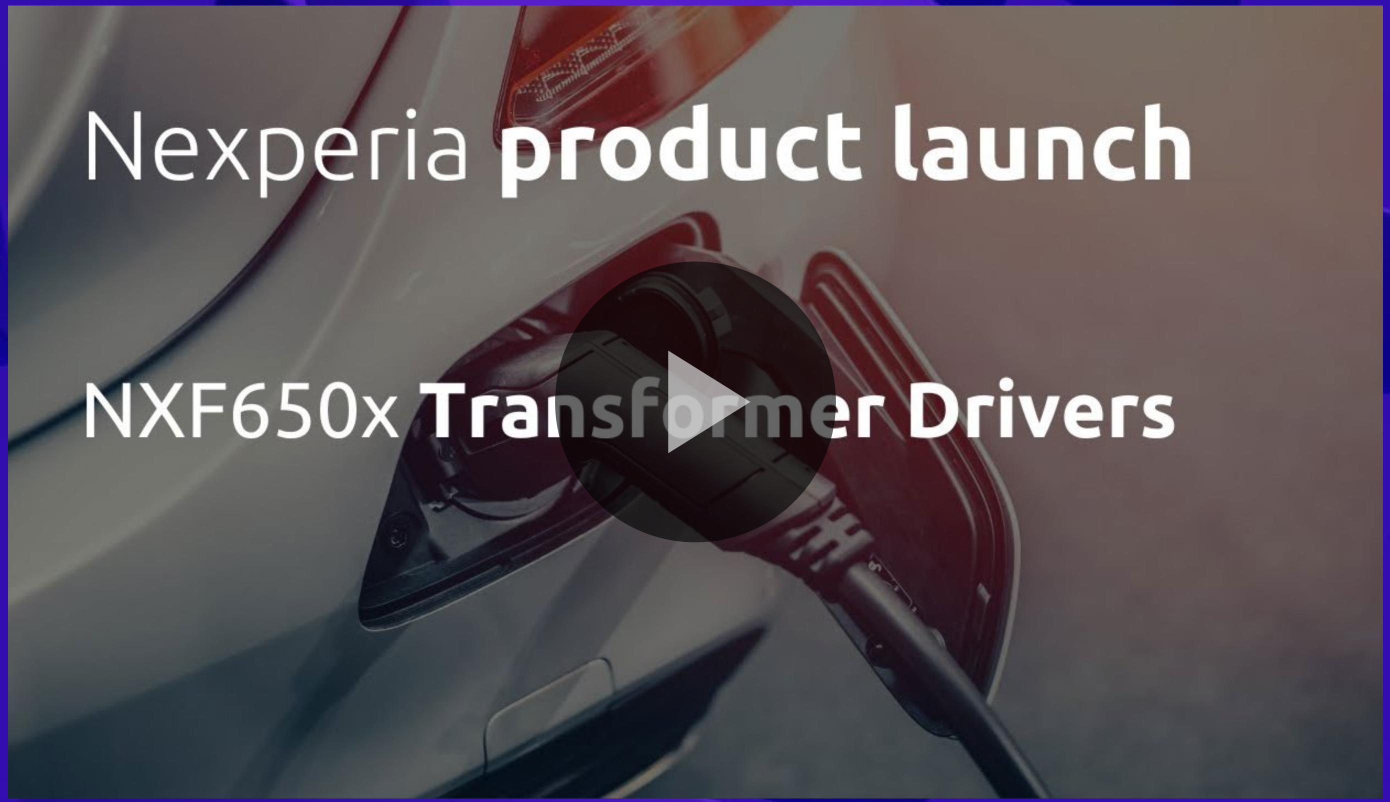

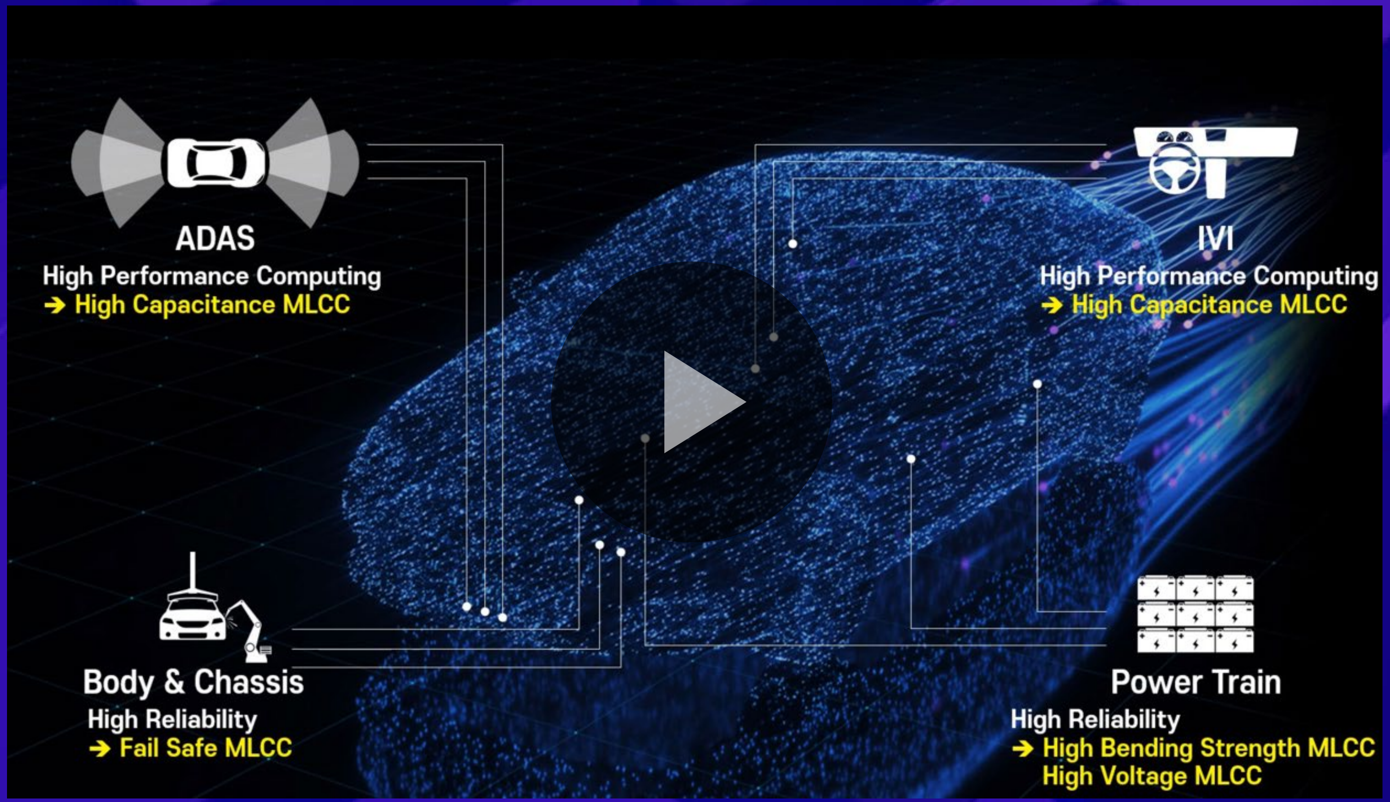

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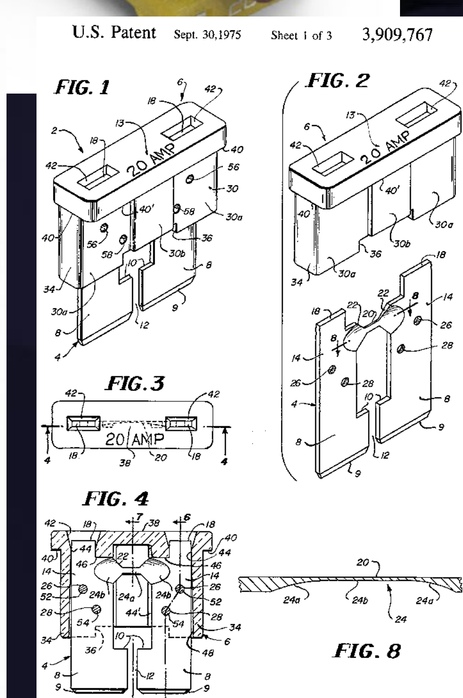
The blade that breaks the circuit: a milestone history of the blade fuse

Written by David Ray, Cyber City Circuits

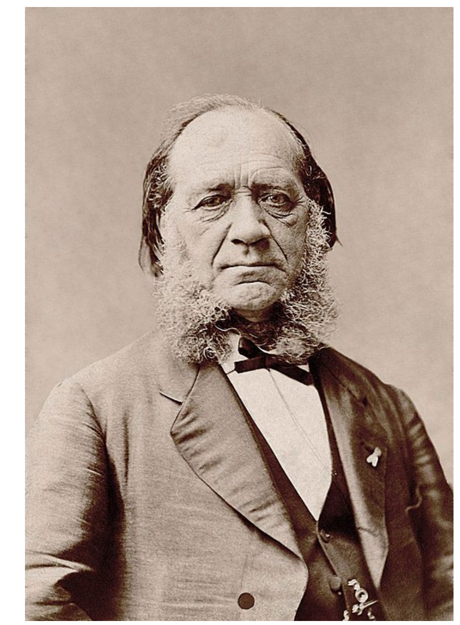


Sacrificed for safety: the story of the fuse

The fuse's core innovation, a sacrificial element that melts to halt dangerous currents, emerged from Louis Breguet's 1847 lightning-struck telegraph, where a thin wire protected equipment and personnel, predating Thomas Edison's 1890 cartridge-style 'Fuse-Block' by decades, which enclosed the wire for safer use in lighting circuits. This progression accelerated with Littelfuse's 1927 tiny, fast-blowing fuses for sensitive devices and the 1970s ATO blade fuses, solving corrosion and space constraints in vehicles, alongside European torpedo fuses from the 1930s. As electrical systems grow more complex in renewable energy and EVs, the fuse's story highlights how front-loading safety through self-destruction has prevented countless hazards since electrification's dawn.

Louis Breguet and a strike of lightning

Louis Clément François Breguet was the grandson of a great Swiss-French watchmaker, Abraham-Louis Breguet, born in 1804. At the age of eight, he was sent from his home in France to live with his godfather in Switzerland, where he learned all of the fine techniques needed for watchmaking. As a young man at the age of sixteen, he returned home to work in the family business. Biographies say that he was forced to stay in the workshop, improving his skills from 5:30 in the morning until 10:00 at night. The next several years are marked with his work as an apprentice for several people between Geneva and Paris.



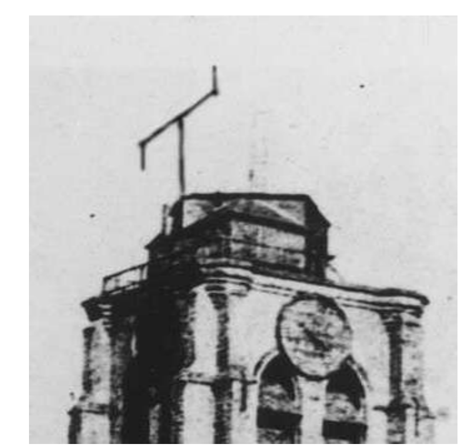
French inventor and watch maker Louis Clément François Breguet

A family friend and physicist, François Arago (later the director of the Paris Observatory), urged him to attend classes at the École Polytechnique in Paris. This is the same university that André-Marie Ampère taught at, and Breguet would have been one of his students. The classes he took under Ampère clearly influenced all the work he did afterward.

In 1843, he was elected to the Bureau des Longitudes, a French institution with the mission of improving astronomical navigation and standardizing timekeeping.

Retro Electro fun fact: did you know that François Arago is the one responsible for bringing Ørsted's compass experiments to the attention of André-Marie Ampère, leading directly to the founding of the field of electrodynamics? Learn that story in the Retro Electro article 'Experiments on the Effect of a Current of Electricity on the Magnetic Needle.'

He soon left the clock-making business for his brother-in-law to tend to, while he performed experiments on electricity, telegraphy, etc. He worked with the military to develop instruments and tools needed to measure the velocity of projectiles. In the mid-1840s, with the popularization of the new telegraph technology in other nations, he was called upon by the French government to design a type of electric telegraph system that could replace France's Chappe optical telegraph system.



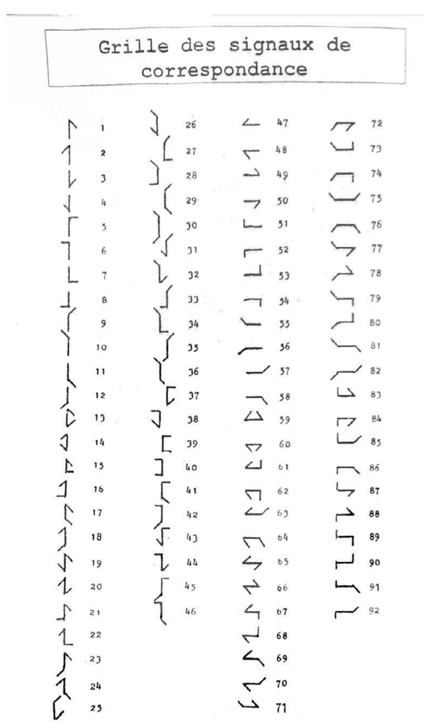
Chappe Optical Telegraph towers were strategically placed throughout France to enable fast communication of invaders to Paris.

The Chappe Telegraph, also known as the Optical Telegraph, consisted of a series of towers 5km-15km apart that could send messages throughout France quickly. It used giant apparatuses mounted on top of mountains, towers, and some buildings, allowing operators to send messages back and forth. It was a very long process to send anything through the series of towers, but by this point in history, the system was already well developed, the crews were already trained, and it worked. It was used to warn Paris of invaders, so that they could be prepared to defend their sovereignty following the French Revolution, and changing it made many people in the government and military nervous. It was decided that they needed a telegraph system that required as little retraining as possible using the existing Chappe symbols.

After a few years, it was decided that the Chappe alphabet was not well suited for telegraphy, and it was abandoned altogether for a more modern system. It was this work on developing the French telegraph system that lightning struck. In 1847, his telegraph system was struck by lightning, destroying a large portion of his work and injuring at least one employee. As the lightning raced along the lines into the building, the room was illuminated by a bright light from the conductors attached to the cabin walls. These conductors, roughly 0.4mm in diameter, fell from the wall to the table below, leaving burn marks on the table's surface. He noticed that the equipment up to the vaporized wires had failed, but other parts were fine, and the other telegraph cabins were unaware that anything had happened.

The Foy and Breguey Telegraph was designed to replace the visual alphabet used in the existing Chappe telegraph system.

In 1847, he wrote a letter to the French Academy of Sciences detailing this observation. Bréguet recognized that telegraph infrastructure, especially when routed near railways, could unintentionally conduct and concentrate lightning strikes. He recommended placing a short length or very thin wire in line with the telegraph lines, about fifteen feet away from the telegraph cabin, to protect the workers and the equipment.



"To prevent the destruction of the equipment and, above all, to protect the telegraph workers from deadly explosions, I believe it would be wise to interrupt the iron conductor wires, 3 to 4 millimeters in diameter, at a distance of 5 to 6 meters from the cabins. The connection between these thick wires and the devices would be made using metallic wires that are much thinner. Then, the amount of electricity that could be transmitted by the thin wire, being of very small cross-section, would never reach the telegraph stations. In the event of a discharge, this wire would melt and break, not inside, but outside the cabins occupied by the workers." – Breguet in a letter to the French Academy of Sciences.

