# POWER ELECTRONICS EUROPE

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## SMART ENERGY GRID

Precision Timing for Energy Infrastructure Resilience

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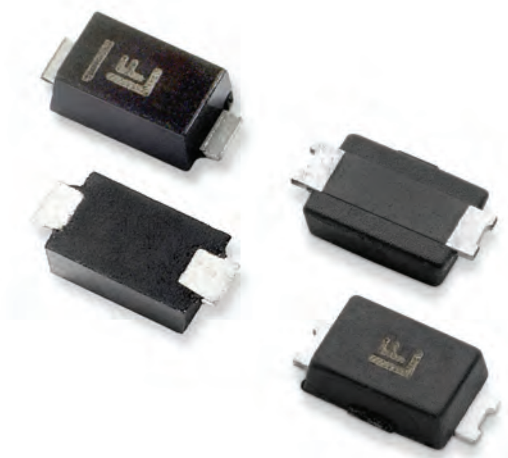
## FEATURE STORY

### Smart Energy Grid: Precision Timing for Energy Infrastructure Resilience

by Rich Kapusta, VP, Segment Marketing, SiTime

More details on page 25.

# Efficient SiC MOSFET gate protection: Littelfuse's SMFA asymmetric TVS diodes – at Rutronik



Ispringen, April 2025 – With the SMFA series of asymmetrical TVS diodes from Littelfuse, Rutronik is introducing an innovative solution for greater resilience of SiC MOSFET gate driver circuits. The diodes have been specifically designed to protect the sensitive gate structures from both negative and positive overvoltages and can therefore be used as a replacement for two separate TVS diodes. This enables designs that are both cost-effective and space-saving, while minimizing parasitic effects. They are particularly suitable for fast-switching SiC applications in the field of demanding power supply for AI / data centers, semiconductor / industrial equipment or e-mobility infrastructure.

They are available in tape & reel standard packaging in various versions **www.rutronik24.com.**

SiC MOSFETs typically have a significantly lower negative than positive gate voltage. Therefore, asymmetric protection with two separate TVS diodes was previously required, which took up more space in the design. To meet this challenge, Littelfuse offers the integrated asymmetric, bidirectional TVS diode Type SMFA.
The components impress with low inductance and excellent clamping capability. They meet the requirements of IEC 61000-4-2 at 30 kV air and 30 kV contact discharge, as well as those of flammability class UL94 V-0. The whisker test is carried out based on JEDEC JESD201A in accordance with Table 4a of Classes 1 and 2.
Depending on the required maximum gate voltage, various types with positive breakdown voltages (VBR) between 17.6 V and 23.4 V are offered. The negative breakdown voltage is 7.15 V in each case.
Overview of benefits:

- Asymmetrical diode for protection against both positive and negative overvoltage
- Excellent clamping ability
- Low inductance
- Glass passivated junction chip
- Surface mountable
- Low profile SOD-123FL package with 1.08 mm height
- Tape & reel standard packaging
- Halogen-free and RoHS compliant

**Overview of available types and their characteristics (Copyright Littelfuse)**

| Part Number | Marking | Maximum Reverse Leakage $I_{R1}$ @ $V_{R1}$ (µA) | Stand-off Voltage $V_{R1}$ (V) | Breakdown Voltage $V_{BR}$ (Volts) @ $I_{T1}$ Min. | Nom. | Max. | Typical Clamping Voltage $V_{C3}$ @ $I_{PP3}$ (V) | Typical Peak Pulse Current $I_{PP3}$ (A) | Maximum Clamping Voltage $V_{C1}$ @ $I_{PP1}$ (V) | Maximum Peak Pulse Current $I_{PP1}$ (A) | Test Current $I_{T1}$ (mA) | Junction Capacitance Typ@ 1 MHz, 0 V Bias (pF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SMFA1505CA | FM | 1 | 15 | 16.7 | 17.6 | 18.5 | 18.57 | 2 | 24.05 | 16.63 | 1 | 565 |
| SMFA1805CA | FT | 1 | 18 | 20.0 | 21.1 | 22.1 | 24.47 | 2 | 28.73 | 13.92 | 1 | 515 |
| SMFA1905CA | FU | 1 | 19 | 21.1 | 22.2 | 23.3 | 25.55 | 2 | 30.29 | 13.21 | 1 | 485 |
| SMFA2005CA | FV | 1 | 20 | 22.2 | 23.4 | 24.5 | 26.40 | 2 | 31.85 | 12.56 | 1 | 440 |

| Part Number | Marking | Maximum Reverse Leakage $I_{R2}$ @ $V_{R2}$ (µA) | Stand-off Voltage $V_{R2}$ (V) | Breakdown Voltage $V_{BR}$ (Volts) @ $I_{T2}$ Min. | Nom. | Max. | Typical Clamping Voltage $V_{C4}$ @ $I_{PP4}$ (V) | Typical Peak Pulse Current $I_{PP4}$ (A) | Maximum Clamping Voltage $V_{C2}$ @ $I_{PP2}$ (V) | Maximum Peak Pulse Current $I_{PP2}$ (A) | Test Current $I_{T2}$ (mA) | Junction Capacitance Typ@1 MHz, 0 V Bias (pF) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SMFA1505CA | FM | 400 | 5.5 | 6.82 | 7.15 | 7.48 | 7.85 | 2 | 10.5 | 33.0 | 10 | 565 |
| SMFA1805CA | FT | 400 | 5.5 | 6.82 | 7.15 | 7.48 | 7.85 | 2 | 10.5 | 33.0 | 10 | 515 |
| SMFA1905CA | FU | 400 | 5.5 | 6.82 | 7.15 | 7.48 | 7.85 | 2 | 10.5 | 33.0 | 10 | 485 |
| SMFA2005CA | FV | 400 | 5.5 | 6.82 | 7.15 | 7.48 | 7.85 | 2 | 10.5 | 33.0 | 10 | 440 |

**Application examples:**
**• Power supplies for AI/data centers or servers**
**• Highly reliable power supplies for semiconductor/industrial equipment**
**• High-efficiency power supplies for EVI (Electric Vehicle Infrastructure)**

**For more information to SMFA series of asymmetrical TVS diodes from Littelfuse and a direct ordering option, please visit our e-commerce platform at www.rutronik24.com.**

# Navitas redefines reliability

**Navitas Semiconductor a pure-play, next-generation power semiconductor company and an industry leader in gallium nitride (GaN) power ICs and silicon carbide (SiC) technology, has announced it has introduced a new level of reliability to meet the system lifetime requirements of the most demanding automotive and industrial applications.**

Navitas says its latest generation of 650 V and 1200 V 'trench-assisted planar' SiC MOSFETs combined with an optimised, HV-T2Pak top-side cooled package, delivers the industry's highest creepage of 6.45 mm to meet IEC-compliance for applications up to 1200V.

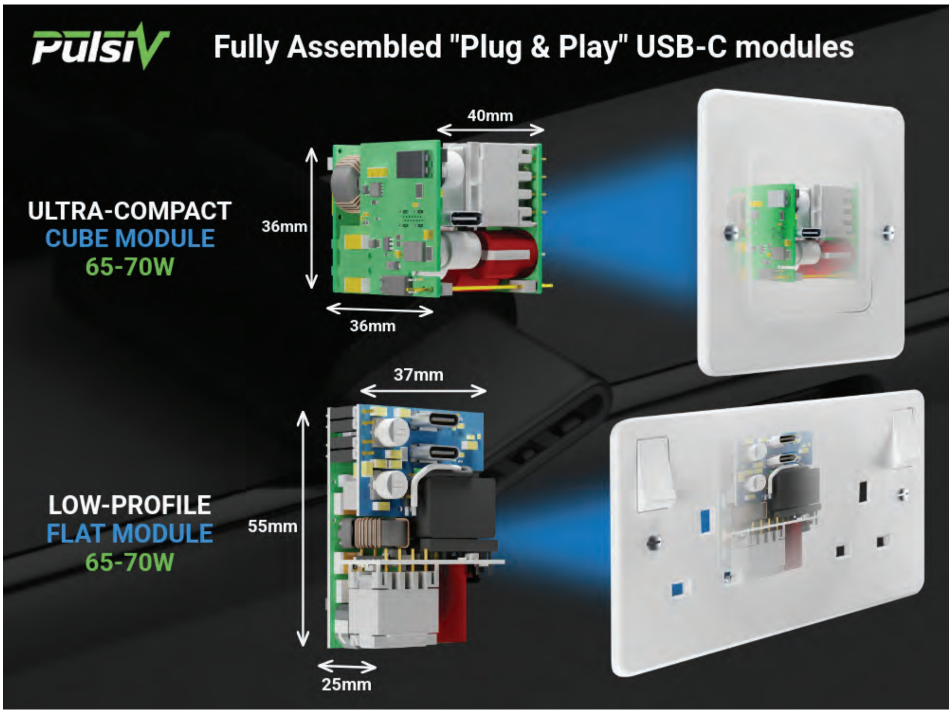
Navitas' HV-T2PaK SiC MOSFETs can significantly increase system-level power density and efficiency while improving thermal management and simplifying board-level design and manufacturability. Target applications include EV on-board chargers (OBC) & DC-DC converters, data-centre power supplies, residential solar inverters & energy storage systems (ESS), EV DC fast chargers, and HVAC motor drives.

AEC-Q101 is an automotive industry standard developed by the Automotive Electronics Council (AEC) to establish common part-qualification and quality-system standards. Navitas says it has created an industry-first benchmark, 'AEC-Plus'*, indicating parts qualified above and beyond the existing AEC-Q101 and JEDEC product qualification standards and this new benchmark showcases its deep understanding of system-level lifetime requirements and a strong commitment to enabling rigorously designed and validated products for demanding mission profiles in automotive and industrial applications.

*Navitas uses the term 'AEC-Plus' to indicate parts exceeding AEC-Q101 standards for reliability testing, published by the Automotive Electronics Council (AEC), based on Navitas test results

www.navitassemi.com


# Pulsiv announces the world's lowest temperature 65-70W USB-C modules




Pulsiv, a UK innovator of power electronics technology, has announced the release of a series of 65W-70W USB-C modules. Aimed at installed applications such as wall sockets, desks, and furniture, the company says these ultra-compact and fully assembled modules achieve the world's lowest operating temperature of just 32°C above ambient with an industry leading efficiency 97.34%.

**The problem**

USB-C charging in wall sockets, desks, and furniture typically offer power levels of 15-30W and often struggle to handle multiple devices and/or fast charging. Limitations on physical size and natural airflow cause higher power solutions at 45W-65W to reach temperature levels in excess of 80°C above ambient causing the power supply to either reduce the power to 15W, or in many cases, cut off altogether.

**The solution**

Pulsiv says its fully assembled USB-C modules have solved all the challenges relating to heat, size and safety, making it the only suitable solution for installed applications. It combines Pulsiv OSMIUM optimised PFC technology with an industry standard QR flyback to safely deliver 65W or 70W (MacBook compatible). Available in an ultra-compact cube or flat module form factor, this GaN-optimised design can operate continuously for more than 8 hours at 100% load and never exceed 32°C above ambient.

The company says furthermore, due to its unique and patented switching method, there is zero inrush current – eliminating the problems caused by power outages where multiple USB-C wall sockets have been installed in a single location.

**www.pulsiv.com**

# New B511-1C Evaluation Board from Panasonic Industry

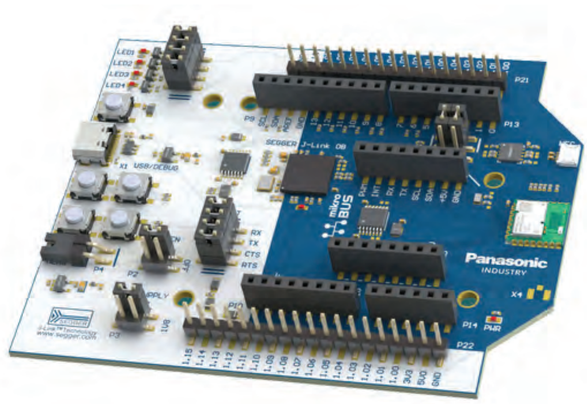
Panasonic Industry has announced it recently introduced the new B511-1C Evaluation Board (ENW89861AXKF) which features a PAN B511-1C (ENW89861A3KF) module which is based on the Nordic Semiconductor nRF54L15 single-chip controller.

The evaluation board features a pin header in Arduino UNO footprint configurable as shield or board and a mikroBUS socket for easy compatibility with external components like sensors and displays for quick prototyping. It comes with an additional 64Mbit memory on board and a board configuration which is available within Zephyr / nRF Connect SDK. Interested parties can access all the different module interfaces like GPIOs (all 32), NFC-A, current measurement pins, and Segger J-Link on-board debugger easily, which makes the evaluation board ideally suited for the evaluation of the PAN B511-1C module and rapid prototyping of lighting applications, home appliances, industrial sensors, medical devices, healthcare wearables, energy management devices and solar farms.

The company says the newly launched small and cost-effective PAN B511-1C Bluetooth module from Panasonic Industry features great performance and great memory while minimising current consumption based on the Nordic nRF54L15 single chip controller.

A dedicated number of GPIOs is positioned at the edge of the module, with the rest of the GPIOs located at the bottom pad, with the module providing access to all 32 GPIOs of the chip. With its hybrid packaging design of castellated holes and LGA, the module remains at the small size of a 2-cent coin. This way, it combines the advantages of both worlds without compromising on size and enables one of the best pin-to-size ratios for Bluetooth modules currently on the market.

**http://industry.panasonic.eu**



# Talking Industry

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# Rethinking the DIY Approach to Automated Test Equipment Design

Developing in-house Automated Test Equipment (ATE) is costly and complex, diverting resources from core innovation. To address this, many companies outsource some or all ATE system design and development to third-party specialists.

In an industrial setting, developing Automated Test Equipment (ATE) in-house is often approached as a DIY (Do-It-Yourself) project involving the ambitious task of constructing a critical support system using internal engineering resources.

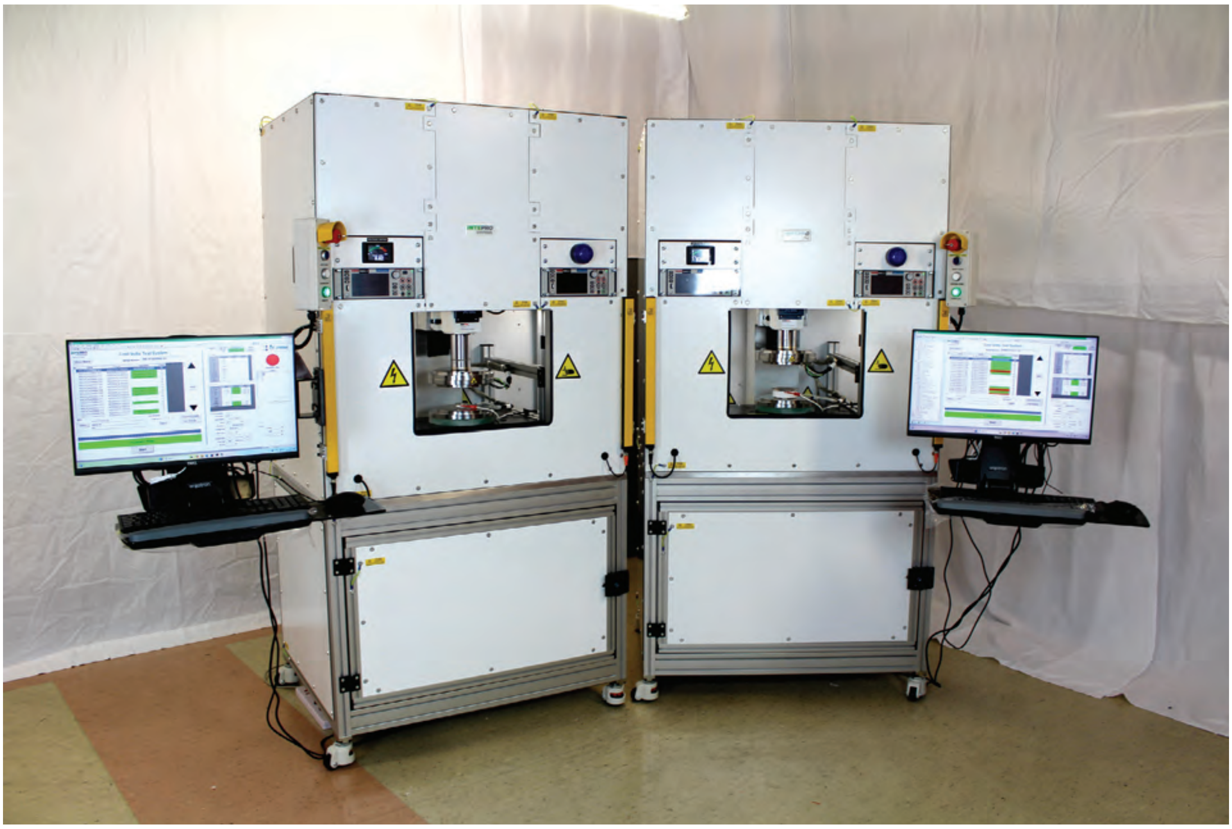
Automated Test Equipment (ATE) systems serve the critical purpose of ensuring that electronic devices operate according to specifications in the field. The aerospace and defense sectors make substantial investments in ATE due to the criticality of lifesaving electronics utilized in military equipment such as aircraft, naval vessels, and ground vehicles, as well as in various systems like weapons, radar, and wireless communication.

Automated Test Systems (ATS) are widely utilized for testing automotive electronics, batteries, and electronic drive systems in the EV market. ATEs are also used to optimize the performance of telecom infrastructure, analyze and improve the efficiency of renewable energy systems, and validate consumer electronics.

However, a common misconception is that designing and building ATE systems is a straightforward process, one that merely requires identifying test requirements and assembling the necessary components. In reality, effective test system development demands expertise in test system architecture, component selection, software integration, and regulatory compliance, making in-house development a significant challenge for most organizations.

While some enterprises attempt to develop ATE systems in-house, the complexity and cost often outweigh the benefits, diverting focus from core technological advancements. For some companies there can be advantages to turning to specialized providers that can provide all, or parts, of ATE systems.

"Many companies are reevaluating in-house design strategies and choosing to outsource all or significant portions of their automated test systems to specialized providers," says Andrew Engler of Intepro Systems, a leading supplier of high-power electronic testing



**Automated Test Equipment (ATE) systems serve the critical purpose of ensuring that electronic devices operate according to specifications in the field.**


**Automated Test Systems (ATS) are widely utilized for testing automotive electronics, batteries, and electronic drive systems in the EV market.**

systems. "This approach not only ensures access to advanced testing capabilities but also allows internal engineering teams to concentrate on core innovations rather than system validation."

According to Engler, companies prefer to keep testing and development in-house for various reasons. "For most companies, the first instinct is to allocate internal engineering resources. This approach ensures direct control over the project but introduces inefficiencies," he says.

Engineers, whose expertise lies in other areas, must take on responsibilities outside their core competencies, requiring them to assemble a solution without in-depth knowledge of testing system design, component sourcing, or software integration. This not only diverts their focus from primary tasks but may also lead to suboptimal solutions and increased project timelines. Intepro creates the documentation including user manual, drawings, and schematics for the system which can be extensive and is extremely time consuming. The company also troubleshoots errors that may arise in the system to avoid having customers pull engineering resources away from their tasks.

In some cases, security and proprietary concerns dictate the decision. Government contracts, for example, may explicitly restrict information sharing, requiring all work to be conducted internally to comply with security protocols. This is common in aerospace, defense, and other industries where confidentiality is critical.

Cost perception is another major factor. Many companies assume that outsourcing is more expensive, reasoning that they are already paying their engineers and should maximize their utilization. However, this overlooks the hidden costs of time spent researching, troubleshooting, and developing automated test systems from scratch—efforts that an experienced external provider could streamline with proven solutions.

"In reality, the cost of a DIY approach can be higher than expected. Engineers are valuable, and their salaries reflect it. When factoring in the hours spent sourcing, vetting, and troubleshooting components, the cost difference between handling it in-house and outsourcing to professional ATE system developers is negligible," says Engler.

There are numerous custom ATE providers that offer fully integrated automated solutions or, when required, specific hardware and software components to meet unique testing needs.

A typical automated test solution consists of hardware, software, test instruments, signal sources, and test probes or handlers. Software also plays a critical role in test development and management of data collection, storage, reporting, and analysis. These components are usually consolidated into all-in-one test stations, which vary greatly in size and portability, from small, compact test stations on wheels, to large stationary test towers.

Even when manufacturers seek to maintain control over the design of their Automated Test Equipment (ATE), they often turn to a hybrid approach that still involves bringing in outside experts, according to Engler.

"A few of our customers choose to manage their own test stations using internal resources while relying on us for specific components and software. This allows them to maintain control over the design while integrating proven, high-quality elements into their systems," says Engler.

A company like Intepro, which specializes in power electronics testing specifically, can offer many of the products used in test stations including AC and DC

**Effective test system development demands expertise in test system architecture, component selection, software integration, and regulatory compliance, making in-house development a significant challenge for most organizations.**

power sources, AC loads, and other standalone equipment.

Intepro's test systems use off-the-shelf equipment, so engineers can independently search for and purchase these components. However, the sourcing process can be overwhelming, particularly when faced with an extensive selection. A simple request such as finding a 30-volt, 5-amp power supply can quickly lead to sifting through hundreds of thousands of options.

Companies like Intepro have a list of pre-vetted suppliers, eliminating guesswork in selecting reliable components and reducing sourcing time.

Beyond technical specifications, sourcing requirements adds another layer of complexity, particularly in industries like aerospace. The county of origin of a component matters, and while sourcing from overseas suppliers is not an automatic disqualifier, it does raise additional considerations. Security concerns, compliance regulations, and supplier reliability must all be evaluated before making a selection. This requires an

**For some companies there can be advantages to turning to specialized providers that can provide all, or parts, of ATE systems.**

additional vetting process to ensure components meet both performance and regulatory standards.

Even the software can be purchased as a standalone product if needed. Every system requires test program software, which plays a critical role in test development and the management of data collection, storage, reporting, and analysis.

"If they prefer to handle hardware selection and system development internally, we can simply provide the software and train the customer how to use it."

Intepro's offering, called PowerStar, provides simplified drag-and-drop test routines designed to dramatically reduce development of test programs, from single instrument functional control to full test procedures with easy-to-use parameter entries. Engineers can customize their programs without having to write code or assemble graphical components.