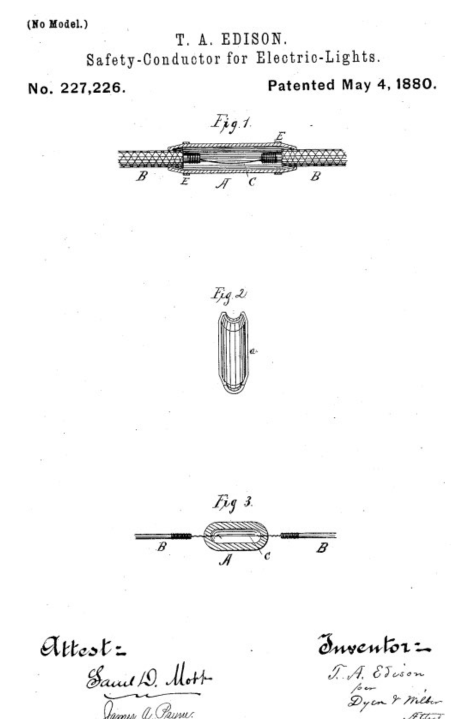
This letter is widely regarded as the earliest description of a deliberately sacrificial conductor designed to protect equipment and personnel, what we would now recognize as a fusible link. Bréguet's description of placing a thin wire outside a structure to safely melt under electrical stress demonstrates a remarkably modern understanding of circuit protection, predating Edison's fuse patents by more than 30 years.

Retro Electro fun fact: Breguet was on the organizing committee for the first International Exposition of Electricity in 1881. This was the event where many units of measure were first standardized internationally. Learn the story of the telegraph engineer who fought to immortalize Ohm as a unit of measure in the Retro Electro article 'Ohm's Day.'

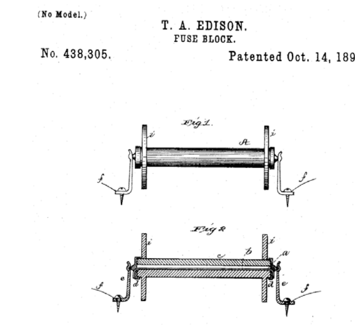
Edison's safety conductor for electric-lights

You could find Thomas Edison a few decades later developing his incandescent lighting networks. One innovation he developed at Menlo Park was the 'Safety-Conductor for Electric-Lights'. In this design, he placed "a piece of very small conductor" in series with each lamp or branch circuit. Under normal conditions, the thin wire (often a strip of easily melted metal) would carry the lamp's current. If an abnormal amount of current flowed through the safety-conductor, the small safety-wire would heat and melt, "breaking the overloaded branch circuit". Edison emphasized that this "safety device" should be enclosed in a small insulating shell or holder to contain hot metal spatter and to relieve mechanical strain on the delicate fuse wire.

In U.S. Patent No. 227,226, issued May 4, 1880, Edison described this fuse concept and its purpose to automatically open the circuit before excess current could cause damage or fire. This invention was implemented as part of Edison's early lighting system at Menlo Park and the Pearl Street station, providing a primitive but effective safeguard in each lamp socket and feeder line. It addressed a key requirement for making electric light "practical, safe, and economical," as Edison knew that "safety fuses" were just as important as the light bulb itself in any usable electrical distribution system.



Edison's Safety-Conductor for Electric-Lights



Edison's 1890 Fuse Block design.

As electrical networks expanded (including telegraph, telephone, and lighting circuits), Edison continued refining his fuse designs. He received U.S. Patent No. 438,305, Fuse-Block, on October 14, 1890. In this patent, which Edison had filed back in 1885, he focused on improving the fuse's form factor and reliability. The fuse element, which he called a "fusible safety-catch", is a strip of thin metal foil or wire housed inside an insulating cylinder. In normal operation, current flowed through the metal strip. If the current became "abnormal" (too high), "the passage of an abnormal electric current fuses the safety-catch and breaks the circuit". This cartridge-style fuse-block from 1890 is a direct predecessor of modern cartridge fuses used in power systems.

Bussman Manufacturing Company

The Bussmann Manufacturing Company was founded by five brothers in 1914. Joe, Al, Frank, Lee, and Harry Bussmann started the company in St. Louis, Missouri.

Starting in the basement of their family home, the brothers developed and manufactured their first product, a non-reusable cartridge fuse. This product addressed the growing need for reliable protection amid the rise of electrification in homes and factories. The company had quick success and relocated to a larger facility in St. Louis.

A Bussman Manufacturing Company retail display that would have been found in stores across the country.

A 1917 article in 'Electrical Review' tells that Bussman Manufacturing Company makes a wide assortment of fuses for every make of car. These fuses were primarily for the ignition and the lights. By 1920 Bussman fuses were listed as the standard fuse by the Underwriters' Laboratories. The company was purchased by entrepreneur Max McGraw in 1929 and made a subsidiary of McGraw Electric. In the 1950s, McGraw Electric merged with Thomas A Edison Inc., becoming the McGraw-Edison Company.

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The BUSS Plan of Merchandising Plug Fuses is the only plan which is Geared to the Public Needs. It is the only plan which provides an opportunity for the public to buy an Approved Plug, Superior in Design, Construction and Utility, together with complete information concerning the proper use of fuses, on a basis which provides a proper compensation to the dealer for his part in conferring this benefit on the public. It is based on the unescapable logic that no part of a public service can be performed for nothing.

The Attractive Carton Automatically Sells *10-AT-A-TIME*

Dealers are finding that few people have a supply of Plug Fuses and that the handy carton sells itself.

The covenient form and size of the carton; the rich colorings of the carton and the counter and window card make an attention-compelling display that results in many sales not only of BUSS Plug Fuses but of other electrical appliances.

INSIST ON BUSS CLEAR-WINDOW PLUG FUSES

Packed in the 10-at-a-time, Self-Selling Carton

BUSS Plug Fuses are guaranteed to have a large CLEAR WINDOW and clean interior, so that the user may *always* tell which fuse is blown. The information on the carton is worth to the customer many times the cost of the ten plug fuses. *The double appeal of utility and service is irresistible.*

BUSSMANN MANUFACTURING COMPANY, St. Louis, Mo.

BUSS FUSES

A Bussman magazine advertisement.

Quicker than a short circuit - Littelfuse

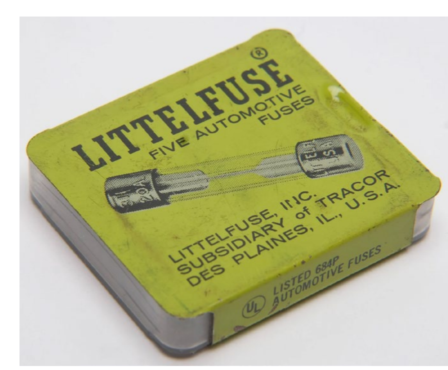
The company Littelfuse was founded outside Chicago by Edward V Sundt, a Canadian immigrant, in 1927. To fund the 'startup', he sold his car for $150.00. His groundbreaking product was the little fuse. A thin glass tube holding a thin metallic strip. Unlike previous fuses that would pop at three amps or up to three hundred amps, Sundt's fuses were made to pop very quickly with as low as thirty milliamps. These were originally designed for use with sensitive test equipment. The value proposition of a relatively tiny quick-action fuse was evident to many, and once they started advertising in periodicals like 'Radio News', sales took off quickly.

INSTRUMENT FUSES

The "Littelfuses" shown, submitted by the Littelfuse Laboratories, 1772 Wilson Avenue, Chicago, Illinois. are quick-acting fuses of low current ratings; the sizes submitted for test were 1/32, 1/16, 1/8, 1/4, 1/2, 1 and 2 amperes. They were found on test to fuse at a current value very close to the figure given by the manufacturer. To protect the tubes of a radio receiver, one of suitable current rating should be selected; the fuse is inserted in the negative "B" voltage supply; when it is used with instruments the fuse is placed in series with one lead of

the instrument. The fuse is 1 inch in length and has an over-all diameter of 1/4-inch; mounting blocks are obtainable, the dimensions of which are 1 3/8 inches long, 1/2-inch wide,

This may be the first magazine ad in 'Radio News' for a Littelfuse product.



A retail case for Littelfuse automotive fuses.

Retro Electro fun fact: Some sources say that before Sundt moved to the United States he was a member of the Royal Canadian Mounted Police (RCMP). Electro article 'Ohm's Day.'

Soon after, they developed a catalog that included parts like automotive fuses. During World War 2, they capitalized on this opportunity and built a manufacturing facility in California to service the growing airplane industry. Soon, Littelfuse was in everything from your home appliances and your television to your car. In 1950, they had nearly two million dollars in sales that year alone. Sometime in the 1960s, Edward Sundt retired from the company he founded, which was then sold to Tracor, Inc. By the 1970s, the company had expanded to include manufacturing plants across the country, with locations in Illinois and even one in Mexico.

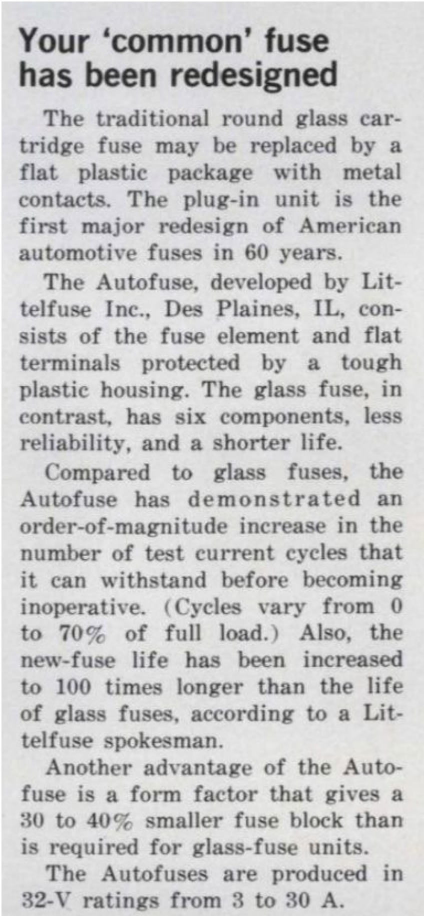
Meanwhile, in Europe – torpedo fuses

Within the European auto industry, they had their own style of fuse. The Bosch type fuse, also known as 'torpedo fuses,' was made up of a strip of exposed metal with a ceramic or porcelain body. Bosch, a German company founded in 1886, designed these fuses for use with their ignition systems. The exact invention date of torpedo fuses is not easily found, but evidence

European manufacturers used Bosch-type, or 'torpedo' fuses in their cars.

of their use dates back to at least the 1930s, as seen in vehicles like the 1933 Alfa Romeo 6C 1750. By the mid-twentieth century, torpedo fuses became a staple in European car manufacturing. They were favored for their compact design, ease of installation in fuse boxes with spring-loaded holders, and standardization across brands. This era saw increasing electrical complexity in cars, with additions like radios, lights, and heaters, necessitating reliable circuit protection.

Torpedo fuses were predominantly used in European vehicles from the 1950s through the 1980s, including models from manufacturers such as BMW, Mercedes-Benz, Audi, Porsche, Alfa Romeo, and even some non-European brands like Datsun (now Nissan) that adopted similar systems. Advantages included their robustness against mechanical stress, clear visual inspection (the fusible element is often exposed), and low cost. However, disadvantages emerged over time: the conical contacts could corrode or loosen due to



Your 'common' fuse has been redesigned

The traditional round glass cartridge fuse may be replaced by a flat plastic package with metal contacts. The plug-in unit is the first major redesign of American automotive fuses in 60 years.

The Autofuse, developed by Littelfuse Inc., Des Plaines, IL, consists of the fuse element and flat terminals protected by a tough plastic housing. The glass fuse, in contrast, has six components, less reliability, and a shorter life.

Compared to glass fuses, the Autofuse has demonstrated an order-of-magnitude increase in the number of test current cycles that it can withstand before becoming inoperative. (Cycles vary from 0 to 70% of full load.) Also, the new-fuse life has been increased to 100 times longer than the life of glass fuses, according to a Littelfuse spokesman.

Another advantage of the Autofuse is a form factor that gives a 30 to 40% smaller fuse block than is required for glass-fuse units.

The Autofuses are produced in 32-V ratings from 3 to 30 A.

A short news article celebrating the release of the Autofuse.

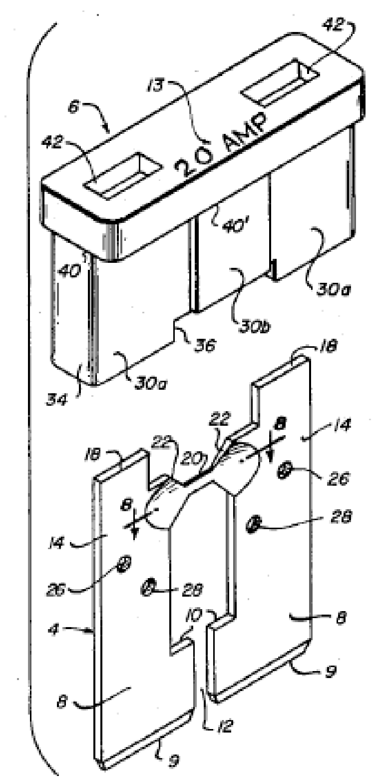
age and vibration, leading to intermittent electrical issues in classic cars. Modern plastic-bodied versions are available as replacements, but original ceramic ones are prone to cracking. Torpedo fuses began to be phased out in the late 1980s and early 1990s as automotive electrical systems grew more sophisticated, with higher current demands and denser fuse boxes.

Your 'common' fuse has been redesigned

Until the 1970s, the US auto industry still used glass fuses. These faced the same reliability issues as European torpedo fuses, with spring contacts loosening and corroding over time. With this problem in mind, Harold L. Williamson, an engineering lead at Littelfuse, headed a team that developed the ATO blade-style fuse, also known as the Autofuse brand. This was heralded as the 'first major redesign of American automotive fuses in sixty years.'

While the writer can't find any documents from Littelfuse specifically discussing the innovations surrounding the ATO Autofuse, the U.S. Patent No. 3,909,767, outlined several problems with previous designs that the ATO Autofuse aimed to solve:

- Space and size constraints: traditional cylindrical glass fuses were too large (often exceeding 1 inch in length and 1/4 inch in width, including terminals), making them unsuitable for modern compact electrical systems requiring smaller footprints. As automobiles became more complex, the fuse box needed to be able to hold even more fuses than before. The original design for the ATO fuse was only slightly smaller than traditional glass fuses, but they soon released fuses in several different sizes. Eventually, a manufacturer could fit four LP-Mini style blade fuses in the same space that a glass tube fuse would occupy
- Handling and accessibility issues: conventional fuses were difficult to remove from mounting clips, often causing the glass tube to shatter, and prior miniature designs had handles that obstructed visibility of the fuse link (especially when mounted closely together) and made grasping challenging due to limited clearances. This design allowed easier insertion/removal into closely spaced sockets on mounting panels, with a visible fuse link to check status without obstruction
- Safety hazards: some earlier miniature fuses had exposed fuse links, risking the spewing of molten fuse material during blowing or creating shock hazards if touched. These had a plastic housing that shields the user from blown fuse material, eliminates shock hazards, and



Torpedo fuses began to be phased out in the late 1980s and early 1990s as automotive electrical systems grew more sophisticated, with higher current demands and denser fuse boxes.