The software solution allows for modifications when project requirements shift – as they often do. Over time, the system's hardware components deteriorate or become outdated. Alterations in test project and change of scope parameters ensue. Government contracts may not be renewed or could be entirely terminated. Test specifications undergo modifications, sometimes necessitating a complete reconfiguration of the test. Faced with these types of challenges, a more easily adaptable software like PowerStar eliminates the need to rewrite entire programs from scratch. This can significantly reduce timelines and decrease costs.

While designing an Automated Test Equipment (ATE) system in-house is technically feasible, the process is complex, costly, and time intensive. Experienced ATE providers offer the necessary expertise, enabling companies to bypass the steep learning curve, accelerate development, and optimize resource allocation.

Partnering with a skilled integrator with multi-disciplinary expertise and leveraging fully vetted components and software streamlines development, enhances reliability, and allows engineers to focus on innovation while maintaining cost efficiency.

**For more information, visit www.inteprosystems.com, call (714) 953-2686 or email sales@inteproate.com.**

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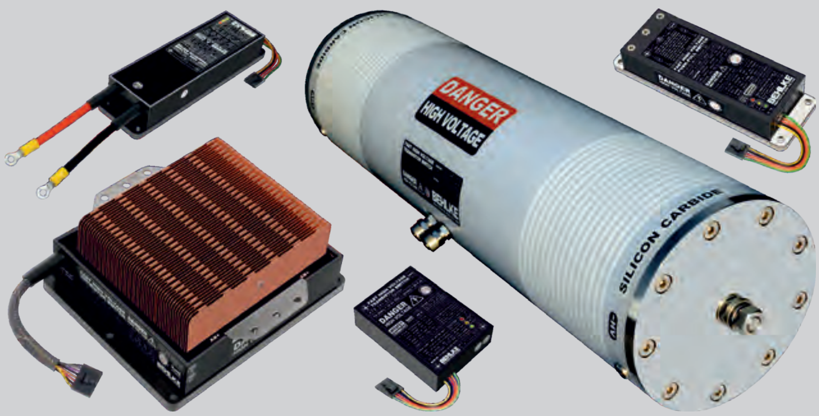


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# Better cooling performance in a compact design

Author: Ralf Hickl, Product Sales Manager in the Automotive Business Unit (ABU) at Rutronik

**For effective component performance, continuous advancements in both MOSFET and package technology are essential. The new OptiMOS series in the SSO10T package is a robust solution for optimizing performance and reliability.**

According to Infineon, more than 120 MOSFETs will be installed in every passenger car with a combustion engine by 2025 [1]. Key drivers of growth are legislation in CO2 reduction, the expansion of driver assistance systems, and applications aimed at enhancing occupant comfort. Reasons enough for suppliers to increase their production capacities and advance MOSFET technology.

### Package and semiconductor chip determine the properties of MOSFETs

The properties of a packaged MOSFET are determined both by the package and the MOSFET die, i.e. the actual semiconductor chip. The overall electrical resistance of the component is the combination of the $R_{DS(on)}$ of the die (chip) and the electrical resistance of the package connection. The smaller the $R_{DS(on)}$ of the MOSFET die, the greater the percentage of the electrical resistance of the package connection in relation to the overall resistance. The respective spice models provide an indication of the distribution of the overall resistance between the actual $R_{DS(on)}$ of the chip and the power resistance of the package. The spice models of Infineon MOSFETs are generally unencrypted and available on the home page.

As soon as current flows through the component, conductivity losses arise according to the following equation:

$$P_{tot} = I^2 \times R_{DS(on)}$$

The resulting heat must be dissipated into the environment. This requires the lowest possible thermal resistance $R_{thJA}$ between the die and the outer surface of the package.

### Efficient cooling is crucial for performance and reliability

In the automotive industry, MOSFET dies are frequently engineered to withstand high temperatures and harsh environments, ensuring they meet the demands of vehicle operation.

Nevertheless, cooling the MOSFETs is crucial for performance and reliability. This is often accomplished through the use of highly conductive materials, optimized heat sink designs, and efficient heat dissipation methods. Top-side cooling is ideal for automotive MOSFETs, as the active components that generate heat during operation are situated on top of the chip. Effective top-side cooling can be achieved using thermal pastes, thermal films, heat sinks, and various other thermal solutions. By dissipating heat from the top-side of the MOSFET, the operating temperature is

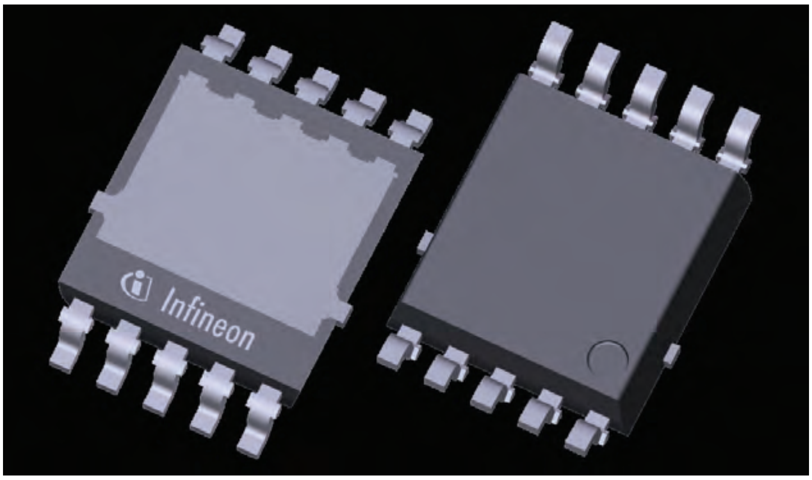


**Figure 1: The SSO10T 5x7 package with top-side cooling (source: Infineon)**

**OptiMOS™6/7 – 40V - SSO10T 5x7 Top Side Cooling Product Portfolio**

| Group | Product | max $R_{DS(on)}$ [mΩ] | $I_D$ (DC current) [A] | $I_D$ (chip limitation) [A] | $Q_G$ typ. [nC] | $V_{GS(th)}$ [LL/NL] |
|---|---|---|---|---|---|---|
| 2 | IAUCN04S7N006T | 0.62 | 165 | 540 | 122 | NL |
| 1 | IAUCN04S6N007T | 0.75 | 120 | 390 | 100 | NL |
| 1 | IAUCN04S6N009T | 0.90 | 120 | 330 | 85 | NL |
| 1 | IAUCN04S6N013T | 1.32 | 120 | 230 | 52 | NL |
| 1 | IAUCN04S6N017T | 1.73 | 120 | 200 | 37 | NL |

**Figure 2: Infineon's product portfolio for 40 V MOSFETs of the OptiMOS 6/7 series with an SSO10T package (source: Infineon)**

**OptiMOS™ 7 - 80V - SSO10T**
**Leading Edge Product Portfolio**

| Group | Product | max $R_{DS(on)}$ [mΩ] | $I_D$ (DC current) [A] | $I_D$ (chip limitation) [A] | $Q_G$ typ. [nC] | $V_{GS(th)}$ [LL/NL] |
|---|---|---|---|---|---|---|
| 1 | IAUCN08S7N016T | 1.6 | 165 | 235 | 20 | NL |
| 2 | IAUCN08S7N019T | 1.9 | 165 | 203 | TBD | NL |
| 2 | IAUCN08S7N024T | 2.4 | 165 | 167 | TBD | NL |
| 2 | IAUCN08S7N046T | 4.6 | 100 | 100 | TBD | NL |

**Figure 3: Infineon's product portfolio for 80 V MOSFETs of the OptiMOS 7 series with an SSO10T package (source: Infineon)**

reduced, thereby improving the performance, reliability, and service life of the component.

To ensure effective component performance, continuous advancements in both MOSFET and package technology are essential. The new OptiMOS-MOSFETs in an SSO10T package serve as a prime example of this (Fig. 1).

In the OptiMOS6 series for 40 V (Fig. 2) and OptiMOS7 series for 80 V (Fig. 3), both featuring an SSO10T package, the dies are contacted in a plane manner using copper clips rather than thin wires. This method ensures excellent thermal and electrical connection between the chip and the package. Heat is mainly dissipated via a contact surface on the top-side of the package.

Thermal interface material (TIM) can be used for the thermal connection to a cooling surface. These films or pastes level out any unevenness and roughness of the surfaces. Depending on the material, the films also provide electrical isolation between the component and the cooling surface. Rutronik stocks thermal interface materials, e.g. from Fischer Elektronik and Innotape.

## High power density – even in limited installation spaces

The advantages of the top-side cooling of MOSFETs are many. In addition to an increase in overall efficiency, more compact designs are possible. This approach allows the thermal flow resulting from the power loss of the MOSFETs to be transferred directly from the component surface to a cooling surface or heat sink. There is no longer a need for diversion through the printed circuit board. This helps reduce the thermal resistance between the MOSFET and the heat sink. The printed circuit board can thus be less complex. Thermal vias and the insulated metal substrate (IMS) embedded in the PCB, which otherwise reduce the heat resistance of the printed circuit board, are no longer needed.

The effective heat dissipation enhances thermal impedance by 20 to 50 percent (Fig. 4), which boosts the operating temperature range or enables the components to achieve greater performance at the same operating temperature. The design also supports higher application currents, which can replace larger packages and provide additional space savings, for example. Top-side cooling in combination with the OptiMOS 40 V family enables higher power densities, which is crucial in applications with limited installation space.

Furthermore, the Infineon SSO10T package is listed as LHDSO-10 JEDEC, which makes it easier to interchange with components from other suppliers. The availability of second sources is a key selection criterion, enhancing the customer's supply assurance for the placement location on the PCB.

Typical automotive applications for top-side cooling MOSFETs are electric power steering, electric brakes, power distributors, and electric auxiliary drives. The design allows for a thermally optimized mechanical construction, resulting in higher power densities and system-level savings. Other suppliers offering MOSFETs with top-side cooling include, e.g., Vishay and Toshiba.

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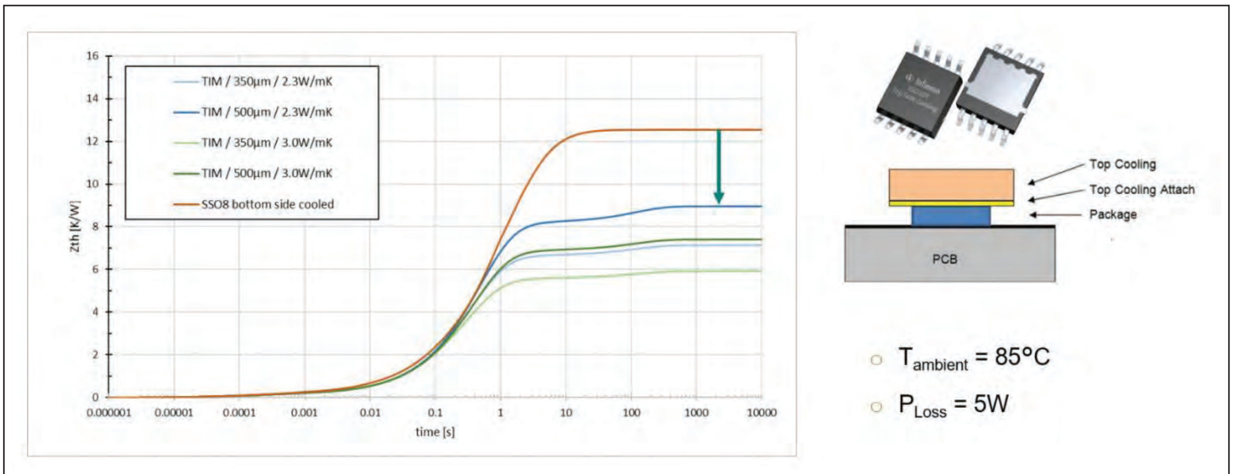



**Figure 4: Comparison of thermal impedance across pulse durations with various thermal coupling methods: Depending on the material and thickness of the thermal interface, the thermal resistance is reduced by 20 to 50 percent (left). Design of the top-side cooling (right) (source: Infineon)**

# An Accurate Active Voltage Positioning Control Reduces up to 50% Output Capacitance for μModule Regulators

Sin Keng Lee, Staff Engineer, and Zhijun (George) Qian, Senior Manager, Analog Devices

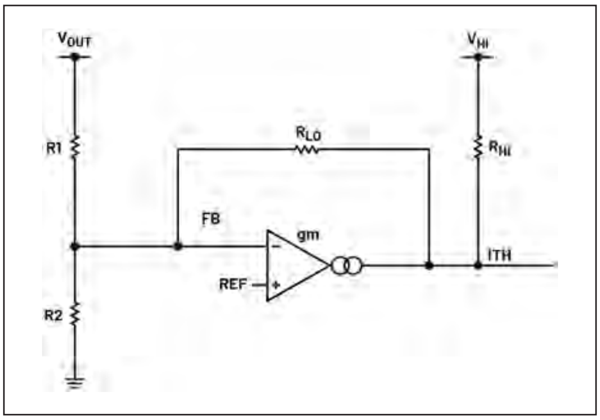
**Abstract**
This article introduces an accurate series active voltage positioning (AVP) implementation method applied on a μModule® regulator. This method achieves a fast load transient response, minimal board space, and an all ceramic capacitor solution. Compared with a shunt AVP design, this series AVP provides a significantly accurate load line accuracy, which greatly improves the output voltage accuracy. The measured results for the load transient response are presented.

**Introduction**
Active voltage positioning (AVP), or active droop technology, regulates the power supply output at higher voltage at light load and lower voltage at heavy load. One major benefit of implementing AVP control is to improve the load transient response and reduce output capacitance since AVP allows more room for the power supply to respond to the load transients. A μModule regulator is a complete, tested, and qualified power supply in a package solution. Fast load transient response, minimal board space, and an all ceramic capacitor solution are preferred by μModule regulator telecom and data centre applications. However, it is challenging to meet all these requirements with traditional non-AVP control.

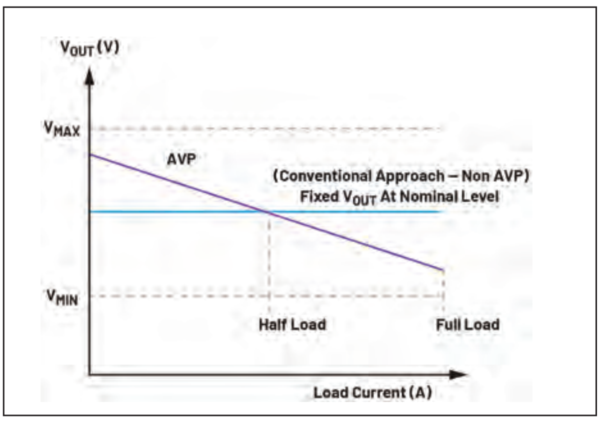
This article introduces an accurate series AVP implementation method by adding two resistors to the feedback control loop. The advantage of this series AVP method is that load line accuracy is almost independent of the gm amplifier gain variations, while other AVP implementation methods like the shunt AVP[1] would suffer from poor load line accuracy if the gm amplifier gain has large variations. After implementing this series AVP, up to 50% output capacitance could be reduced while peak-to-peak output voltage transient is also slightly improved. Only ceramic capacitors would be needed due to 50% less capacitance, which greatly improves system reliability and cost since the aluminum electrolytic capacitor is much less reliable and higher cost than the ceramic capacitor.

Another benefit to implementing AVP control is to lower the output voltage when the load current is large and thereby reduce load power consumption. The LTM4650-2 example shows that the net power savings is 1.4W or 5.6%, which greatly saves power consumption and extends battery life.

**Series AVP Implementation**
AVP refers to the regulator output voltage regulated at a point that is dependent on the load current, while with the conventional approach (non-AVP) that voltage is fixed at nominal $V_{OUT}$ for all loads as shown in Figure 1. With the AVP approach, the output voltage drops gradually when the output current is increased. At light load, the output voltage is set to regulate to slightly higher than the nominal value, while at heavy load, the output voltage is set to regulate to slightly lower than the nominal value.1 When load current suddenly increases, the output voltage starts from a level higher than nominal so the output voltage can droop more and stay within the specified voltage range. When load current suddenly decreases, the output voltage starts at a level lower than nominal so the output voltage can have more overshoot and stay within the specified voltage range. The output voltage should be constrained within the specified voltage limits (between $V_{MAX}$ and $V_{MIN}$) for all load current ranges.




LEFT: Figure 2. AVP series compensation circuit.




LEFT: Figure 1. VOUT with AVP vs. the fixed nominal VOUT of a conventional approach (non-AVP).

Figure 2 shows the AVP series compensation circuit. The internal reference voltage ($V_{REF}$) and $V_{OUT}$ feedback are connected to the positive and negative inputs of the error amplifier, respectively. $V_{HI}$ (or $INTV_{CC}$) connected with $R_{HI}$ supplies the appropriate DC voltage to the amplifier output (ITH or COMP) that keeps the output from going into saturation. $R_{LO}$ (feedback resistor) is placed from the output (ITH) to the negative input (or FB). Therefore, $R_{LO}$ dominates the gm amplifier gain. $R_{HI}$ and $R_{LO}$ values should be much higher than R1 and R2.

The load line Equation 1 is shown as:

$$LoadLine_{AVP} = \frac{\Delta V_{OUT}}{\Delta I_{OUT}} = K_i R_{SENSE} \left[\frac{R_1}{R_{LO}}\right]$$

Ki is the current sense gain, and RSENSE is the current sense resistor value (or inductor DCR value for DCR sensing).

Compared with the AVP shunt compensation circuit1, the advantage of the series compensation circuit is that the load line is dependent on $R1/R_{LO}$ gain and almost independent of the tolerance of the error amplifier transconductance (gm). IC processes and designs are vast. Unfortunately, some ICs' gm values have a part-to-part variation as large as ±30%, plus the shunt compensation circuit AVP has its load line directly proportional to 1/gm gain. As a result, the shunt AVP suffers a poor load line.

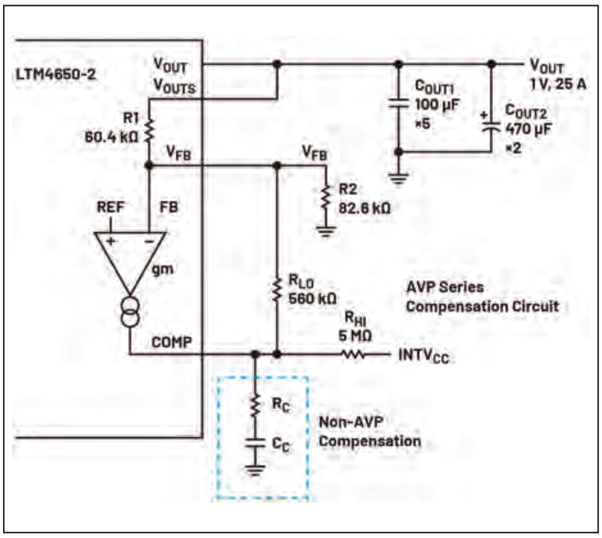
### AVP Solution on the LTM4650-2 Regulator

On the LTM4650-2 (current-mode synchronous buck regulator), a nominal 1V output capable of delivering 25A load with about ±8% (a 160mVp-p) transient window. On this conventional regulator (non-AVP), an external RC filtering circuit is required to achieve fast Type II control loop compensation. There is a bank of 5×100µF ceramic capacitors + 2× 470µF POSCAPs on the output side. With a 19A load step (75% of full load) and a slew rate of 19A/µs, 136mVp-p of the transient response was as shown in Figure 3.

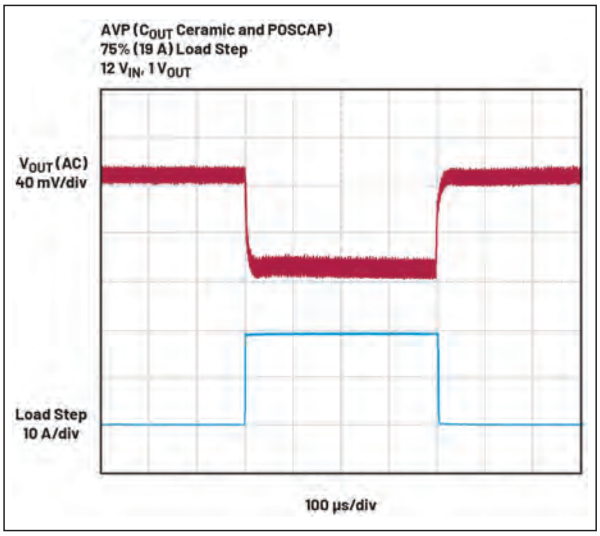
On AVP implementation, an AVP compensation circuit is applied on COMP as shown in Figure 4, but the RC compensation is not required. At the half load (12.5A), purposefully set the output voltage to a nominal value (1V) by fine-tuning the R2. On the load transient response, 95mVp-p of the VOUT was obtained as shown in Figure 5. The transient performance has been improved. With the setting output voltage 1V at 25A (full load), the load power is 25W. By decreasing the output voltage to 0.945V at 25A load, the load power is now 23.6W, and the new savings is 1.4W for a single output. For the two outputs, the total net savings is 2.8W.

With the AVP implementation, the two POSCAPs can be replaced by two ceramic capacitors, so a total of 7× 100µF ceramic capacitors are used on the $C_{OUT1}$. The benefit of using a ceramic capacitor is that it has lower equivalent series resistance (ESR), equivalent series inductance (ESL), cost, smaller size, and more reliable performance. The transient performance has been improved, and the measured result was 104mVp-p of the $V_{OUT}$ as shown in Figure 6.