MINI® Smart Glow

Specifications

Smart Glow fuses are innovative automotive style fuses (ATO, MINI, and MAXI) that feature an indicator light that glows when the fuse is blown, saving time to troubleshoot an open circuit.

Voltage Rating 14 Vdc
Sample Part 0MIN010.VPGLO

MINI® Fast-Acting

Specifications

The MINI® Fuse, with its miniature design patented by Littelfuse, meets the need for more circuits to be protected while utilizing less space.

Voltage Rating 32 Vdc
Sample Part 0MIN020.V

littelfuse.com/mini

Fuses Rated 58 V Low Profile MINI®

Specifications

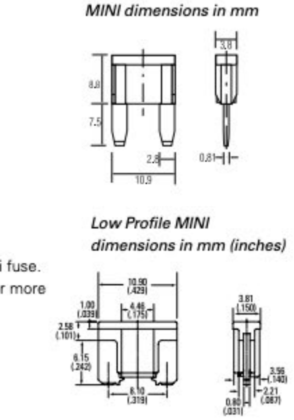
The low profile MINI has similar performance as the standard mini fuse. The lower overall height allows for more space and weight savings.

Voltage Rating 58 Vdc
Sample Part LMIN010.V

littelfuse.com/lmin

MINI dimensions in mm

Low Profile MINI dimensions in mm (inches)



MINI Fuses are available in packaged and bulk configurations. See 297 series on web.

ATO® Smart Glow

Specifications

Smart Glow fuses are innovative automotive style fuses (ATO, MINI, and MAXI) that feature indicator light that glows when the fuse is blown, saving time to troubleshoot an open circuit.

Voltage Rating 14 Vdc
Sample Part 0ATO010.VPGLO

ATO® Fast-Acting

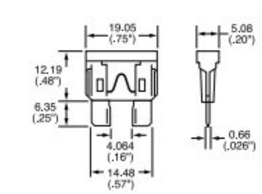
Specifications

The ATO® Fuse was designed and patented by Littelfuse in 1976 and set the standard for automotive circuit protection. It features industry standard color coding to indicate amperage rating.

Voltage Rating 32 Vac/dc
Sample Part 0ATO020.V

littelfuse.com/ato

ATO dimensions in mm (inches)



ATO® / MINI® Color Key

CURRENT RATING	HOUSING COLOR
1 A	Black
2 A	Grey
3 A	Violet
4 A	Pink
5 A	Tan
7.5 A	Brown
10 A	Red
15 A	Blue
20 A	Yellow
25 A	Clear
30 A	Green
40 A	Orange

Note: MINI not available in 1 A or 40 A.

ATO Fuses are available in packaged and bulk configurations. See 287 series on web.

MAXI™ Smart Glow

Specifications

Smart Glow fuses are innovative automotive style fuses (ATO, MINI, and MAXI) that feature an indicator light that glows when the fuse is blown, saving time to troubleshoot an open circuit.

Voltage Rating 14 Vdc
Sample Part 0MAX030.XPGLO

MAXI™ Slo-Blo

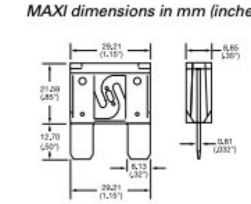
Specifications

Designed and patented by Littelfuse, the MAXI™ Fuse is ideal for motor powered applications which have large inrush currents.

Voltage Rating 32 Vdc
Sample Part 0MAX030.X

littelfuse.com/maxi

MAXI dimensions in mm (inches)



MAXI™ Color Key

CURRENT RATING	HOUSING COLOR
20 A	Yellow
25 A	Grey
30 A	Green
35 A	Brown
40 A	Orange
50 A	Red
60 A	Blue
70 A	Tan
80 A	Clear

Today, the legacy of the fuse persists in many forms, from traditional cartridge designs to modern electronic versions, protecting everything from household appliances to advanced industrial machinery.

provides an insulated gripping surface

- Reliability problems: solder connections in terminals of previous designs led to corrosion, poor connections, or 'hot spots' over time, reducing overall reliability. The new fuse box eliminated the solder connections to avoid corrosion/hot spots, and reduce manufacturing costs compared to prior enclosed designs
- Misinstallation risks: fuses with varying current ratings (e.g., 5-15 amperes vs. 20-30 amperes) had identical external configurations and sizes, increasing the chance of errors despite markings or color codes, potentially causing circuit damage. These fuses were colored differently depending on the different current ratings and were visually distinguishable to prevent hazardous misinstallations
- Manufacturing and cost challenges: enclosed fuse designs were more expensive to produce than the newer design. Much of this new design was made with large cost savings in mind throughout

A short time later, they gave an exclusive license for the ATO Blade Type fuse to also be manufactured by Bussman. Some other companies didn't feel like they needed a license, however, and started to flood the auto parts market with knockoffs and counterfeits from Taiwan. In a landmark case, the United States International Trade Commission in 1982 unanimously determined that these companies, both foreign and domestic, had violated international trade treaties with clear injury to the domestic operation, because all of the blade fuses made by Bussman and Littelfuse were made in the United States. This banned the importation of any blade-type fuses into the United States until the patents expired in the late 1990s.

Today, Littelfuse makes several variants of the original Autofuse, with some as small as 11mm x 4mm and even smaller. All of which are available directly from Digikey.

Lightning strike to lifeline

In reflecting on the origins of the fuse, we see a profound evolution from a discovery to an indispensable guardian of electrical systems. Louis Breguet's encounter with a lightning strike in the mid-nineteenth century illuminated a simple yet revolutionary principle: a slender wire, designed to fail under extreme conditions, could avert catastrophe by interrupting the flow of destructive current. This 'sacrifice' not only protected early telegraph installations but also laid the groundwork for subsequent innovations, such as Thomas Edison's refinement of fuses for incandescent lighting circuits. Through these advancements, the fuse transcended its humble beginnings, becoming a symbol of proactive safety in an increasingly electrified world, where preventing disaster often requires deliberate vulnerability.

Today, the legacy of the fuse persists in many forms, from traditional cartridge designs to modern electronic versions, protecting everything from household appliances to advanced industrial machinery. As technology moves toward smarter, more connected systems, the fundamental principle of Breguet's invention remains crucial, emphasizing safety through self-sacrifice amid the ongoing pursuit of efficiency and power. In the age of renewable energy and electric vehicles, the fuse's history serves as a reminder that real progress isn't just about harnessing forces like lightning but managing them responsibly, ensuring that innovation benefits humanity without undue risk.

1847 Louis Bréguet writes a letter with his innovation that led to the first fuses.

1880 Edison Patents the 'Safety Conductor'

1890 Edison Patents the Fuse Block

1914 Bussmann Manufacturing Founded

1920 UL Standardizes Bussmann Fuses

1927 Littelfuse Founded by Edward Sundt

1933 Torpedo Fuses in Use in Europe

1950 Littelfuse Achieves Major Market Penetration

1976 ATO Autofuse Patented by Littelfuse

Suggested reading

1. Littelfuse – History
2. "History of the Humble Automotive Blade Fuse" by Classic Retrofit
3. "Littelfuse Celebrates 90 Years of Protecting the World" by Dave Scheuerman – IEEE Industry Applications Magazine, Nov 2017
4. "Littelfuse Inc" from Encylopedia.com
5. "Low-Capacity Fuses in Telephone Plant" in Telephone Engineer 1932-03
6. "Your 'common' fuse has been redesigned" by Electronic Design Vol 13, June 221, 1976
7. In the Matter of Certain Miniature Plug-In Blade Fuses: Investigation No,. 337-TA-114
8. "Introduction to the History of Selective Protection" by Walter Schossig in PAC Magazine, Summer 2007, Pages 70-76
9. "Louis Clement Francois Breguet and Antoine Louis Breguet" by Paolo Brenni in the Bulletin of the Scientific Instrument Society, Vol 50 (1996)
10. "LOUIS BREGUET His life, the company and the telegraph equipment."
11. "TELEGRAPHY – Extract from a Letter from Mr. Bréguet to Mr. Arago" printed in the Comptes rendus hebdomadaires des séances de l'Académie des sciences v.24 1847 (Pg 992)
12. "Bussman Inclosed Fuses for Automobiles" in the Electrical Review, July 21, 1917
13. 'Bussman Manufacturing Company listed as UL standard' in Electrical World, January 24, 1920
14. "Torpedo Fuses: The Bane of Classic German Automobiles" by Tig Kindel

Road-tested GMSL cameras drive into new markets

Written by Pete Bartolik

Technologies developed for automotive applications frequently transfer to other markets due to automobile manufacturers' rigorous requirements for reliability, performance, and the need for fast data rates in an electronically hostile environment. That's why Gigabit Multimedia Serial Link (GMSL) cameras are finding ready markets for vision applications in areas such as automation and robotics, smart agriculture, digital healthcare, avionics, robotaxis, and retail, and warehouse inventory management.

Initially introduced for addressing applications for high-speed video and data transmission in vehicles, Analog Devices GMSL is a widely adopted and proven technology for bringing new levels of performance to high-speed video links and enabling multi-streaming over a single cable.

Vision applications require very large data streams to ensure high-quality video. A full HD image is comprised of 1080 rows by 1920 columns. That amounts to 2 million pixels, each of which consists of a red, green, and blue element, resulting in 6 million elements. Each element represents 8 bits of data, so every frame results in nearly 50Mbps of data. At 60 frames per second, the required data rate for one camera is over three-and-a-half Gbps.

First-generation GMSL, first available in 2008, utilized the low-voltage differential signaling (LVDS) standard to deliver parallel data downlink rates up to 3.125Gbps. That was particularly suited for conveying data from multiple camera systems and other advanced driver assistance applications (ADAS), as well as the growing use of in-car, high-definition flat panel displays.

A second generation, GMSL2, was introduced in 2018, increasing data rates up to 6Gbps and supporting more standard highspeed video interfaces, including HDMI and the MIPI interface standard, a popular image sensor interface for consumer and automotive cameras. These advances accommodated full high definition (FHD) displays and cameras with resolution up to 8MP.

GMSL3, the next generation, can deliver data up to 12Gbps over a single cable, supports multiple 4K resolution streams, the daisy-chaining of multiple displays, and aggregation of multiple cameras such as those located on the front, back, and sides of a vehicle to provide a 360° viewing capability. Today, increasing numbers of automobile manufacturers supplement rear and side-view mirrors with cameras, utilize forward and rear-facing cameras for collision avoidance, and internal cabin cameras for monitoring driver and passenger safety. GMSL3 can aggregate data from multiple video feeds as well as LiDAR and radar.

With cameras scaled down to the level of CMOS sensors, they can produce what once was considered incredible quality at low cost and with low power demands. Image sensors have millions of receptor elements, each of which converts measurements into digital values to be streamed via serial data lanes of a parallel interface, along with synchronization information.

Both GMSL2 and GMSL3 utilize MIPI interface standards that provide designers and vendors access to a wide range of image sensors for GMSL cameras.

GMSL versus GigE

Engineers starting out on vision applications will no doubt quickly face a decision on whether to use GMSL or gigabit Ethernet (GigE) vision technology. GigE is widely used in industrial applications due largely to its reliance on Ethernet network infrastructure and standards.

GigE Vision cameras with 2.5 GigE, 5 GigE, and 10 GigE are commonplace in applications today, and 100 GigE state-of-the-art cameras can utilize up to a 100Gbps data rate. GMSL is designed to transmit data over coaxial cable or shielded twisted pair cable at up to 15 meters, compared to 100m for GigE, although both may be exceeded under certain conditions.

Each technology is capable of transmitting data and power through the same cable: GMSL uses Power over Coax (PoC) so video, audio, control, data, and power can be transported on a single channel. Most GigE Vision applications rely on Power over Ethernet (PoE) for 4-pair Ethernet, or less commonly, Power over Data Line (PoDL) for Single-Pair Ethernet (SPE).

System requirements and application needs will determine which vision technology is most appropriate. GigE Vision, for example, may offer some advantages for single-camera applications, particularly where they connect directly to a PC or an embedded platform with an Ethernet port.

When using multiple cameras, GigE Vision applications will require use of a dedicated Ethernet switch, a network interface card (NIC) with multiple Ethernet ports, or an Ethernet switch IC. That switching requirement can potentially reduce the maximum total data rate and introduce unpredictable latency between the cameras and the terminal device, whereas GMSL provides a simpler, more direct architecture.

GigE Vision devices may support higher resolution and a higher frame rate – or both simultaneously – with additional buffering and compression. Frame buffering and processing are not provided by GMSL devices, so resolution and frame rate depend on what the image sensor can support within the link bandwidth. Engineers will need to determine a simple trade-off between resolution, frame rate, and pixel bit depth.

GMSL simplifies high-speed video architecture

GigE Vision cameras typically utilize a signal chain that includes an image sensor, a processor, and an Ethernet physical layer (PHY) (Figure 1). Raw image data from the sensor is converted by the processor into Ethernet frames, often relying on compression or frame buffering to fit the data rate of the supported Ethernet bandwidth.

The GMSL camera signal chain utilizes a serializer/deserializer (SerDes) architecture that avoids the use of a processor (Figure 2). Instead, image sensor parallel data is converted by the serializer into a high-speed serial data stream. On the back end, a deserializer converts the serial data back into parallel form for processing by an electronic control unit (ECU) system-on-chip (SoC).

The GMSL camera architecture makes it simpler to design small form factor cameras with low power consumption. Serializers can directly connect to cameras through standard MIPI CSI-2 interface and transmit packetized data through the GMSL link.

A typical host device is a customized embedded platform with one or more deserializers that transmit image data through MIPI transmitters in the same format as the image sensor MIPI output. New GMSL camera drivers are required for customized designs, but if there is an existing driver for the image sensor, it can be utilized with just a few profile registers, or register writes to enable a video stream from cameras to a control unit.

GMSL components

ADI offers a comprehensive portfolio of serializers and deserializers to support a variety of interfaces. These feature robust PHY designs, low bit error rates (BER), and backward compatibility. Any video protocols can be bridged together – for example, HDMI to the Open LVDS Display Interface (oLDI).

Engineers will need to select the best components based on application needs, such as device interfaces, data rates, bandwidth, power consumption, environmental conditions, and cable length. Other factors include EMI, error handling, and signal integrity. Some examples of ADI's GMSL components include:

- MAX96717, a CSI-2 to GMSL2 serializer (Figure 3), operates at a fixed rate of 3Gbps or 6Gbps in the forward direction and 187.5Mbps in the reverse direction
- MAX96716A, which converts dual GMSL2 serial inputs to MIPI CSI-2. The GMSL2 inputs operate independently and video data from both can be aggregated for output on a single CSI-2 port or replicated on a second port for redundancy
- The MAX96724, a quad tunneling deserializer, converts four GMSL 2/1 inputs to 2 MIPI D-PHY or C-PHY outputs. Data link rates are 6/3Gbps for GMSL2 and 3.1 Gbps for GMSL1, and reverse link rates of 187.5Mbps for GMSL2 and 1Mbps for GMSL1
- The MAX96714 deserializer converts a single GMSL 2/1 input to MIPI CSI-2 output, with a fixed rate of 3Gbps or 6Gbps in the forward direction and 187.5Mbps in the reverse direction.
- The MAX96751 is a GMSL2 serializer with HDMI 2.0 input that converts HDMI to single or dual GMSL2 serial protocol. It also enables full-duplex, single-wire transmission of video and bidirectional data
- The MAX9295D converts single- or dual-port 4-lane MIPI CSI-2 data streams to GMSL2 or GMSL1

ADI also offers several development tools, such as the MAX96724-BAK-EVK# evaluation kit for the MAX96724 devices.