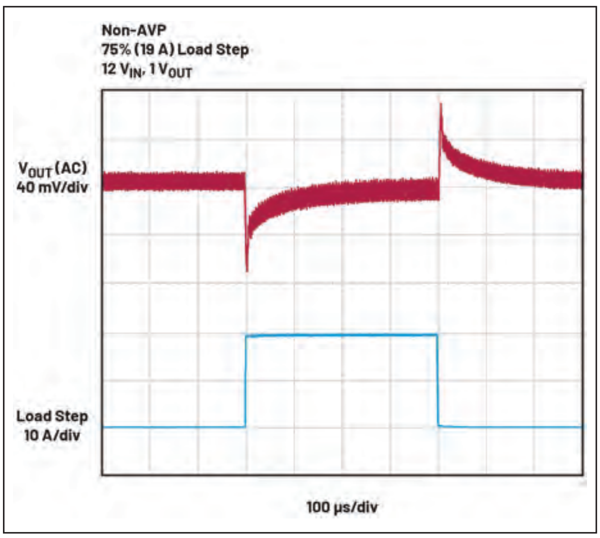
**RIGHT: Figure 4. Circuit with AVP (series compensation circuit).**




**RIGHT: Figure 5. Load transient waveform of Figure 4 circuit with AVP, 95mVp-p output voltage transient. $C_{OUT1}$ = 5×100µF ceramic and $C_{OUT2}$ = 2× 470µF POSCAPs.**




**RIGHT: Figure 3. Load transient waveform of non-AVP circuit, 136 voltage transient, COUT1 = 5× 100µF ceramic, and COUT2 = 2× 470µF POSCAPs.**



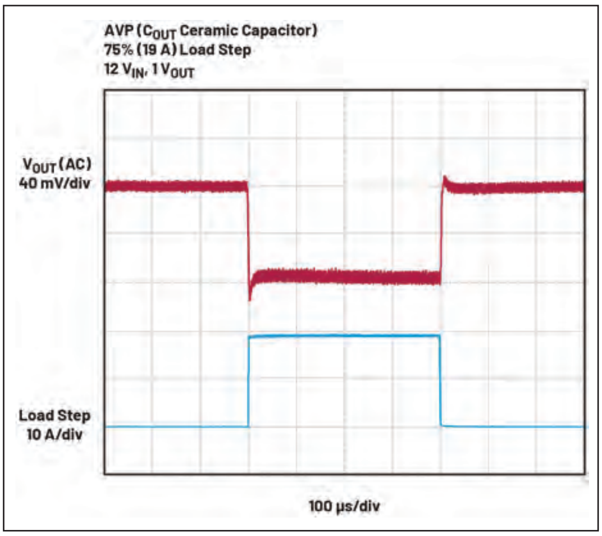



**Figure 6. Load transient waveform of the circuit with AVP, 104mVp-p output voltage transient. COUT1 = 7×100µF ceramic capacitors.**

Table 1 shows the above measured Vp-p of the load transient response of the non-AVP (benchmark), AVP, and AVP using only output ceramic capacitors for comparison.

**Table 1. The Vp-p of Load Transient Response Comparison Between Non-AVP, AVP, and AVP Using Only Output Ceramic Capacitors**

| | Non-AVP 5× 100?F Ceramic Capacitors + 2× 470µF POSCAPs | AVP 5× 100µF Ceramic Capacitors + 2× 470µF POSCAPs | AVP 7× 100µF Ceramic Capacitors Only |
|---|---|---|---|
| Load Transient Response, Vp-p (mV) | 136 | 95 | 104 |

## Conclusion

Implementing the AVP series compensation circuit on the LTM4650-2 µModule regulator achieved an improved transient response performance and lower load-power consumption at high load. Output capacitance of less than 50% is required. Hence, it can replace POSCAPs with ceramic capacitors, reducing cost and minimising circuit board space. This AVP circuit is also applicable for many other ?Module regulators that have an external compensation pin with external RC compensation network (for example, LTM4630-1, LTM4626, LTM4636, LTM8055-1, etc.).

Analog Devices: www.analog.com

## Reference

*1Robert Sheehan. "Active Voltage Positioning Reduces Output Capacitors." Linear Technology, 1999.*

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# PCIM Review

The PCIM Expo & Conference 2025 again proves to be a catalyst for innovation and progress in power electronics

From 6 – 8 May 2025, the PCIM Expo & Conference once again delighted international industry visitors with solutions, presentations, and much more from the world of power electronics. As the central industry platform for pioneering product premieres, innovations, and the latest research findings, the leading expo and conference provided plenty of inspiration for the evolution toward greater efficiency and sustainability in the sector.

For the first time extending over six exhibition halls and 41,500 m? of exhibition space, the event brought together big industry names to drive forward technological developments and unleash the full potential of power electronics. With 685 exhibitors and around 16,500 visitors, this year's exhibition was once more a resounding success. Underscoring the event's global relevance was the strong international presence of exhibiting companies, 62% of which came from outside of Germany – a new record. Besides promoting international dialog, this gave attendees a comprehensive overview of the global market.

433 high-calibre presentations on the latest research topics gave the 818 attendees from 26 countries the chance to delve deeper into the world of power electronics and discover and discuss the latest research findings and technological advances.

Varied supporting program offering concentrated expertise

All three days of the exhibition were accompanied by a highly focused, specialized program of presentations covering current topics in the industry, such as decarbonization.

Across the three stages of the PCIM Expo, attendees were able to discover more about solutions for electromobility and energy storage, product innovations, and research progress, and speak directly to the experts. The varied presentations also demonstrated the broad applicability of power electronics across numerous industries, including industrial electronics, automation, and drive systems.

The strong response was reflected in the positive atmosphere: "The company has been exhibiting here for 20 years for the simple reason that we think that PCIM is one of the most important exhibitions for power electronics in the world. We've checked fairs in other countries, but we've not found any equivalent to the PCIM. This Expo has a deep, uncompromising focus on power electronics. And even after 20 years, we continue to meet new contacts within the community whether customers, leads, suppliers or engineers – they're all here over three inspiring days – year after year!" as Karim Zaibat, Business Manager, Cefem Industries, stated.

This sentiment was echoed by Thomas Neyer, Senior Vice President, Infineon Technologies: "The PCIM is much more than a conference - it offers space for dialog, international partnerships and innovative forms of collaboration across company boundaries."

Focus on industry trends: Current challenges and practical solutions

This year's PCIM Expo & Conference once again addressed key topics that are impacting the entire power electronics industry, such as improving energy efficiency, system integration, and the increased use of new semiconductor materials.

The event offered both industrial and scientific perspectives and demonstrated how research and practice work hand in hand to translate current challenges into innovative solutions.

Pietro Scalia, Sr. Director, Renesas Electronics added: "Our time at the PCIM is full of highlights – expected and unexpected ones! For us at Renesas, it is three days of valuable encounters starting at breakfast, all through the day and going on well into the evening. ¶

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# Driving innovation in power-supply designs with integrated TOLL-packaged GaN devices

Srijan Ashok – Product Marketing Manager, Texas Instruments


Today's power-supply designs require high efficiency and power density. As a result, designers are using gallium nitride (GaN) devices across various power-conversion topologies.

GaN can enable high-frequency switching, which reduces the size of passives and therefore increases the density. GaN also lowers switching, gate-drive and reverse-recovery losses compared to technologies such as silicon and silicon carbide (SiC), which increases the power design efficiency.

You can use 650V GaN FETs for the AC/DC-to-DC/DC conversion, or 100V or 200V GaN FETs for DC/DC conversion to implement the power supplies.

If you work on cutting-edge products, it is also important to choose devices with an industry-standard footprint in order to streamline the supply chain for procurement teams. For this reason, in the 650V space, the transformer outline leadless (TOLL) package is gaining popularity in high-power-supply designs.

Apart from choosing industry-standard devices, integrated devices such as TI's LMG3650R035 GaN field-effect transistor (FET) can play a major role in creating designs with high density and reliable operation across various power topologies. This device has an integrated gate driver, and protection circuitry such as overcurrent protection, overtemperature protection and short-circuit protection. The integration of protection circuitry helps reduce external components to implement these features. The device can also support multiple power topologies in the high-voltage space, including totem-pole power factor correction (PFC), inductor capacitor, phase-shifted full bridge and dual active bridge.

Integrating the gate driver helps you create a simple, high-density and clean layout with significantly reduced parasitic coupling, as illustrated in Figure 1. Integration becomes especially important in high-switching- frequency power conversion because circuit parasitic coupling in the gate loop causes an increase in gate noise and overlap losses. By using integrated power stages, the parasitic coupling becomes negligible and simplifies layouts.

## Application areas of the TI high voltage TOLL devices

Let's review several major application areas for TI's TOLL devices where you can leverage the integrated protection features, integrated zero-voltage detection (which reduces third-quadrant losses), and the reduced overlap switching losses caused by negligible parasitic coupling.

### PSUs for data center and telecommunication power

As demand for data centers and hyperscale computing increases, the need to create highly efficient, power- dense power-supply units (PSUs) will grow exponentially. Even as the telecommunications space moves from 4G to 5G – and now 6G – the power requirements of the equipment keep increasing, but the form factor remains the same.

This scenario becomes a potent use case for integrated 650V TOLL devices, which primarily convert AC power into a DC bus through the PFC and DC/DC stage, as shown in Figure 2. Our GaN

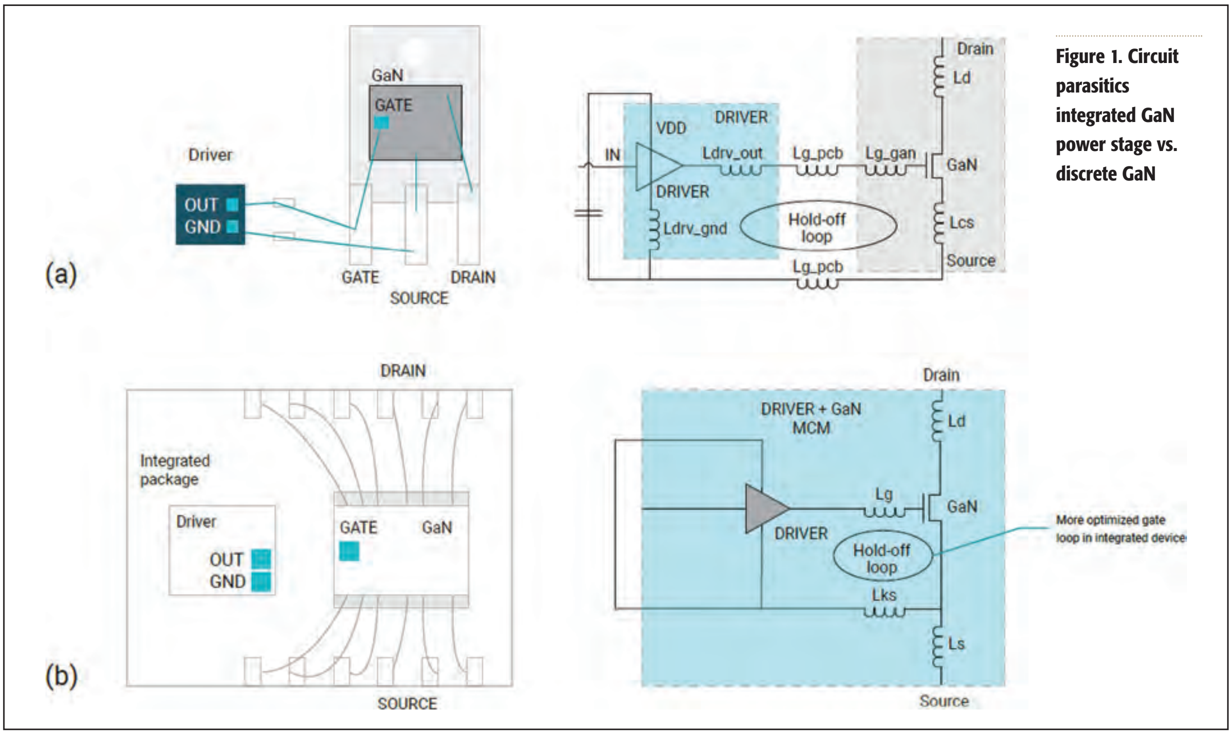
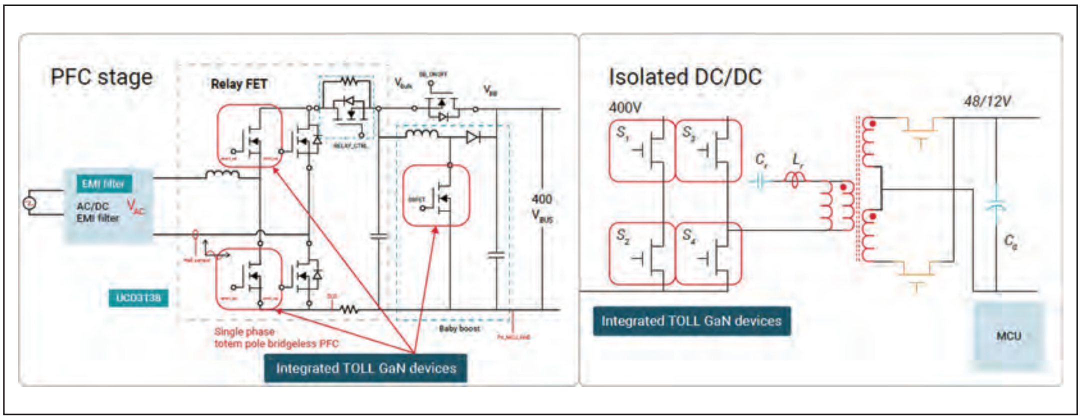



**Figure 1. Circuit parasitics integrated GaN power stage vs. discrete GaN**

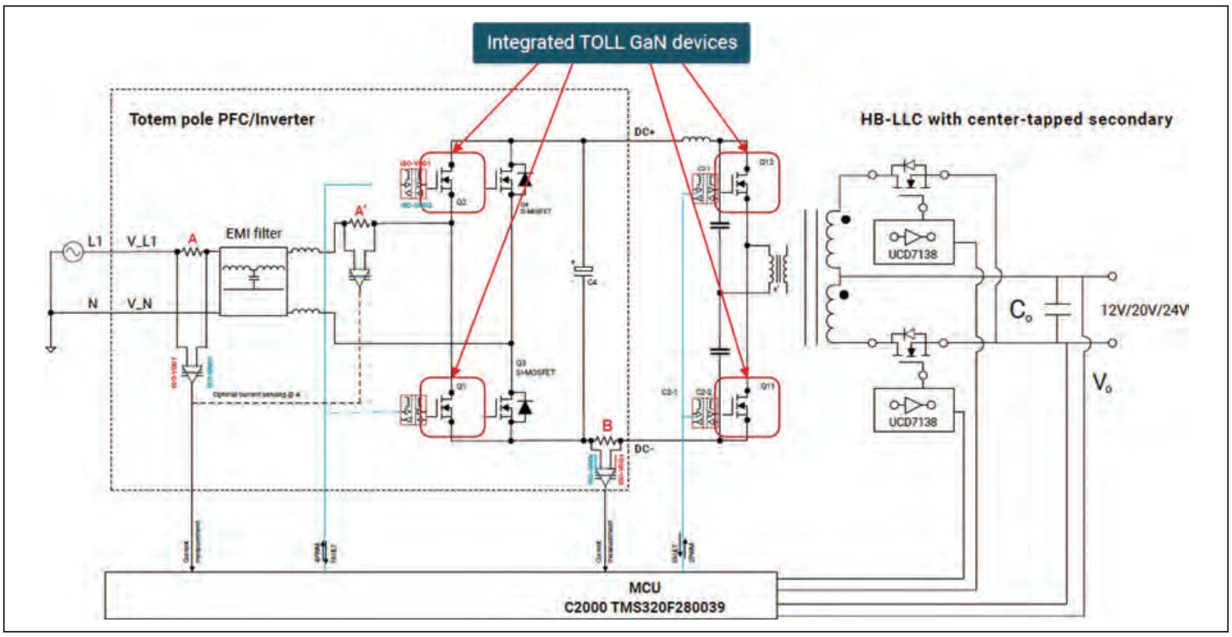
devices in the TOLL package can achieve greater than 99% efficiency in the PFC stage and greater than 98% efficiency in the DC/DC stage across the topologies I mentioned earlier.

## Solar microinverters

Solar energy as a power source is on the rise. As shown in Figure 3, both the bidirectional DC/DC and the PFC and inverter stage can use an integrated GaN TOLL device to convert the solar panel




**LEFT: Figure 2. PSU block diagram**




**BELOW: Figure 3. Microinverter block diagram**

voltage to AC power.

As clean energy requirements scale rapidly, it's important to deliver high efficiency and high power with a small footprint using industry-standard devices.

A TOLL GaN device can add value with an industry-standard footprint and integrated features. These devices can help you scale to different power levels and with different topologies using different drain-to-source on- resistances while not struggling with layout, since most sensing and optimization features are integrated in the power stage.TV power supplies

There is sizeable growth potential in the large-screen (>40 inch) television market, as well as a trend toward lighter and thinner screens for aesthetic reasons. Because the power requirements increase with larger screens but the size is thinner, it's important to make televisions more power efficient. AC/DC conversion can use the TOLL devices in the PFC and DC/DC stage.

Integrated TOLL GaN devices enable you to keep the size of the passives the same and keep the external circuitry to a minimum with simple routing to deliver thinner printed circuit boards. The design will also be more efficient, while sticking to an industry-standard footprint.

## 2W, 3W and 4W onboard chargers

Vehicle electrification is always in the news as the world strives toward reducing tail-pipe emissions. Easy access to on-the-go charging necessitates electric vehicle onboard chargers (OBCs). Because its location in an electric vehicle is in the chassis, an OBC should be power dense and efficient in order to occupy minimal space and reduce losses, as there is no active cooling to dissipate losses.

Figure 4 shows a typical OBC block diagram. An integrated TOLL GaN device can help both the PFC and DC/DC stage by optimizing design size through integration and a higher switching frequency, and reduce losses (gate drive and switching losses) for more effective heat dissipation. With TOLL GaN devices, at the device level all protections are enabled as well, which will help with the resiliency of the OBC design while keeping an industry-standard footprint.

## Conclusion

One of the biggest design challenges that a power designer of the future will face is to deliver ever increasing power levels at the lowest possible losses with a high-density design. An integrated TOLL GaN device helps here by combining integrated GaN with an industry standard footprint and eliminates the hassle of extra circuitry and complicated PCB layouts. This helps in making the design less cumbersome. Additionally, this will also enhance designs in other end equipment spaces such as motor drives, industrial power supplies and appliance power who also value simple, high density designs.

With the GaN FET technology making leaps, we will keep investing and improving the figure of merit of the TOLL devices in the future, aiding the designers endeavor to deliver even higher power in the same space.

## Additional resources

- Check out the LMG3650R035 Evaluation Module EVM User's Guide.
- Learn more about LMG3650EVM-113 evaluation module.
- Learn more about our GaN technology.

## Trademarks

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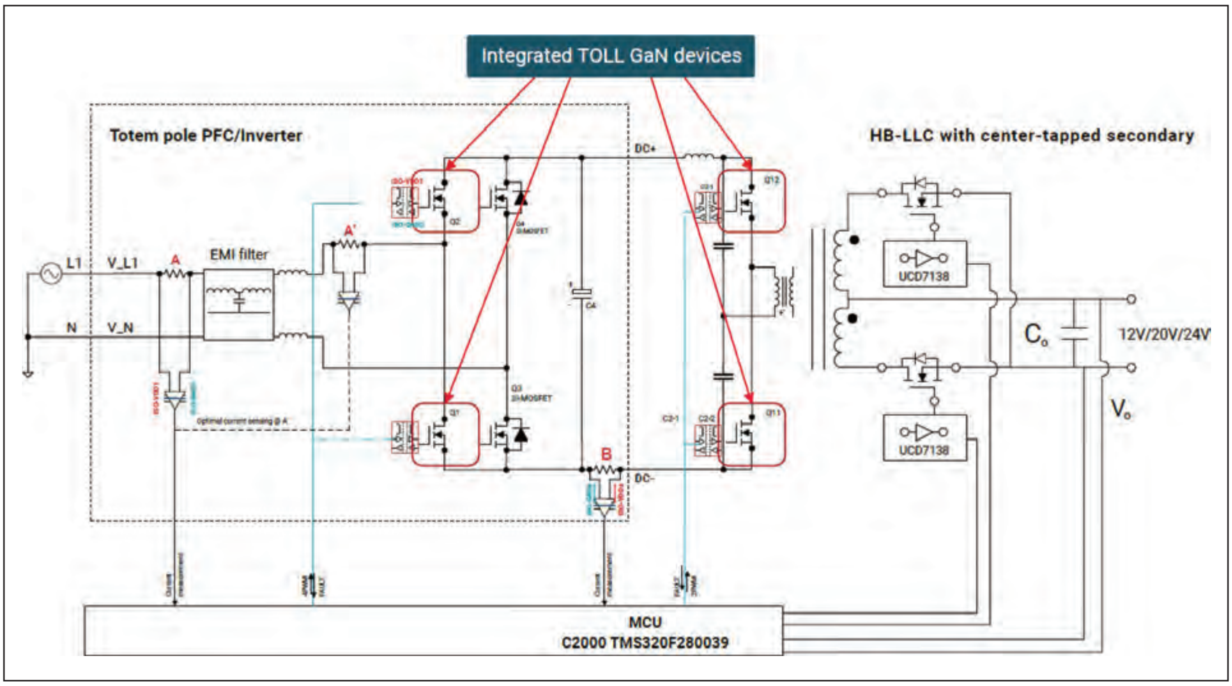


Figure 4. Onboard chargers

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# Power modules accelerate the path from 800V to 48V SELV in automotive

The BCM6135 DC-DC converter module enables unprecedented EV power design innovation

By Patrick Wadden, Global Vice President of the Automotive Business Unit at Vicor Corporation

The electrification of automobiles is one of the toughest power challenges of our time. At the heart of these increasingly complex electrical systems is the 800V battery and the power conversion challenges it presents. In parallel, OEMs are moving from 12V distribution network to 48V bus to capitalize on the greater efficiency that results from lower current, more power and a lighter wire harness /cabling.

So, there are multiple moving parts and the path to the perfect power delivery network (PDN) is laden with trade-offs.

For example there is a robust ecosystem of 12V loads that have been commoditised for automobiles over the decades that are not compatible with 48V. But the benefits of moving to 48V are undeniable. For example, the 12V wiring harness, one of the heaviest subsystems in today's vehicles, can be reduced dramatically moving to 48V. It is comprised of thousands of copper wires totalling over a mile in length and weighing as much as 150 lbs (68kg). Distributing power at 48V means moving to 10 AWG wiring that is less expensive and up to 85% lighter than a conventional 12V harness. This reduces size, weight, costs and design complexities. It's an indisputable win with no significant downside.

Driving the move to 48V are power-hungry loads, such as active suspension, which has a storied history of overwhelming power engineers. 12V has never been enough to adequately power active suspension, nor many other sizable loads found in today's vehicles. 48V combined with high-density DC-DC power modules will change the way power engineers view this one-time albatross. 48V is making it easier to power heated windscreen, power-assisted steering and braking, plus a host of pumps, fans and actuators. Together 48V and power modules will help power engineers innovate more than ever.