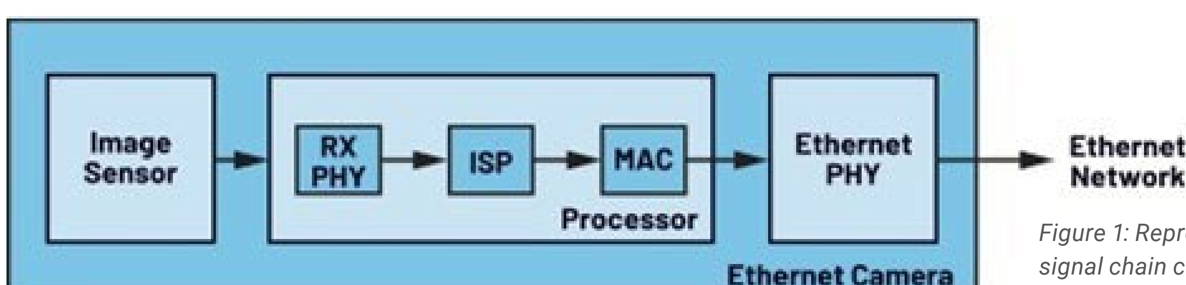


Figure 1: Representation of key signal chain components on the sensor side of GigE Vision cameras. Image source: Analog Devices, Inc.

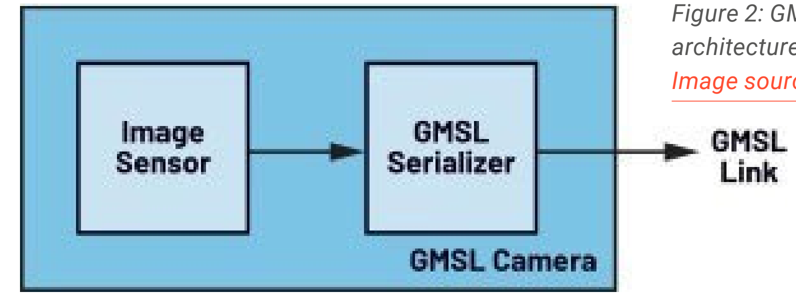


Figure 2: GMSL cameras utilize a simpler signal chain architecture on the sensor side than GigE Vision. Image source: Analog Devices, Inc.

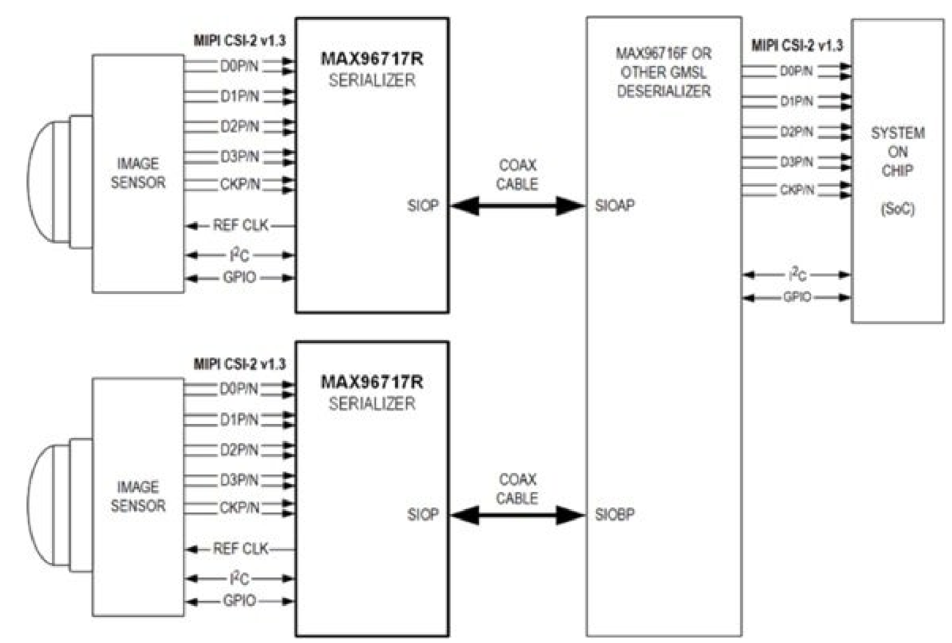
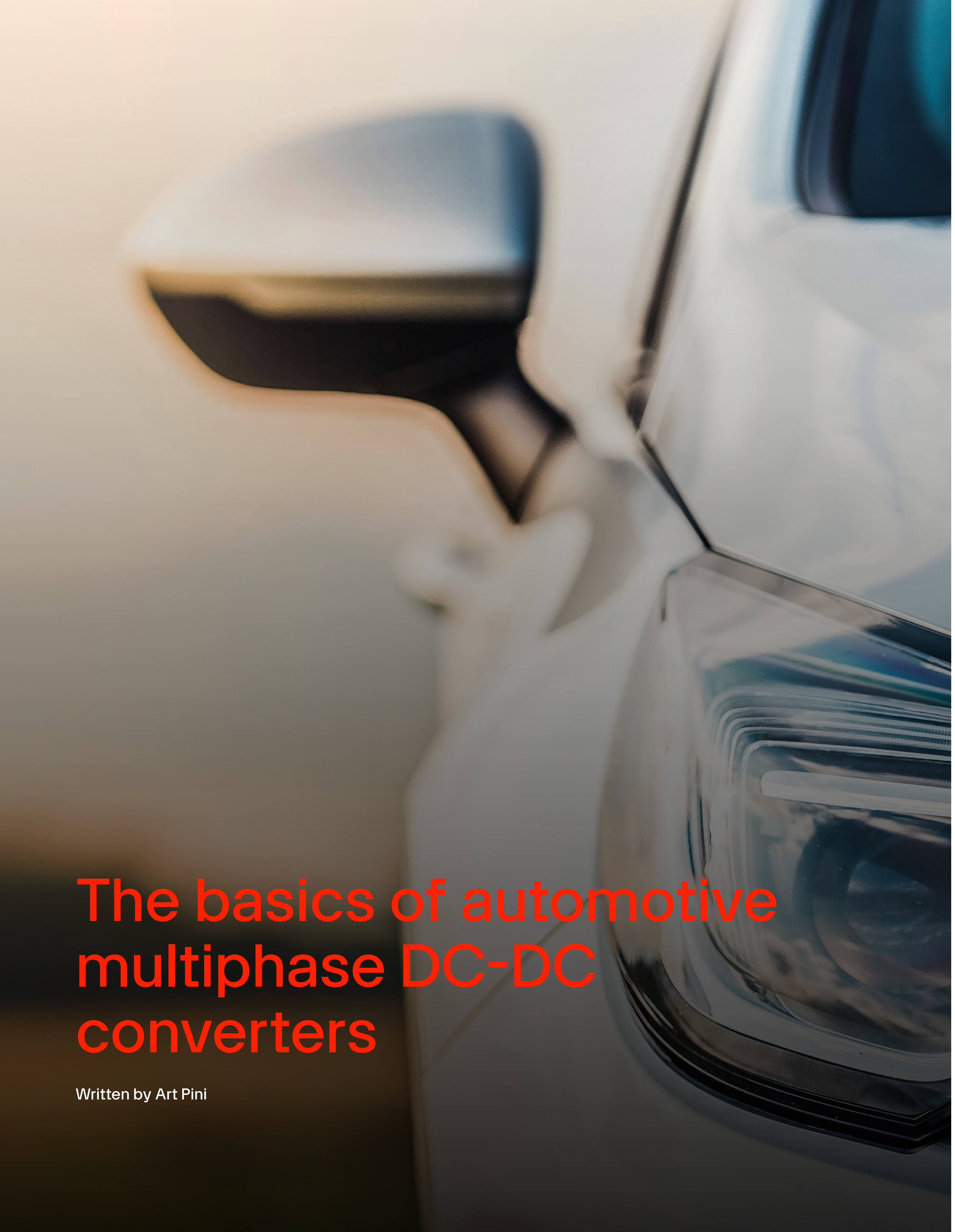


Figure 3: A schematic illustrating the data stream utilizing MAX96717 serializers. Image source: Analog Devices, Inc.

Conclusion

With their reduced complexity, GMSL cameras are more compact and generally able to provide a more cost-effective solution compared to GigE Vision. GMSL provides reliable transport of high-resolution digital video with microsecond latency for a growing range of camera and display-based applications, from machine learning and autonomous operations to infotainment and safety. Millions of GMSL links are enhancing the driver experience on the road today, attesting to their reliability and performance.



The basics of automotive multiphase DC-DC converters

Written by Art Pini

Automotive applications like infotainment systems require powerful AEC-Q100 qualified processors that need to be in ever-smaller form factors, and that must run off supply voltages that continue to get lowered. The lower voltages mean that supply currents must increase proportionally to meet the devices' power needs. While buck converters are a great choice for powering high-current digital loads like processors and FPGAs, they have limited maximum output current capabilities. However, using a multiphase approach to DC-DC converter design, developers can increase the maximum current capacity, reduce size and output ripple, and improve transient response.

This blog describes a multiphase buck topology and provides examples of AEC-Q100-qualified converters from Texas Instruments that designers can use in automotive applications.

What is a multiphase buck topology?

Basically, a multiphase buck topology supply uses a parallel set of buck regulators. Each regulator runs at a controlled duty cycle, but they are phased to be active at spaced intervals so that only one phase is active at any given time. A multiphase converter contains the core of a buck converter as well as the switch. The inductors, the input capacitors, and the output capacitors are external to the device (Figure 1). A multiphase controller has the buck converter core, but the switch and inductor are external components.

Multiphase converters and controllers typically have from two to six phases. The currents from each phase inductor are summed at the output. Since the inductor currents are not in phase, the summed current levels are lower than the current in each inductor (Figure 2).

Figure 2 shows the currents for a quad-phase implementation used for the Texas Instruments LP875610BRNFRQ1 quad buck converter with integrated switches. Since the peak inductor currents occur at different times due to the phase timing offset, the ripple voltage of the sum is reduced. The larger the number of phases, the lower the ripple amplitude. Note also that the ripple frequency of the total current is higher by a factor equal to the number of phases. Lower ripple current and higher ripple frequency mean that smaller output capacitors can be used. The controller monitors each phase current and adjusts each separately to ensure the current drawn from each phase is equal.

The LP875610BRNFRQ1 has four step-down converter cores that are configured as a single four-phase output. Each core includes the FET switches and is capable of an output current of 4 amperes (A) (16A total for a four-phase single

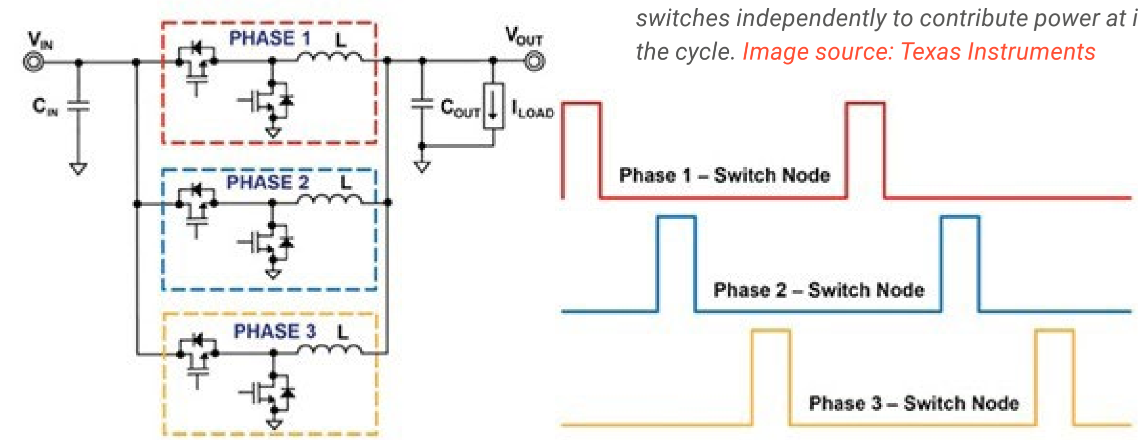


Figure 1: A functional diagram of a three-phase buck converter. Each of the three converter cores has a common input and output. Each phase switches independently to contribute power at its prescribed portion of the cycle. Image source: Texas Instruments

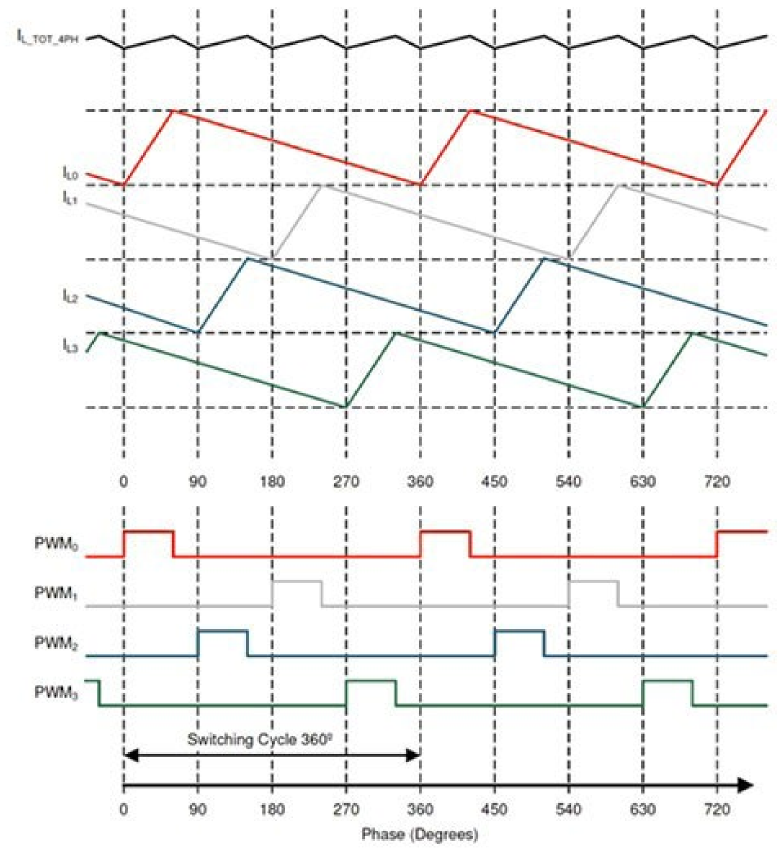


Figure 2: The sum (IIL_TOT_4PH) of the phase inductor currents (IL0 - IL3) has a lower peak-to-peak amplitude and a higher frequency than the individual inductor currents due to the currents being out of phase. Image source: Texas Instruments

output configuration). The cores are designed to allow optimization of regulator operations; most of the functions are programmable, thus ensuring flexible regulator operation in each application (Figure 3).