## Solving the high-voltage 800V to SELV power challenges

Converting from 800V to the SELV— or 48V nominal and below — can be complex. The architecture needs to operate at high efficiency and ensure safe operation with adequate cooling. Rapid transient response times are another important feature for many subsystems, delivering the ability to adapt to rapid changes in load while maintaining stability. This helps to ensure safe operation of loads like braking and steering where any delay can become a serious safety risk.

Conventional DC-DC converters can deliver power without the need for an intermediate battery, but the trade-off is that they are bulky and lack the fast response time required to meet the power draw by the wide variety of subsystems that require redundancy.

The high-density power module is an alternative to a traditional DC-DC converter that is having a big impact in EV power system design today. Its planar design, specialized magnetics and advanced packaging supports high efficiency, rapid response time and a very small footprint. The Vicor BCM® bus converter technology delivers low path impedance and fast response time, transforming the high voltage battery into something that can simulate a 48V or 12V battery, thus eliminating the need for intermediate energy storage. BCMs provide 98% peak efficiency and are capable of delivering up to 65A (over 3000W) of power continuously. These characteristics can support a broad spectrum of high-power PDNs in a vehicle.

## BCM DC-DC fixed-ratio converter perfect problem solver for EVs

Unlike a conventional converter, which regulates the input voltage range to a specific output voltage, a BCM converter is a fixed-ratio converter where the output voltage is a fixed fraction of the input voltage, known as the 'K factor'. Operation is in three stages: primary-side switching

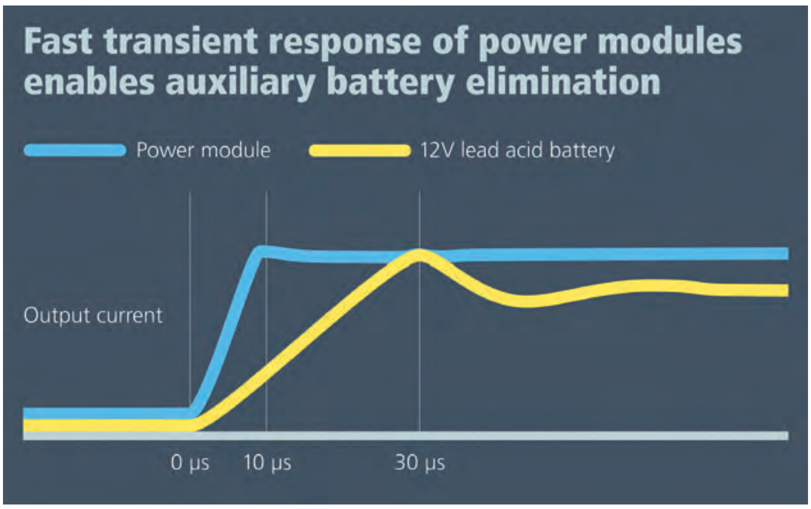


**Figure 1 The Vicor BCM® bus converter technology delivers low path impedance and fast response time, transforming the high voltage battery into a "virtual low voltage battery" that can simulate a 48V or 12V battery, thus eliminating the need for intermediate energy storage. BCMs provide 98% peak efficiency and are capable of delivering up to 65A (over 3000W) of power continuously. These characteristics can support a broad spectrum of high-power PDNs in a vehicle.**

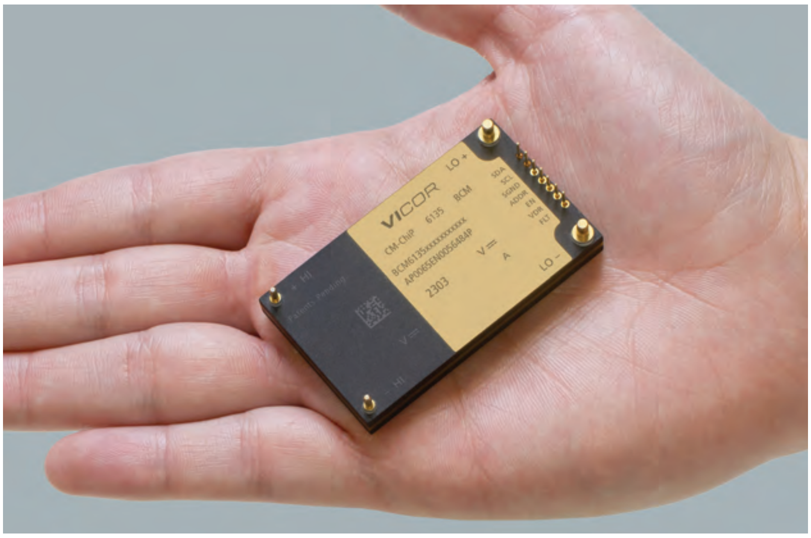


**Figure 2 The BCM6135 is a fixed-ratio converter supporting 800V to 48V conversion. The family of BCMs are inherently bidirectional, enabling even more opportunity to innovate a variety of subsystems throughout the vehicle. With the BCM designers can reduce the amount of bulk capacitance needed at the load by effectively 'reflecting' the capacitance across the module based on the specified K factor. BCMs are high density, high performance automotive grade converters used in today's most innovative active suspension systems.**

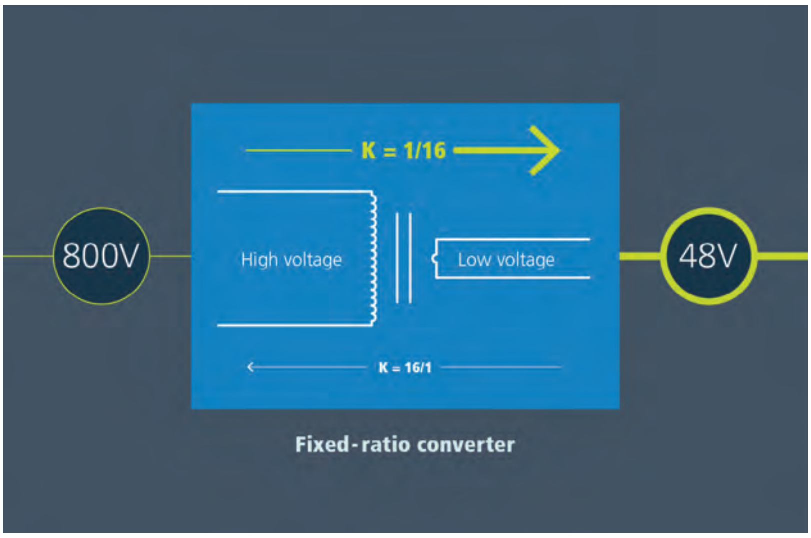


**Figure 3 The BCM is a fixed-ratio converter supporting 800V to 48V conversion with various K factors to suit a wide range of applications and markets. Based on a proprietary Sine Amplitude Converter (SAC™) topology, high-voltage BCMs can reach peak efficiencies up to 98% and achieve power densities up to 2,400W/in?. These flexible modules can be easily paralleled into high-power arrays and outputs can be put in series to achieve a higher output voltage.**

converts DC input into a sinusoid, an ideal transformer stage scales the voltage by the ratio of the turns between the primary and secondary side, and secondary-side switching converts the sinusoid into a DC output.

The BCM family converts from 800V to 48V inputs with various K factors to suit a wide range of applications and markets. Based on a proprietary Sine Amplitude Converter (SAC™) topology, high-voltage BCMs can reach peak efficiencies up to 98% and achieve power densities up to 2,400W/in?. These flexible modules can be easily paralleled into high-power arrays and outputs can be put in series to achieve a higher output voltage. Additionally, BCMs are inherently bidirectional, enabling even more opportunity to innovate subsystems throughout the vehicle. BCMs also enable designers to reduce the amount of bulk capacitance needed at the load by effectively 'reflecting' the capacitance across the module based on the specified K factor.

Additionally, zero-current switching (ZCS) and zero-voltage switching (ZVS) topologies minimize losses. The ability to perform either a step-down conversion from high voltage to low, or step-up from low to high enables the BCM to symmetrically convert power with the same efficiency and quantity in either direction. This makes the approach well suited for applications in automotive where there is rapid charging and discharging from a vehicle power load, such as active suspension.

ZCS/ZVS switching also enables BCM converters to operate at higher frequencies than conventional converters, providing a fast response to changes in load currents and a low impedance path from input to output. Transient response times of eight million amps per second can be achieved compared with the 250A per second times when using conventional techniques.

This fast response, combined with fixed-ratio conversion, bidirectional operation and a low impedance path, enables a BCM to serve as a virtual battery, while offering reduced cable weight using lighter 10 AWG wiring. This is important because power still needs to be distributed across a vehicle's subsystem to a mix of 48V and 12V loads. The BCM is an essential element to optimizing zonal architecture that extends 48V distribution around the vehicle before converting to 12V loads

### BCM6135 enables 50% size reduction of active suspension power system

The BCM6135 has been instrumental in optimizing a historically problematic PDN. Active suspension has been a notoriously heavy, power-intensive system that is costly to design. It has plagued power designers for decades.

However, with the combination of larger primary batteries, a 48V bus and miniature DC-DC power modules, active suspension systems can be optimized like never before.

Today Hongfa, an automotive tier-one supplier, is working with Vicor to develop 800V-48V DC-DC converters to build the ultimate active suspension system. The PDN capitalizes on 48V coupled with Vicor power modules to reduce overall size and weight. Further, it takes advantage of the BCM6135 power density to achieve a system box volume under 1.8l, and it leverages the BCM's bidirectional power capacity to support regenerative power loads. This power design is the smallest active suspension system today – nearly half the size of the nearest competitor.

One of the greatest benefits of linking active suspension directly to the battery is energy recuperation. Similar to how a spring can absorb and expend energy, active suspension can absorb energy that be stored in the battery. While this can technically be done via a DC-DC converter, few manufacturers are able to design a

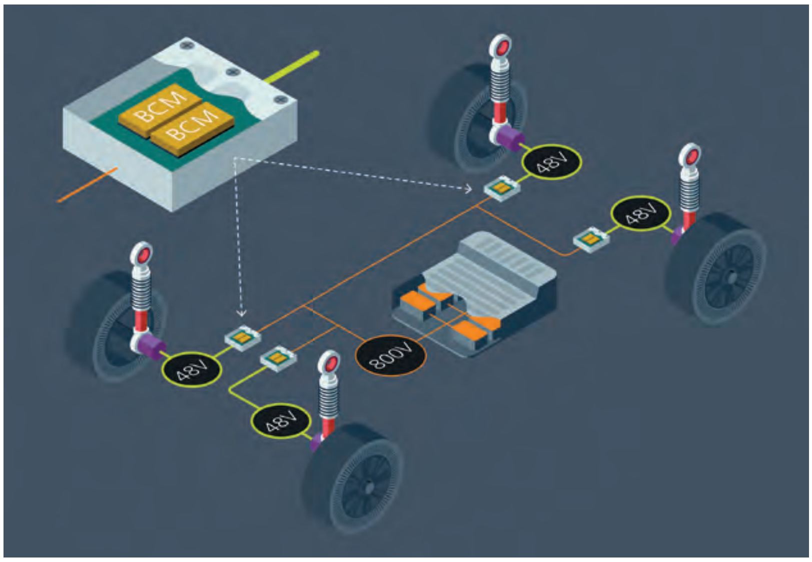


**Figure 4 BCM6135 enables active suspension power system size to be reduced by half. Active suspension has been a notoriously heavy, power-intensive system that is costly to design. It has plagued power designers for decades. Today Hongfa, an automotive tier-one supplier, is working with Vicor to develop 800V-48V DC-DC converters to build the ultimate active suspension system. The system capitalizes on 48V coupled with Vicor power modules to reduce overall size and weight.**

system with a fast enough transient response, high slew rate, and power efficiency to manage bidirectional power flow between a device and its power source…until now.