The converter can operate in either a pulse width modulated (PWM) or a pulse frequency modulated (PFM) mode depending on the load current. PWM adjusts the width of the phase pulses at a fixed frequency, while PFM holds the pulse width constant and varies the frequency. PWM is used for output currents above approximately 600 milliamperes (mA), and it can be turned on under program control.

The multiphase converter has improved transient response to changes in load current compared to a single-phase regulator. If a transient event occurs, the multiphase controller can overlap active phases during a load increase. This effectively puts the inductors of all the phases in parallel with one another, reducing the equivalent inductance seen by the output by a factor equal to the total number of phases. This lowers the devices' output impedance. Similarly, a multiphase regulator can turn all the phases off during a load release to reduce a voltage increase. All the cores are overvoltage and overcurrent protected.

The multiphase buck converter is also more thermally efficient than a single, higher current converter. Heat is proportional to the square of the current, so it is distributed among all four cores instead of being concentrated in a single core. The controller monitors the current output of each phase, either internally or by an external sensing circuit coupled to the converter via a differential connection.

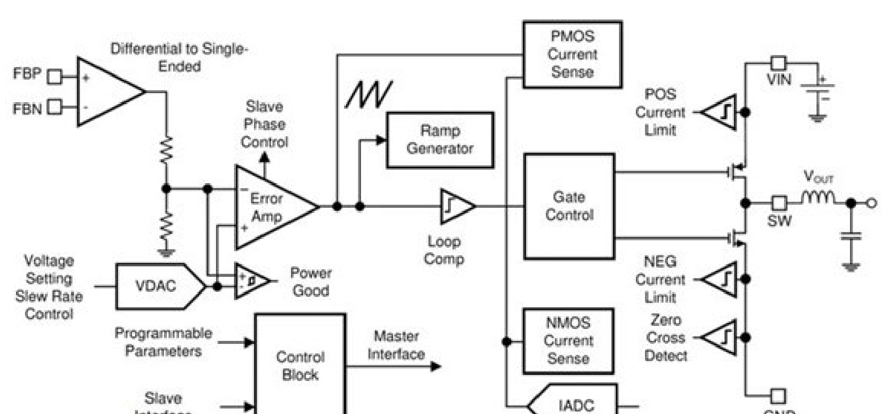


Figure 3: The functional block diagram of a single core showing the control elements that manage the phasing and voltage control of each of the four cores in the LP875610BRNFRQ1. Image source: Texas Instruments

The converter has a programmable provision for spread-spectrum clocking to reduce electromagnetic interference (EMI). Spread-spectrum mode varies the switching frequency periodically about the center frequency to reduce the electromagnetic interference (EMI) emissions of the converter, as well as associated passive components and printed circuit board (pc board) traces (Figure 4).

Multiphase controllers are also available in a dual-phase configuration. For example, the Texas Instruments LP87565URNFRQ1 has two dual buck converters, each of which can supply 4A for a total output current of 8A per device. The Texas Instruments LP87564TRNFRQ1 is a quad multiphase buck converter that is configurable as a single four-phase buck converter (Figure 5).

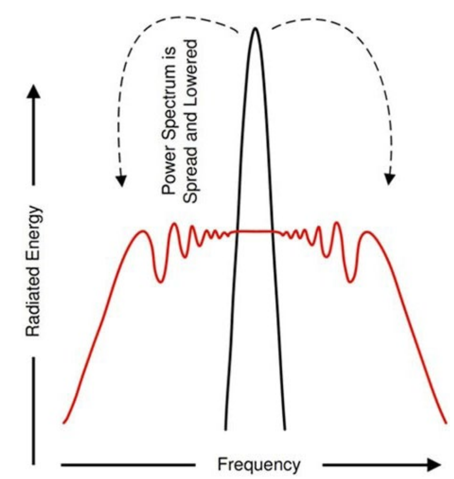


Figure 4: Spread-spectrum clocking varies the clock frequency periodically, spreading the RF energy over a broader bandwidth at a reduced amplitude. Image source: Texas Instruments

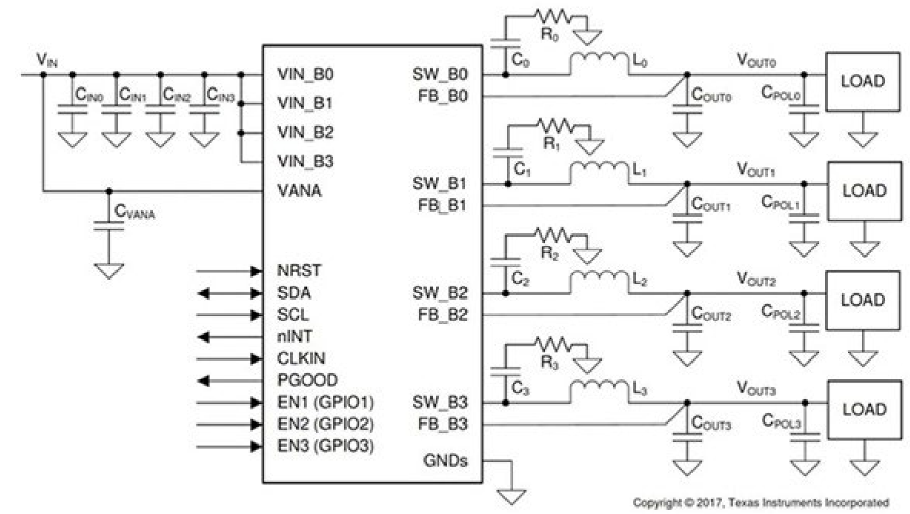
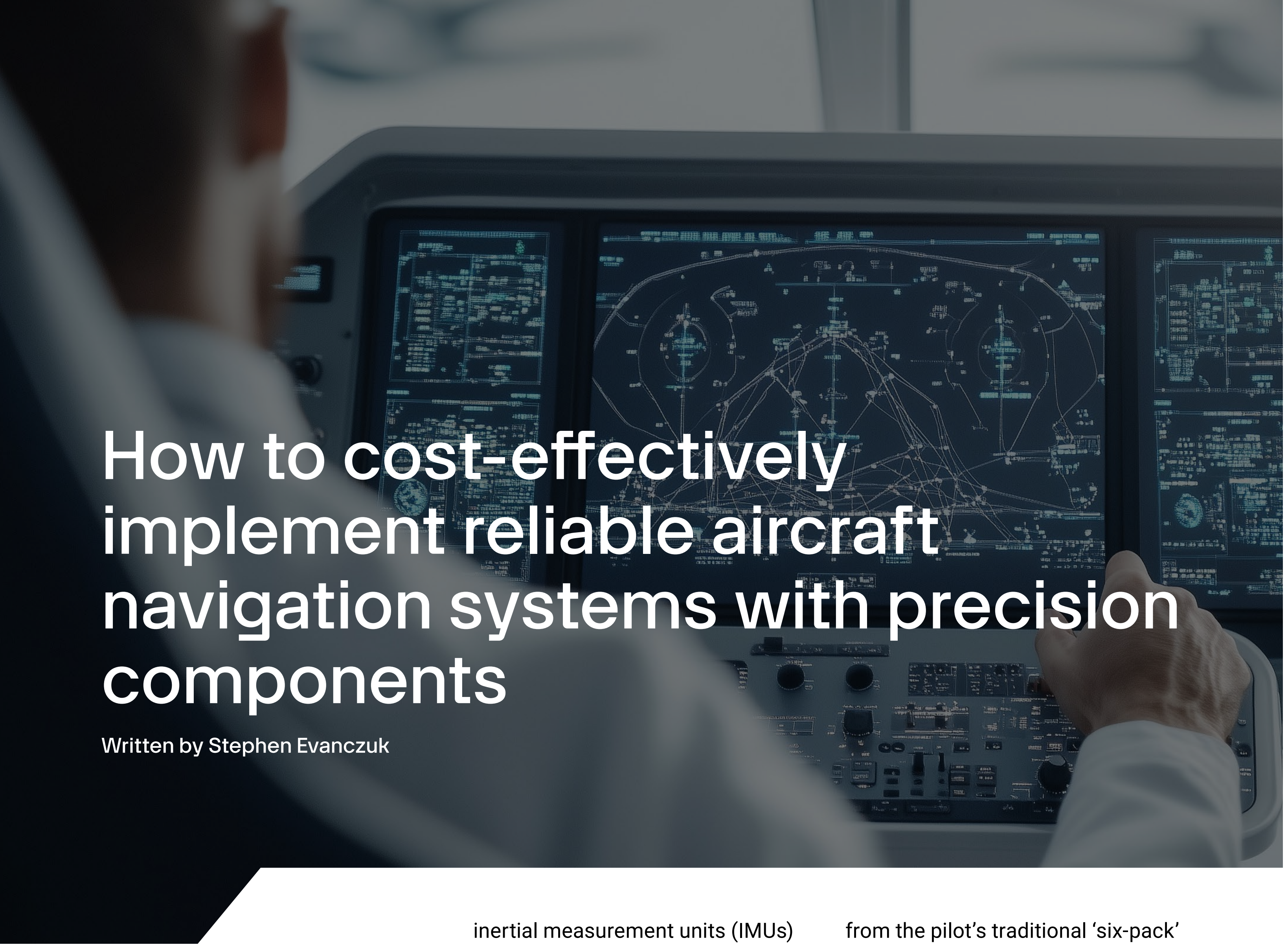


Figure 5: The LP87564TRNFRQ1 is a quad multiphase buck converter that is configurable as a single four-phase buck converter. Image source: Texas Instruments

All of these multiphase converters are AEC-Q100 qualified for automotive applications. The Automotive Electronics Council (AEC) was established by three major automotive manufacturers to establish common part qualification and quality system standards. The AEC-Q100 standard is a stress test qualification for packaged integrated circuits based on failure mechanisms. These devices are qualified for an operating temperature range of -40 to +125°C, as well as two electrostatic discharge classifications.

Conclusion

To meet the power management needs of the latest automotive processors, designers can use AEC-Q100 qualified multiphase buck converters. Available in a variety of configurable packages, these converters provide the required current capacity, output ripple, and transient response characteristics in a compact form factor.



How to cost-effectively implement reliable aircraft navigation systems with precision components

Written by Stephen Evanczuk

Developing sophisticated air data, attitude, and heading reference system (ADAHRS) solutions is crucial to ensure accurate navigation and safety in manned and unmanned aircraft systems. To create robust, reliable ADAHRS designs, developers need components that can address multiple challenges in avionics navigation systems design, including sensor accuracy, environmental resilience, and system integration.

This article describes how precision data acquisition modules and inertial measurement units (IMUs) from Analog Devices address these challenges and simplify the development of effective ADAHRS solutions.

Aviation safety builds on sophisticated sensor-based systems

The availability of accurate flight performance information is critical to safety in all aviation segments, ranging from unmanned aerial systems (UASs) to heavy passenger jets. Matching aerodynamic improvements in aircraft, avionics systems' capabilities have evolved from the pilot's traditional 'six-pack' of flight instruments based on magnetic compasses, mechanical gyroscopes, and vacuum-driven flight instruments, to increasingly sophisticated graphical display electronic flight instrument system (EFIS) 'glass cockpits'.

Underlying the EFIS, the ADAHRS integrates the capabilities of an air data computer and an attitude and heading reference system (AHRS) required to complement long-range global navigation satellite system (GNSS) navigation aids, such as the US global positioning system (GPS) and the GPS's associated ground-based wide area augmentation system (WAAS).

	High-End MEMS	Low-End MEMS	Piezoelectric	Spinning Mass	Fiber Optic Gyroscope	Ring Laser Gyroscope	Atomic Gyroscopes
Size	Small	Small	Very Small	Large	Medium	Medium	Small
Durability	Excellent	Average	Average	Poor	Poor	Poor	??
Cost	~$1000	~$50	$50	~$10,000	~$5,000	~$30,000	~$15,000
Interface	Easy to Interface	Variable	Analog Only	Difficult - Mechanical	Moderate	Moderate	??
Accuracy	~ 1dph	~60dph	~60dph	~10dph	< 1dph	< 1dph	< .1dph
Service	None	None	Minimum	Frequent	Occasional	Occasional	??
Lifespan	20 Years	5 Years	10 Years	2 Years	20 Years	20 Years	??

Figure 1: High-end MEMS gyroscopes offer unique characteristics that make them the preferred technology for electronic avionics systems. Image source: Analog Devices

The air data computer calculates altitude and vertical, air, and ground speed using atmospheric pressure measurements and outside air temperature. To provide the aircraft attitude (pitch, roll, and yaw) and heading data needed for dead reckoning in inertial navigation, the ADAHRS relies on a combination of gyroscopes for changes in angular velocity, accelerometers for changes in linear velocity, and magnetometers for magnetic heading. Advances in sensor technology have dramatically changed the nature of these critical sensors.

In the past, complex fiber optic or ring laser gyroscopes were among the few available technologies that could deliver sufficient accuracy for aviation. Today, the availability of advanced microelectromechanical systems (MEMS) provides developers with a technology that can satisfy requirements across diverse aviation platforms (Figure 1).

Along with gyroscopes, accelerometers, and magnetometers, ADAHRS functionality also depends on reliable data streams from sensors reporting outside air temperature and pressure. Other pressure, force, and position sensors deliver data on the position and loading of flight surfaces, landing gear, and nosewheel steering. Additional sensors provide essential data on engine performance and fuel needed for engine information systems, as well as cabin temperature, pressure, and oxygen levels.

A combination of high-performance sensor data acquisition modules and MEMS IMUs from Analog Devices provides developers with the critical components required to deliver avionics solutions with reliability, accuracy, size, and cost characteristics that permit their application across the full range of aviation flight systems.

Applying sensor data acquisition modules and IMUs in modern avionics

For acquiring data from the broad array of sensors in any flight platform, high-performance data acquisition modules offer a

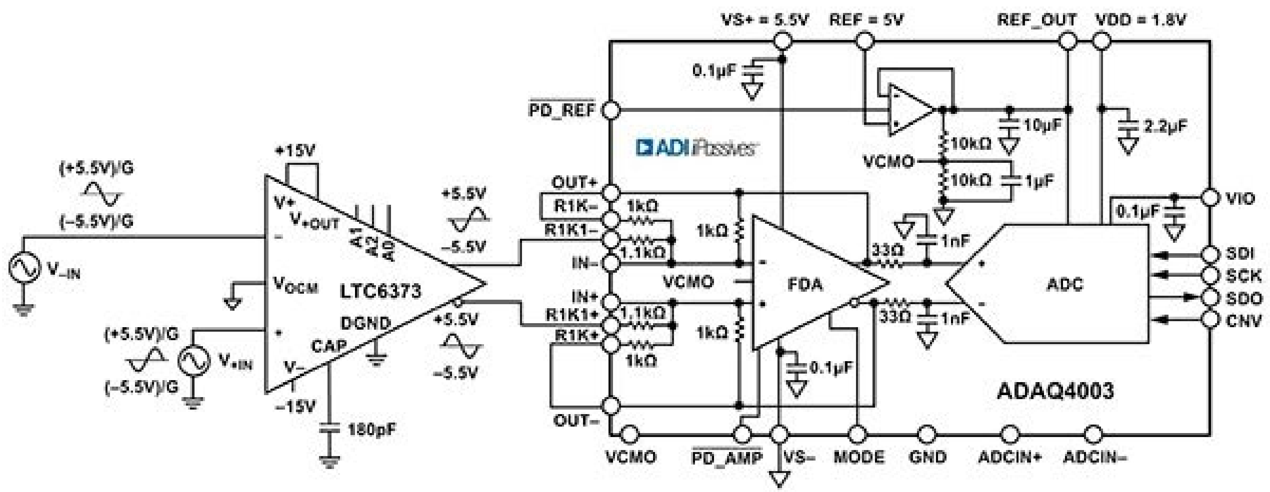


Figure 2: Developers can efficiently meet many aviation sensing requirements by combining an LTC6373 fully differential PGIA with an ADAQ4003 μModule data acquisition system. Image source: Analog Devices

range of performance capabilities for each sensor modality and functional requirement. With its Precision Signal Chain μModule Solutions, Analog Devices integrates common signal processing subsystems including signal conditioning blocks and analog-to-digital converters (ADCs) in a compact system-in-package (SIP) device to solve tough design challenges. The μModules also incorporate the critical passive components with superior matching and drift characteristics built using Analog Devices iPassive technology, which minimize temperature dependent error sources and simplify calibration while mitigating thermal challenges. Significant solution footprint reduction enables addition of more channels/functions for scalable aviation instruments requiring precision and stability over temperature and time. The μModules simplifies signal chain Bill of Material (BOM), reduces performance sensitivity to external circuitry, shortens design cycles,

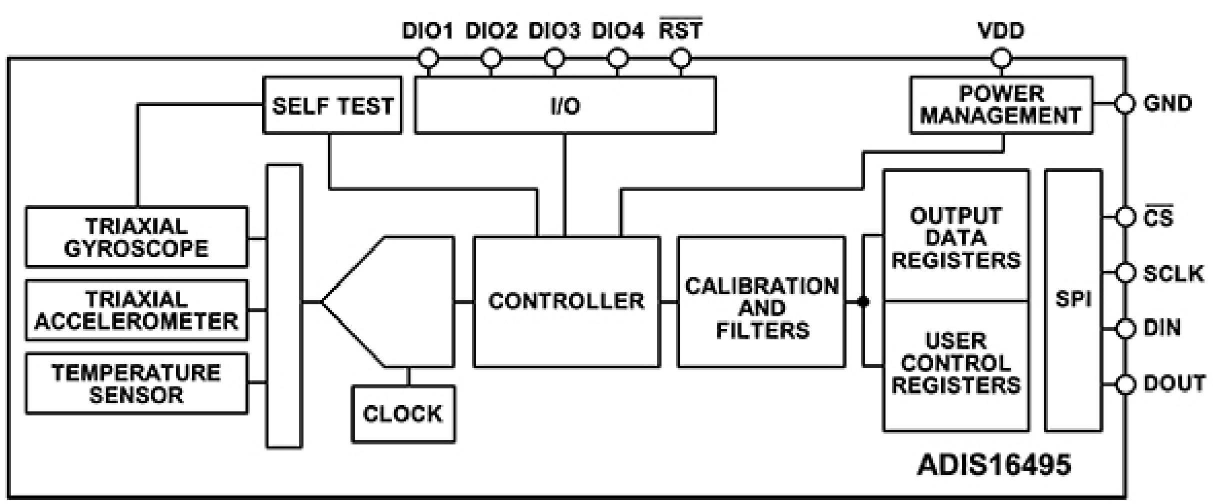


Figure 3: The ADIS16505 IMU and ADIS16495 IMU (shown here) integrate sensors with a controller, calibration, signal processing, and self-test blocks to provide a complete solution for electronic measurement systems' underlying avionics systems like ADAHRS. Image source: Analog Devices

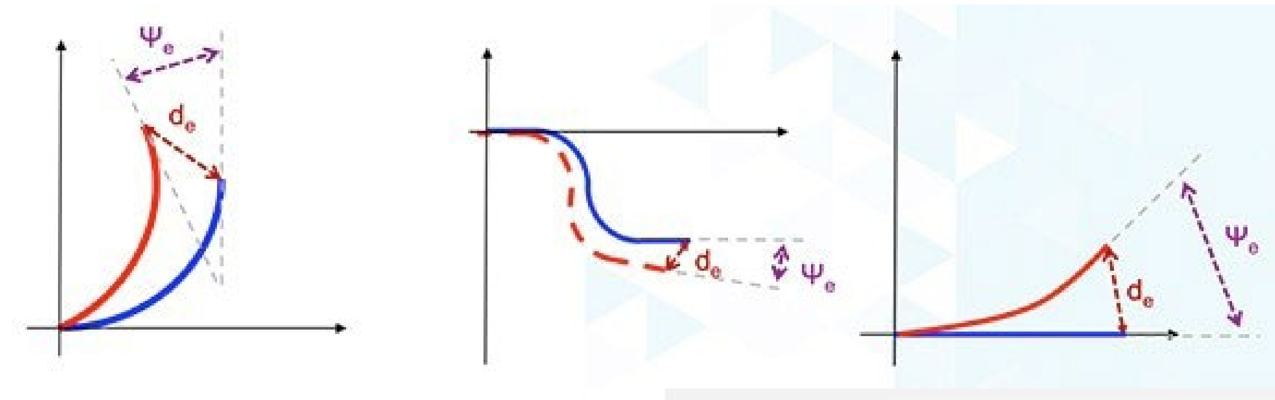


Figure 4: Gyroscope sensitivity limitations, nonlinearity, and bias can result in the accumulation of heading error (Ψ) and position error (de) during turns (left), S-turns (middle), and cruise (right). Image source: Analog Devices

therefore reducing the total cost of ownership.

Designed to meet the demanding data acquisition requirements, Analog Devices' ADAQ4003 and ADAQ23878 μModules integrate a fully differential ADC driver amplifier (FDA, Figure 2) with a 0.005% precision matched resistor array, a stable reference buffer, and an 18-bit successive approximation register (SAR) ADC, capable of delivering 2 megasamples per second (MSPS) and 15 MSPS performance, respectively.

By combining a μModule data acquisition device like the ADAQ4003 with a fully differential programmable-gain instrumentation amplifier (PGIA), such as Analog Devices' LTC6373, developers can implement a simple solution to many of the complex sensing requirements of aviation systems.

As noted earlier, MEMS-based sensors offer an effective solution for delivering the critical data required for ADAHRS functionality. By integrating MEMS triaxial gyroscopes and triaxial accelerometers with temperature sensors and other functional blocks, IMUs with six degrees of freedom, such as Analog Devices' ADIS16505 precision miniature MEMS IMU and ADIS16495 tactical-grade inertial sensor, provide the complete set of functionality

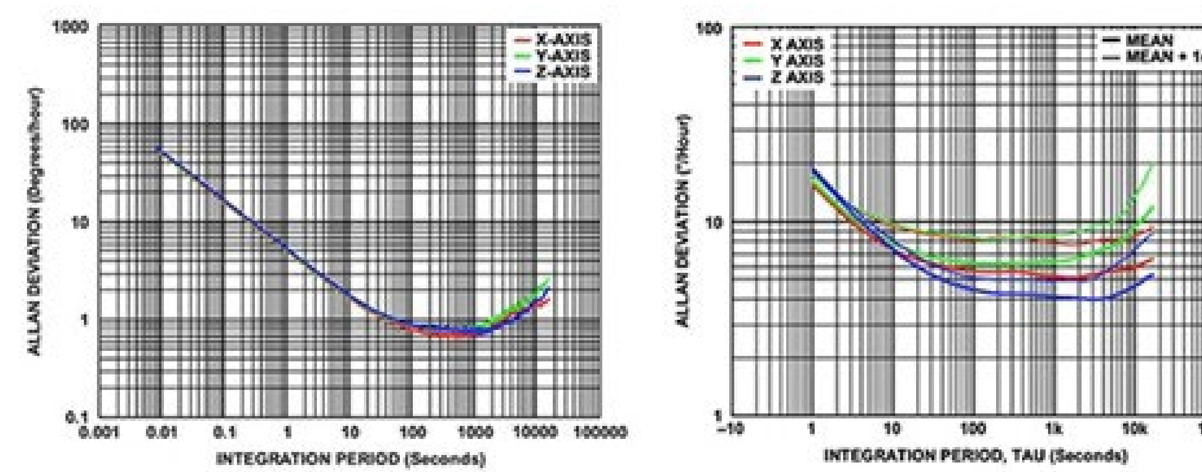


Figure 5: Allan deviation plots for the MEMS gyroscopes in the ADIS16495 IMU (left) and ADIS16505 IMU (right) describe the ability of extended sampling time to compensate for random drift. Image source: Analog Devices

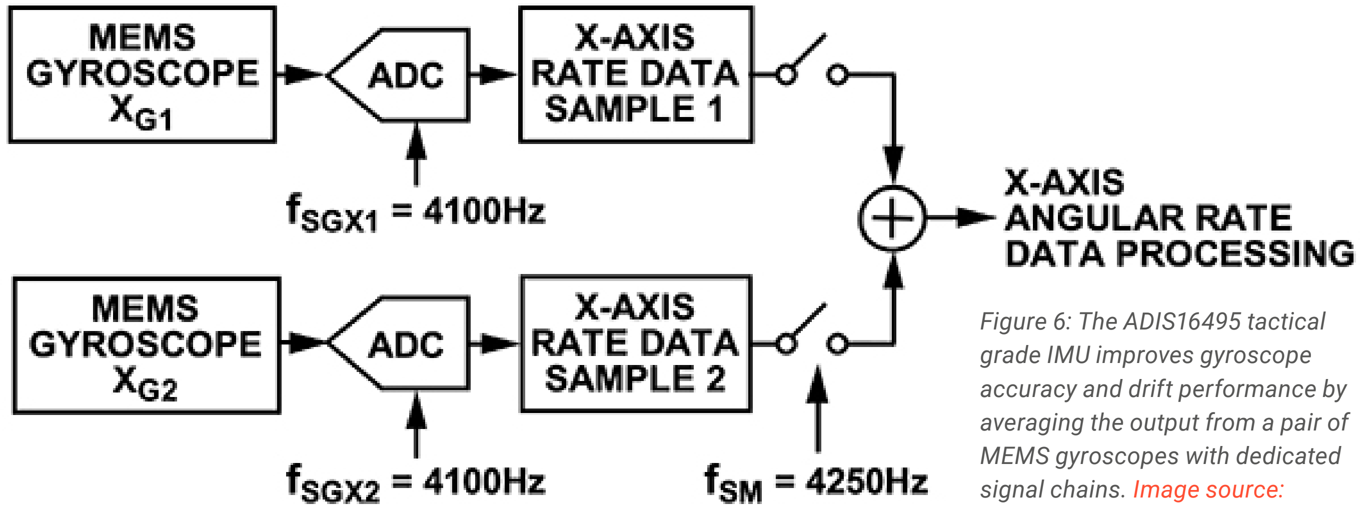


Figure 6: The ADIS16495 tactical grade IMU improves gyroscope accuracy and drift performance by averaging the output from a pair of MEMS gyroscopes with dedicated signal chains. Image source: Analog Devices

required to simplify development of avionics subsystems (Figure 3).

Combined in the ADAHRS, these systems can provide the essential components of inertial navigation systems able to provide the required heading to the desired destination even without satellite or ground-based navigation aids. As with any manufactured device, MEMS-based devices are subject to different sources of performance limitations that can degrade the accuracy of computed navigation. For example, inevitable variations in manufacturing, internal noise sources, and environmental effects limit a MEMS gyroscope's accuracy.

Manufacturers document the performance effects of these variations in numerous datasheet parameter specifications. Among these specifications, sensitivity, nonlinearity, and bias parameters can directly impact ADAHRS accuracy. In gyroscopes, limited sensitivity (angular rate measurement resolution) can result in heading error (Ψ) and position error (de) during turns (Figure 4, left); nonlinear response (deviation from ideal linear response) can result in similar errors following a series of maneuvers such as S-turns (Figure 4, middle); and gyroscope bias results in a drift in heading and position even during cruise (straight and level flight with no acceleration) (Figure 4, right).

Bias errors arise from the misalignment of each gyroscope axis to other axes or the package, scaling errors, and the gyroscope's incorrect response to linear acceleration as rotation due to asymmetries in the MEMS fabrication. For its ADIS16505 and ADIS16495 IMUs, Analog Devices determines bias correction factors specific to each device by testing them at multiple rotation rates and temperatures. These part-specific bias correction factors are stored in each part's internal flash memory and applied during sensor signal processing.

In addition to the correctable bias factors, random noise from various sources impacts bias error over time. Although it is not possible to compensate for this random noise directly, its effects can be reduced by sampling over longer integration times. The degree to which longer sampling times will reduce noise is described in a gyroscope datasheet's Allan deviation (or Allan variance) plot, which displays noise in degrees per hour (°/hr) versus the integration period (τ) (Figure 5).

To help speed the development of designs based on its IMUs, Analog Devices provides a comprehensive set of development tools.

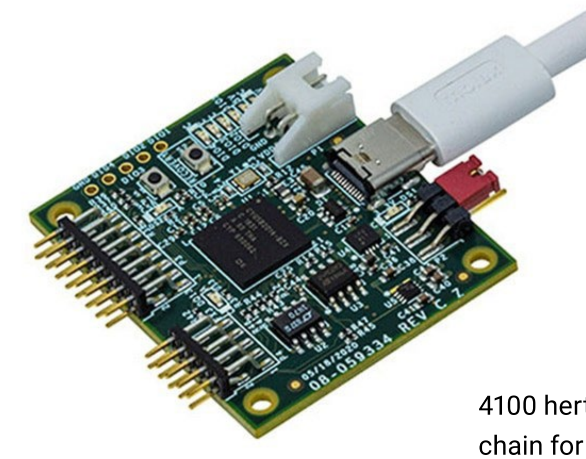


Figure 7: The EVAL-ADIS-FX3 evaluation board is part of a comprehensive hardware and software support package to help exercise Analog Devices' IMUs. Image source: Analog Devices

The minimum of the Allan deviation plot represents the best case for the gyroscope's drift over time, a parameter called in-run bias stability (IRBS) typically specified in terms of the sum of the mean and one standard deviation in datasheet specifications. For developers creating highly accurate ADAHRS solutions, an IMU's IRBS provides an essential parameter for understanding the best-case performance possible with that part. Gyroscope experts classify IMUs such as Analog Devices' ADIS16495 as 'tactical grade' when their gyroscope's IRBS values are between 0.5° and 5.0°/hr.

The ADIS16495 features tight specifications across multiple vital parameters to meet more demanding tactical applications. Aiding its enhanced performance, the ADIS16495 integrates a pair of MEMS gyroscopes and a dedicated 4100 hertz (Hz) sampling signal chain for each of its three axes (Figure 6).

Samples from each signal chain are then combined using a separate 4250Hz sample frequency (fSM) to provide an angular rate measurement that reduces the effect of noise. Combining this sampling method with more stringent performance specifications results in an IMU capable of meeting more demanding avionics requirements.

Rapid development and exploration of IMU-based designs

To help speed the development of designs based on its IMUs, Analog Devices provides a comprehensive set of development tools. Designed to support its EVAL-ADIS-FX3 IMU evaluation board (Figure 7) and associated breakout boards, Analog Devices' FX3 software stack comprises a firmware package, a .NET-compatible application programming interface (API), and a graphical user interface (GUI). A wrapper library provided with the API allows developers to work with any development environment that supports .NET, including those for MATLAB, LabView, and Python. During development, the FX3 evaluation GUI enables developers to easily read and write registers, capture data, and plot the results in real time.

Conclusion

ADAHRS avionics solutions form the heart of the evolving EFISs. With the development of precision gyroscopes, accelerometers, and magnetometers based on MEMS technologies, avionics systems can offer flight performance and navigation capabilities that have been beyond the reach of all but the largest fleets of commercial aircraft. Using data acquisition modules and highly integrated IMUs from Analog Devices, avionics developers can design more cost-effective, smaller solutions to meet the stringent requirements for functionality, safety, and reliability in aviation systems.

How to ensure circuit protection, high speed data, and power conversion for eMobility platforms

Written by Jeff Shepard

The need for reliable circuit protection, high-speed communications, and compact power conversion solutions in eMobility and transportation systems is growing across a range of platforms including hybrid and electric cars, buses, medium and heavy-duty on and off-highway vehicles, and marine platforms. These trends are being driven by increasing emphasis on sustainability and safety as the transportation industry transitions to more autonomous control and electric vehicles (EVs) or hybrid EVs (HEVs). As a result, new vehicle systems are emerging that are progressively becoming more dependent on safe and sustainable vehicle operation.

To ensure safety and reliability, designers of connected, electric, and automated vehicles need a wide variety of circuit protection, along with communications and power conversion solutions that are designed for reliable operation in challenging environments, and are certified to meet AEC-Q200, SAE, USCAR, and other performance standards.

This article briefly reviews some of the specifications of circuit protection devices that designers need to consider. It then introduces specific circuit protection, connectivity, and power conversion solutions from Bel Fuse and examines the use of those products in eMobility systems.

EV protection components and standards

To meet the challenges around EVs, designers can turn to an array of automotive qualified and certified circuit protection, high-speed communications, and power conversion solutions including:

- Automotive qualified fuses in cartridge, PC board mounted (through hole and surface mount) and offset bolt configurations optimized for power systems and subsystems, plus fuses for auxiliary applications and accessories such as driver-assist radar systems, brake pump motors, portable chargers, battery systems, infotainment, cameras, programmable lighting, and power-assisted steering. In addition, specific applications will require high inrush, fast-acting, slow blow, and resettable polymeric positive temperature coefficient (PPTC) fusing
- AEC-Q200 qualified electromagnetic interference (EMI) suppression chokes to filter out noise and protect high-speed data signals for the numerous sensor subsystems that make up ADAS and navigation systems, multimedia systems, vehicle-to-everything (V2X) clusters, and antennas, and provide differential noise suppression for automotive Ethernet, Controller Area Network (CAN) bus, FlexRay, and

automotive Universal Serial Bus (USB)
- Fully shielded RJ45 connectors that comply with the Society of Automotive Engineers (SAE) USCAR2-6 'Performance Specification for Automotive Electrical Connector System – Revision 6', and enable designers to replace CAN buses with faster and lighter weight automotive Ethernet to support growing in-vehicle computing needs in a range of ADAS systems such as driver-assist cameras and radar-based driver assist systems, as well as telematics, media converters, and gateways
- IP67 certified power converters, including electric and hybrid vehicle battery chargers that are automotive qualified and are offered in convection or liquid-cooled implementations with galvanic isolation

Selecting circuit protection devices

When selecting an appropriate device, a clear understanding of its operating characteristics is important when specifying circuit protection devices for eMobility systems. Some basic specifications include:

- Voltage rating: the maximum permissible voltage for safe operation
- Current rating: the current in amperes (A) that the fuse can carry under normal operating conditions
- Breaking capacity (also called interrupting rating or short circuit rating): the maximum current the fuse can interrupt at its rated voltage without being damaged; breaking capacity must meet or exceed the maximum fault current anticipated for the circuit
- Time current curves: define whether the fuse is fast-acting or slow blow (also called delayed acting); fast-acting fuses are used where speed of protection is critical; slow-blow fuses are used in applications that experience a short-term current surge or overload

I2t: a specification without a test standard

A specification that deserves special attention is the nominal melting rating, I2t (pronounced 'I squared T'). This is a measure of the energy required to melt the fuse element, an important fuse characteristic for any application. I2t is expressed as 'Ampere squared seconds' (A2sec). Unfortunately for designers, neither the UL/CSA 248 or IEC127 standards for miniature and micro fuses include a test procedure or testing criteria for I2t. The industry standard definition of I2t is:

MELTING I2t measured at 10In, using constant direct current (DC), where In is the rated current of the fuse.

The use of 10In can be problematic and does not always result in accurate opening times. Slow-blow fuses, in particular, may require a higher multiple than 10 times the nominal current rating to arrive at the true I2t value. Since different manufacturers deal with this dilemma differently, it is important for designers to have a clear understanding of the method used to arrive at the I2t values for specific fuses. A more detailed discussion of these challenges is available here: I2t explained.

Figure 1: Chip fuses like the slow-blow C1T series are used in a variety of automotive applications where a compact form factor is important. Image source: Bel Fuse

Fast-acting and slow-blow chip fuses

Designers of automotive navigation systems, lithium-ion (Li-ion) battery management systems (BMS), LED headlamps, automotive power over Ethernet (PoE), PoE+, and liquid crystal displays (LCDs) can benefit from using surface mount chip fuses based on thick film technology, such as the 0685P series of fast-acting fuses. The 0685P series features high inrush current withstand capability. These AEC-Q200 compliant and UL approved 1206 size fuses are available with current ratings from 2A to 50A, and voltage (volt) ratings of 50 volts alternating current (AC) and 63 volts DC. The model 0685P3000-01 is rated for 6A with an I2t rating of 1.3 A2sec at 10In.

For designers needing slow-blow fusing, Bel offers the C1T series of 1206 size chip fuses (Figure 1). These are available with current capacities from 750 milliamperes (mA) to 8A and are rated for 63 volts AC or DC. The model 0685T6000-01 is rated for 6.0A with an I2t rating of 6.0 A2sec at 10In. The C1T series slow-blow fuses are UL, CSA, and CE approved and carry the TUV certification to IEC 60127 for miniature fuses.

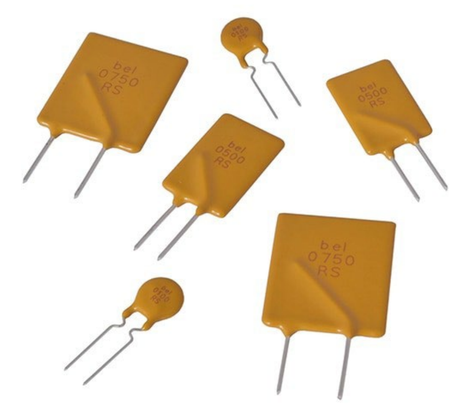


Figure 2: The OZRS radial-leaded PPTCs are rated for 32 volts DC and up to 10A. Image source: Bel Fuse

Resettable PPTC devices

Designs that can benefit from resettable circuit protection with very low operating resistance and very high hold current can use PPTC devices. PPTCs can be especially useful in applications such as motor and motor circuit protection in power door locks, mirrors, seats, sunroofs, and windows, as well as heating ventilation and air conditioning (HVAC) systems and electronic control unit (ECU) I/O protection.

Testing Current	Blow time minimum	Maximum
100%	4 hours	N/A
200%	N/A	120 seconds
300%	0.15 seconds	3 seconds
800%	0.01 seconds	01. seconds

Table 1: Electrical characteristics of the 0680L series surface mount slow-blow fuses. Image source: Bel Fuse

Bel offers two families for PPTC devices. Both are AEC-Q compliant, TUV certified to EN/IEC 60738-1-1 and EN/IEC 60730-1, and UL recognized to UL1434:

- 0ZRS radial leaded PPTCs are rated from 500mA to 10A with a maximum voltage of 32 VDC, and typical power ratings from 0.9 to 7.0W (Figure 2). For example, the 0ZRS0100FF1E has a trip current of 1.9A, a hold current of 1.0A and is rated for 1.4W
- 0ZCG surface mount PPTCs are rated from 100mA to 3A with maximum voltages from 6 to 60 volts DC, and typical power ratings from 0.8 to 1.3W. The 0ZCG0110BF2B device from this family is rated for 24 volts DC, and has a hold current of 1.1A, a trip current of 2.2A, and a power rating of 1W

In-rush current withstand fusing

The 0680L series of square style 2410 package size surface mount ceramic fuses have high in-rush current withstand capability (Table 1). These slow-blow fuses are designed for applications that require high DC interrupting ratings and high DC voltage ratings. They are rated up to 125 volts DC or AC and offer current ratings from 375mA to 12A. The 0680L fuses are AEC-Q compliant.

These slow-blow fuses are often used for PoE, PoE+, power supply, and battery charging circuit protection; the 0680L3000-05 is rated for 3A and 0.81W with an I2t rating of 13 A2sec at 10In.

Fast-acting EV power fuses

Designers can turn to fast-acting fuses in cartridge and bolt-down configurations for protecting high-power batteries and EV power converters. These fuses are in full compliance with EU Directive 2011/65/EU and amending directive 2015/863. They are designed to meet UL 248-1 as well as the reliability requirements of JASO D622 and ISO8820-8. Typical applications include:

- Main system fusing
- Charging stations
- Energy storage and battery packs
- Power distribution units
- On-board DC-to-DC converters
- Brake pump motors
- Air conditioning compressor motors
- Electric steering systems

They can handle currents up to 600A and have voltage ratings from 500 to 1,000 volts DC; the 0ADAC0600-BE is a good example of a cartridge type fuse rated for 600mA and 600 VDC or VAC, with an I2t rating of 0.073 A2sec at 10In.

EV time lag fuses

The 0697W series of sub-miniature, radial lead, time-lag fuses have ratings of 350 volts AC or 72 volts DC, a current rating of 1 to 6A, and comply with IEC 60127-3 (Figure 3). These fuses are compliant with AEC-Q quality and Mil-Std 202G environmental standards.

Figure 3: The 0697W series are AEC-Q compliant, radial lead, high voltage, time-lag fuses. Image source: Bel Fuse

Applications for the 0697W devices include ECUs, motors, climate and ventilation controls, plugs and cigarette lighter accessories, power outlets, and wire harnesses. For example, the 0697W2000-02 is rated for 2A and 0.63W with an I2t rating of 30 A2sec at 10In.

Common-mode chokes for high-speed communications

Designers of automotive infotainment, multimedia, and ADAS systems using an Ethernet, CAN bus, FlexRay, or USB communications bus can turn to Signal Transformer's SPDL series of AEC-Q200 certified ultra-compact common-mode chokes for suppression of differential mode noise (Figure 4). These compact surface-mount device (SMD) chokes are offered in four metric sizes, 2012, 3216, 3225, and 4532, and 26 different component ratings. The SPDL series have a rated current range from 150 to 400mA and an impedance range from 90 to 2200 ohms (Ω). The model SPDL3225-101-2P-T is rated for 150mA and 2200 Ω with an inductance of 100 microhenries (µH).

Figure 4: The SPDL series of ultra-compact SMD common mode chokes can be used with Ethernet, CAN bus, FlexRay, or USB communications interfaces. Image source: Signal Transformer

Upgrade to Ethernet

Due to its faster data rate and lighter weight cable, designers are replacing CAN bus with Ethernet in a growing number of eMobility applications. The Bel Fuse MagJack automotive Ethernet single-port integrated connector modules (ICMs) have the Ethernet magnetics solution integrated into the connector package. This results in a more compact solution and simplifies the task of upgrading existing CAN bus systems with Ethernet signaling and cabling styles (Figure 5). MagJack Ethernet ICMs operate up to 100°C and are SAE/USCAR2-6-compatible. These ICMs are approved by Broadcom, Intel, and Marvell, and are compatible with standard automotive grade transceivers, further simplifying the switch to Ethernet.

Figure 5: The MagJack automotive Ethernet single-port ICMs feature integrated magnetics to meet the need for compact solutions. Image source: Bel Fuse

An example is the A829-1J1T-KM automotive Ethernet ICM that meets all IEEE 802.3 10/100Base-T electrical requirements.

Power conversion for HEVs and EVs

Bel Power Solutions offers designers a complete range of power conversion options for eMobility including DC-DC converters, bidirectional DC-DC converters, on-board chargers, auxiliary inverters, and inverter charger systems that integrate a bidirectional inverter charger with two DC-DC down converters. For example, the 22 kilowatt (kW) BCL25-700-8 is a liquid-cooled, on-board battery charger for HEVs and EVs on medium and heavy-duty platforms for on and off-highway operation (Figure 6). Features and specifications of the BCL25-700-8 include:

- Single-phase (190 to 264 volts AC) or three-phase (330 to 528 volts AC) input
- Can connect to AC grid power or to an Electric Vehicle Supply Equipment (EVSE) charging station (EV Std. IEC 61851-1)
- Constant output current of 60A over a voltage range from 250 to 800 volts DC
- Up to four units can be placed in parallel
- IP67 and IP6K9K compliant
- IEC 61851-21-1 and ECE R10.6 certifications
- SAE J1772 & CAN interface SAE J1939 compliant
- Active high-voltage DC interlock monitoring
- Operates from -40 to 60°C at full load
- Over temperature, overcurrent, and output overvoltage protections

Figure 6: The BCL25-700-8 is a 22kW, on-board, liquid-cooled battery charger for HEVs and EVs that are intended for medium to heavy-duty applications, for both on and off-highway. Image source: Bel Fuse

A wide variety of circuit protection, communications, and power conversion solutions will be needed to support the safety and sustainability requirements of the next generation of connected, electric, and increasingly automated vehicles.

Conclusion

A wide variety of circuit protection, communications, and power conversion solutions will be needed to support the safety and sustainability requirements of the next generation of connected, electric, and increasingly automated vehicles. As shown, designers have ready access to solutions in the form of automotive qualified circuit protection devices, EMI suppression chokes that comply with AEC-Q200, fully shielded RJ45 Ethernet connectors that comply with SAE/USCAR2-6, and IP67 certified power converters. These will help HEV and EV designers meet the many current and emerging design challenges as autonomous designs evolve.

Recommended reading

1. Tomorrow's Vehicles Will Have Even More Technology

Meet the challenge of accurate voltage sensing in electric vehicles with isolation amplifiers

Written by Kenton Williston

Designers of electric vehicles (EVs) and hybrid electric vehicles (HEVs) need to meet the demand for higher performance, faster charging, and greater efficiency. One of the many electronic functions that can help satisfy these demands is accurate voltage sensing for optimal power control.

However, automotive applications are particularly challenging. Power electronics must function reliably for decades despite temperature extremes and the presence of high voltages that demand suitable isolation. Voltage-sensing circuits for these applications must offer high bandwidth, low error and drift, and high common-mode transient immunity (CMTI) while meeting automotive standards like AEC-Q100. These requirements are especially relevant for critical components in EVs and HEVs, including inverters, DC-DC converters, and onboard chargers.

Transformer-based isolation amplifiers are well suited to these applications. These devices use advanced technology to achieve excellent performance over decades of exposure to harsh conditions.

This article examines the operating principles of isolation amplifiers. It then introduces a transformer-based example that uses iCoupler technology from Analog Devices, reviews its potential applications in EV/HEV development, and presents an evaluation board to help begin the design process.

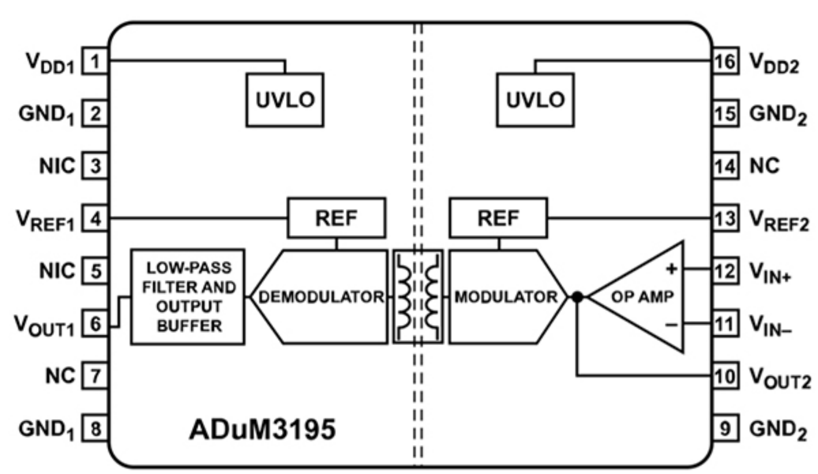


Figure 1: The ADuM3195 isolation amplifier uses transformer-based isolation. Image source: Analog Devices, Inc.

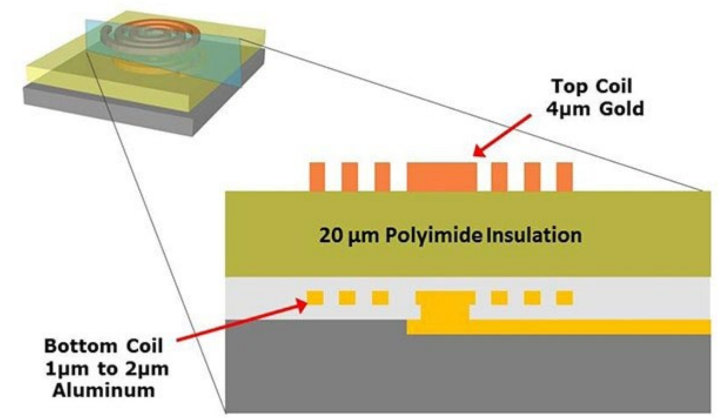


Figure 2: Central to iCoupler performance is a polyimide insulation layer that provides high thermal and mechanical stability. Image source: Analog Devices, Inc.

Operating principles of transformer-based isolation amplifiers

Isolation amplifiers are specialized differential amplifiers that provide electrical isolation between input and output circuits. This isolation can be achieved through several means, but transformer-based isolation amplifiers like the ADuM3195 (Figure 1) offer unique advantages for EV/HEV applications.

In transformer-based designs, isolation is achieved through transformer coupling. The basic principle of operation involves the following steps:

1. The input signal is converted into a high-frequency carrier signal
2. This carrier signal is then transmitted across the isolation barrier via a transformer
3. On the secondary side of the transformer, the original signal is reconstructed from the carrier

The transformer serves two crucial functions. It provides galvanic isolation between input and output circuits, allowing safe measurement of high voltages and protecting sensitive circuitry. It also enables signal transfer without a direct electrical connection across the isolation barrier.

Transformer-based isolation offers significant advantages for voltage-sensing applications. These amplifiers effectively reject common-mode voltages, crucial in noisy electrical environments. In addition, modern designs achieve wide bandwidths suitable for many power electronic applications.

Performance advantages of planar micro-transformers for isolation amplifiers

iCoupler technology, developed by Analog Devices, represents an advancement in isolation amplifier design. iCoupler devices feature planar micro-transformers with a typical diameter of approximately 0.5 millimeters (mm), enabling

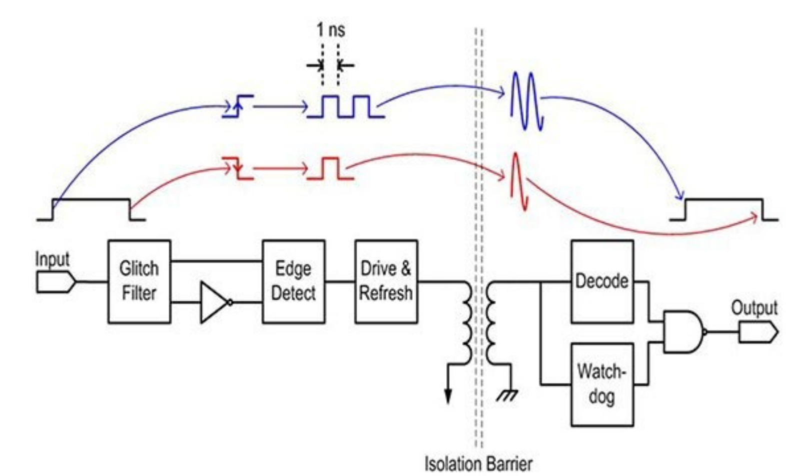


Figure 3: A highly efficient encoding method allows iCoupler devices to transfer data at 150 Mbits/s and draw typically less than 1mA per channel. Image source: Analog Devices, Inc.

remarkably compact solutions. The small size also provides inherent resistance to external magnetic fields, enhancing reliability.

Central to iCoupler performance is a polyimide insulation layer (Figure 2). This insulation provides high thermal and mechanical stability, making the device exceptionally durable. It can withstand surge voltages exceeding 10 kilovolts (kV) and offers long-term reliability when operating continuously at 400V root mean square (VRMS).

An essential feature of iCoupler technology is its ability to operate at high frequencies, supporting data transfers up to 150 megabits per second (Mbits/s). This is achieved in part through a highly efficient signal encoding methodology. Data is encoded into 1 nanosecond (ns) pulses that enable fast data transfer and low power consumption, typically less than 1 milliampere (mA) per channel (Figure 3).

Additionally, iCoupler devices incorporate input glitch filters to reduce noise and ensure clean signal transmission, enhancing performance in electromagnetically noisy automotive environments.

Key features of automotive-qualified isolation amplifiers

iCoupler technology has been implemented in several devices, including the ADuM3195WBRQZ isolation amplifier. This AEC-Q100-compliant version of the ADuM3195 is specifically designed for automotive environments. It has an isolation voltage of 3,000 VRMS, an output offset voltage of ±6 millivolts (mV) (max) at 25°C, a gain error of ±0.5% (max), a bandwidth of 210 kilohertz (kHz), a gain drift of ±27 parts per million per °C (ppm/°C) (max), and an offset drift of -22 microvolts per °C (μV/°C) (typical). The device has a CMTI of 150kV per microsecond (kV/μs) (typical), an operating temperature range of -40 to 125°C, configurable gain settings, and comes in a 16-lead QSOP.

These features make the ADuM3195WBRQZ suitable for accurate, isolated voltage measurements in challenging automotive applications, including:

- Voltage monitoring in battery management systems (BMSs)
- Feedback loops in power supplies
- Inverter and motor drive systems

Designers of EVs and HEVs require precision sensing in various subsystems to achieve performance and efficiency goals.

The high accuracy, wide bandwidth, low power consumption, and robust isolation capabilities make the ADuM3195WBRQZ a particularly effective solution for voltage sensing in EV/HEV systems.

Isolation amplifier requirements for inverters, DC-DC converters, and onboard chargers

The ADuM3195WBRQZ isolation amplifier addresses critical challenges in EV/HEV power systems, including inverters, DC-DC converters, and onboard chargers.

Its 210kHz bandwidth enables sub-5 μs response times, crucial for efficient charging, precise inverter control, and minimized voltage ripple in DC-DC converters. This high bandwidth also allows for smaller passive components and supports wide-bandgap device integration, enhancing overall system efficiency and power density.

The high-impedance input of the ADuM3195WBRQZ minimizes measurement-related power loss and stabilizes converter and inverter operations. Reducing current draw also decreases stress on auxiliary circuits, improving system reliability.

The ADuM3195WBRQZ's high temperature tolerance allows it to be placed near heat-generating components like electric motors, onboard chargers, and regenerative braking systems to help prevent thermal runaway, manage thermal cycling, and avoid hotspots in power electronics.

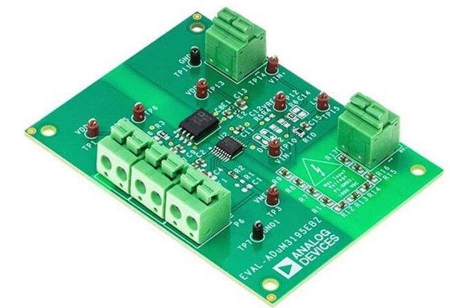


Figure 4: The EVAL-ADuM3195EBZ evaluation board is designed for setup and testing of the ADuM3195.
Image source: Analog Devices, Inc.

For DC-DC converters handling various output voltages, the ADuM3195WBRQZ's low offset error and offset drift ensure accurate voltage feedback across temperature variations. This accuracy contributes to precise control, reduced ripple, and improved drivetrain performance.

The 3,000 VRMS isolation voltage of the ADuM3195WBRQZ protects low-voltage electronics and occupants from high-voltage systems (up to 400V). It provides effective noise rejection between power stages and control circuits in EV battery systems while interfacing with low-voltage systems (12/48V).

By meeting these critical requirements, the ADuM3195WBRQZ enhances the performance, efficiency, and safety of EV/HEV power systems.

It is worth noting that the ADuM4195 is available for higher voltage system requirements, providing an isolation voltage up to 5,000 VRMS and low-voltage electronics operation up to 800V.

Jumpstart ADuM3195 development

The EVAL-ADuM3195EBZ (Figure 4) is a compact evaluation board designed for testing and evaluating the performance characteristics of the ADuM3195 isolation amplifier. It is an isolated voltage monitoring board that can be configured for both DC and AC measurements. This board is pre-configured to handle input voltages up to 1,000 VDC (continuous).

The features of the EVAL-ADuM3195EBZ evaluation board can help jumpstart the development of EV/HEV applications in several ways:

- High-voltage isolation and measurement: the board is designed to safely measure high DC voltages up to 1,000V, which is especially relevant for EV/HEV battery systems. This allows developers to monitor battery pack voltages, measure individual cell voltages in a BMS, and interface with high-voltage DC bus lines
- Configurable input range: the input voltage divider can be adjusted to accommodate different voltage ranges common in EV/HEV systems. For example, a 400 VDC bus is typical in many EVs, 800V systems in newer EV architectures, and lower voltage ranges for 48V mild hybrid systems.
- AC measurement capability: with minor modifications, the board can measure AC voltages, which can be helpful for motor drive inverter output monitoring, AC charging system measurements, and electromagnetic interference (EMI)/noise analysis on high-voltage lines
- Low-power option: for lower power consumption, the power disable (PDIS) input can disable the internal power supply when energy needs to be used judiciously

Conclusion

Designers of EVs and HEVs require precision sensing in various subsystems to achieve performance and efficiency goals. A micro-transformer-based isolation amplifier, such as the AEC-Q100-qualified ADuM3195WBRQZ, is well suited to this application, offering a mix of performance, miniaturization, and longevity that meets the critical design requirements. The associated evaluation board for this isolation amplifier helps designers quickly get up and running.

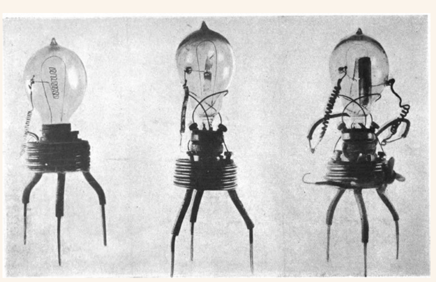
This month in history

1904

November 16

Sir John Ambrose Flemming patents his thermionic valve

John Ambrose Fleming filed GB 24850 for his thermionic "valve." Using a heated cathode and anode in a vacuum, it rectified radio signals and AC, unlocking detection and power conversion, and launching the age of vacuum tubes. It also set the stage for triodes and amplifiers.



The first prototype units of Flemming Valves.

1931

November 12

Philo Farnsworth patents the TV camera tube

Philo T. Farnsworth secured patents refining the Image Dissector, an all-electronic camera tube. By scanning photoelectron beams, it turned scenes into signals, replacing mechanical scanners and beginning the path to studio-grade television.

Philo Farnsworth posing with his two most notable inventions: the image dissector in his right hand and the cathode-ray tube in his left.

1952

November 4

UNIVAC predicts the U.S. election on live television

CBS aired UNIVAC's live election forecast. Feeding early precinct returns, the mainframe predicted Eisenhower decisively, shocking anchors. It showcased statistical computing for news, boosted trust in electronic data, and foreshadowed election-night analytics.

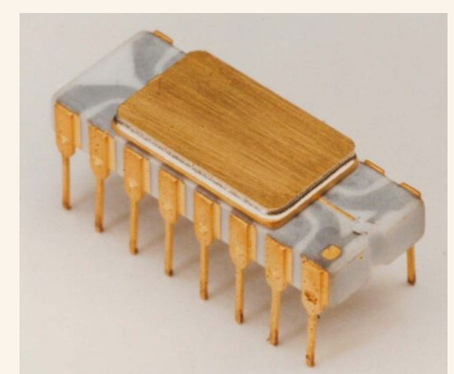
The UNIVAC was the first computer built for commercial use. The accurate election prediction made UNIVAC a household name.

1971

November 15

Intel announces the 4004

When Intel announced the 4004, a 4-bit CPU in a ceramic DIP. Born from a calculator contract, it proved that a full processor could fit on one chip. WithROM/RAM/I/O companions, it launched the microprocessor era and inspired later 8- and 16-bit families.



The Intel 4004 rewrote the rules for general computing.

2000

November 20

Intel releases the Pentium 4 Processor

Intel revolutionized personal computers in 2000 with the release of the Pentium 4. It was designed to hit very high clock speeds, making headlines in the "gigahertz" race, causing the price of high-speed computers to drop below $1000. It added new math features that sped up photos and video, but it also ran hot—so PCs needed better fans, bigger heat sinks, and stronger power parts.

Thirty years after releasing the 4004, the Pentium 4 changed the way people used computers once again.

2003

November 8

IEEE 802.11g is ratified

With 54 Mb/s at 2.4 GHz with 802.11b backwards compatibility, the 802.11g WiFi standard revolutionized wireless computers. Using OFDM on legacy bands, it delivered faster Wi-Fi without new radios, accelerating home and enterprise deployments and setting expectations for over half a decade.

The 802.11g standard enabled the first significant proliferation of WiFi use among everyday consumers.


The parts we sell
help get you there safely
Today’s cutting-edge vehicles can contain hundreds of sensors for systems that keep you comfortable, entertained, informed, and most importantly, safe.
The sensors we sell help engineers create these systems, but helping you enjoy your journey safely is what really drives us.
Find sensors for any application at digikey.com
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