The BCM6135 high slew rate (eight million amps per second) enables the fastest bidirectional power transfer for energy recuperation for active suspension systems. Using power modules from Vicor, Hongfa has designed the most advanced solution for powering active suspension. Not only are the Vicor DC-DC converters capable of matching the power and transient requirements to optimize energy recuperation, they also offer the highest power density in the industry enabling OEMs to reduce the overall system footprint.

### Vicor BCM6135 poised to solve a wide variety of EV power dilemmas

The Vicor BCM power modules embody the characteristics power engineers are seeking to solve complicated power problems. The BCM6135 is light-weight, power-dense, bidirectional and extremely fast— features needed to solve this decades-old, active suspension power problem. A0nd this is just the beginning.

Vicor power modules enable new levels of scalability and flexibility, high efficiency and passive cooling. Power modules help reduce component count and simplify automotive power engineers' most complex problems. The BCM6135, a compact DC-DC converter module, is the perfect a problem-solving product for today's engineers trying to find better solutions in the rapidly-changing world of automotive electrification.

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# Smart Energy Grid: Precision Timing for Energy Infrastructure Resilience

by Rich Kapusta, VP, Segment Marketing, SiTime

The winter storm Uri hit the heart of Texas in February 2021, knocking out power for roughly 4.5 million residents. 210 citizens died as a result of the storm and the financial losses are estimated at $80 to $130 billion. There were many causes for the disruption in power, ranging from generation unit outages to troubles in transmission and distribution, including a maximum load shed and the lowest grid frequency ever experienced in the state. Uri is just one example that underscores the importance of a resilient energy infrastructure. As extreme weather conditions become more common, continuity of service during system stress is never more important.

Today's power grids are complex with a wide mix of energy sources, including gas, coal, nuclear, wind and solar. This is overlayed by a dizzying array of technologies involved in power production, storage and transmission and distribution. These technologies and the data signals moving through them must be precisely synchronized. One weak link in the infrastructure can disrupt power access for households and businesses.

To better ensure reliable power access, the power grid is becoming smarter. Cutting edge sensors, processing power, advanced communications and more are enabling more efficient and resilient power grids. This article focuses on how timing devices are critical components of a smart energy grid to keep the power flowing.

## Why the Existing Power Grid Is Fragile

The power grid is fragile due to aging infrastructure, centralized design and an inability to meet modern energy demands. Built decades ago, many components are deteriorating and prone to failure. A centralized structure creates single points of failure, where issues at major nodes can trigger widespread outages. External threats like extreme weather and cyberattacks targeting outdated systems increase the fragility. Additionally, the grid struggles to integrate renewable energy sources like solar and wind, highlighting its inability to adapt to modern energy needs.

Demand figures into a power grid's resilience. Operators must maintain grid frequency within a narrow tolerance (e.g., ±0.050 Hz from 60 Hz in North America or 50 Hz in Europe). The Electrical Reliability Council of Texas (ERCOT), the organization who manages the Texas grid, warns that prolonged frequency deviation can rupture AC connections and damage equipment. In fact, high demand exceeding supply causes frequency drops, forcing power plant shutdowns or blackouts, while low demand with high supply raises frequency, requiring supply cuts. These vulnerabilities leave the grid ill-equipped for a more electrified future.

In the case of Uri, the demand for power was up due to the freezing temperatures. The frequency of the grid on February 15 was below 59.4 Hz for four minutes and 23 seconds. "The entire system was within minutes of collapse, which would have required a 'black start' that could have taken days if not weeks (or even months) to implement. To restart would require a slow process of starting individual plants and then building the grid back up gradually," states the paper Cascading Risks: Understanding the 2021 Winter Blackout in Texas in Energy Research & Social Science.

### What Is a SmartGrid?

A smart grid is an advanced energy network that integrates modern communication and automation technologies to optimize the generation, distribution and consumption of electricity. Unlike traditional grids, it enables two-way communication between energy providers and consumers, allowing real-time monitoring, demand management and fault detection. Smart grids support the integration of renewable energy sources, such as solar and wind, enhancing sustainability and reducing reliance on fossil fuels. They also improve energy efficiency, reliability and resilience by quickly identifying and addressing outages or imbalances. By leveraging sensors, data analytics and control systems, smart grids create a more adaptive and intelligent energy infrastructure tailored to meet evolving energy demands.

### How Timing Chips Enable Smart Grids

Timing chips are crucial in a smart grid because they provide precise synchronization for communication, data processing and control across the grid. Accurate timing ensures that distributed energy resources, such as renewable energy systems and energy storage, can seamlessly integrate and coordinate with the grid's operations. They enable real-time monitoring, fault detection and load balancing, which are essential for maintaining grid stability and efficiency. Furthermore, timing chips support secure and reliable communication between electronic devices, reducing latency and minimizing errors in critical grid operations, making them a foundational component of smart grid infrastructure.

Timing chips are essential for:

■ Grid Data Synchronization: Precise synchronization of data transmission across the grid, enabling seamless coordination between energy generation, distribution and consumption.
- SiTime Super-TCXOs
- SiTime Epoch Platform™ OCXOs

■ Frequency Stability: Precise frequency of the grid (e.g., 50 Hz or 60 Hz) ensures stability even during fluctuations in energy supply and demand.
- SiTime Super-TCXOs

■ Fault Detection and Response: Accurate timing is critical for identifying and responding to faults in milliseconds, preventing outages from cascading through the grid.
- SiTime Super-TCXOs

■ Integration of Renewable Energy: Timing devices help manage the variable output of solar and wind energy by synchronizing storage systems and grid operations.
- SiTime MHz Oscillators

■ Real-Time Data Communication: Precision timing supports real-time monitoring and control, allowing utilities to make quick, informed decisions.
- SiTime Cascade Jitter Cleaners
- SiTime Chorus™ Clock Generators

■ Energy Efficiency: Timing chips enable efficient load balancing by aligning energy delivery with real-time demand, reducing waste and improving overall grid performance.
- SiTime kHz Oscillators
- SiTime MHz Oscillators

■ Energy Storage: Timing chips enable precise synchronization and communication in energy storage systems, optimizing performance, efficiency and integration with the power grid.
- SiTime MHz Oscillators

■ Cybersecurity: Timing devices are essential for securing communication protocols and ensuring the integrity of data across smart grid systems.
- AN10052 IEEE 1588 Precision Time Protocol (PTP) in ITU-T Standards

### Why Choose SiTime for Smart Energy Grid Applications

SiTime precision oscillators incorporate MEMS resonators and advanced analog circuitry, superseding traditional quartz-based oscillators for smart energy grid applications including advanced sensors that monitor grid performance, voltage fluctuations and other critical parameters.?Timing devices are critical in communication networks transmitting data between various grid components, enabling real-time control and optimization. They are also optimal solutions for storage applications such as, energy storage systems (ESS) and battery management systems (BMS).

SiTime precision timing devices are highly robust and more resistant to environmental stressors than competing quartz devices. These stressors can include temperature fluctuations, vibration and mechanical shock, which are common in field-deployed grid equipment. MEMS durability enhances the reliability of smart grid systems, especially in outdoor or harsh environments. Additionally, MEMS timing devices are smaller, lighter and more energy-efficient than quartz oscillators, aligning with the design goals of compact and energy-conscious grid equipment. As smart grids evolve to become more complex and interconnected, the growing adoption of MEMS precision timing technology is expected to drive greater efficiency and resilience in timing-critical smart energy grid systems.

https://www.sitime.com/


**SiTime offers precision timing products for energy grid applications. For instance, the SiTime Super-TCXOTM is used for precise synchronization of data transmission, frequency stability and fault detection and response.**

# For the mobility of tomorrow

Traction inverters are crucial for the performance and efficiency of modern electric and hybrid drivetrains. Especially for the increasingly popular micromobility market, they must meet special requirements in terms of their size, weight, efficiency, and costs. Rahul Naik, Field Application Engineer in the Automotive Business Unit (ABU) at Rutronik

Micromobility refers to lightweight, often electrically powered, transportation designed for short distances in urban environments. Prime examples include e-scooters, e-bikes and e-skateboards. Due to their efficiency, comfort, and environmental friendliness, these mobility solutions have become very popular – especially for distances that are too far to walk comfortably but too short for conventional vehicles.

The traction inverter is a key component in the drive system of electric vehicles. It converts direct current (DC) from the vehicle battery into alternating current (AC), which powers the electric motor to drive the wheels. The traction inverter also manages the flow of current from the battery to the motor, controlling speed, torque, and regenerative braking. It plays a crucial role in determining the overall performance, efficiency, and responsiveness of the vehicle.

## Lightweight, compact, and cost-efficient

Micromobility places special demands on traction inverters – they have to be compact, lightweight, and capable of efficiently managing the power needs of the small electric motors. Technological advancements have propelled the development of traction inverters, resulting in smaller, lighter, and more efficient designs. Traditionally, bipolar traction inverters with an insulated control electrode (IGBTs) based on Si technology were used for power conversion. The use of semiconductors with a wide-bandgap offers improvements in terms of efficiency and thermal behavior: Modern materials such as silicon carbide (SiC) and gallium nitride (GaN) enable higher switching frequencies, lower power losses, and greater power density. Additionally, effective cooling methods are necessary to maintain optimal performance and reliability under demanding operating conditions. The challenge of dissipating the heat generated during operation has been solved by advances in thermal management.

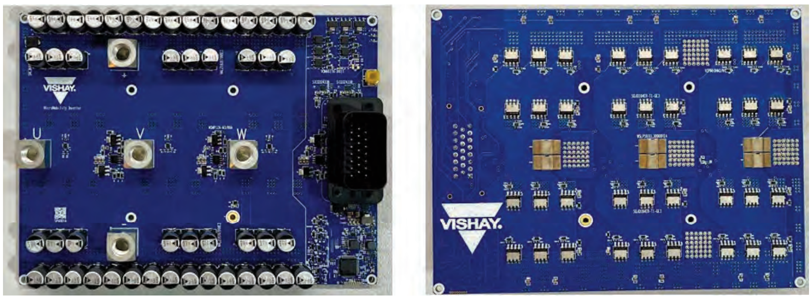

**Figure 2: Printed circuit board of the traction inverter. Upper side with the DC link capacitors MAL218397998E3 (left). The surface-cooled MOSFETs are located on the underside of the PCB. The Power Metal Strip resistors WSLP5931 (right) are located in the center (source: Vishay)**

## Reference designing as a team

Together with its partner Vishay, the Automotive Business Unit at Rutronik has developed a traction inverter that meets the requirements of 48 V micromobility (Fig. 1). A decisive step was selecting the right components. In addition to current market requirements, the term “micro” also implies size requirements. Besides installation space, factors such as compatibility, heat dissipation, mechanical load, and component life cycle were also considered when selecting the components.

The result is a model implementation of a universal traction inverter designed for 48 V electrical systems for drivetrains in lightweight L7e electric vehicles (four-wheeled vehicles with a maximum power output of 15 kW and a maximum speed of more than 45 km/h) and lower.

The reference design is based on cutting-edge, high-performance components such as power MOSFETs, TVS diodes, switching diodes and rectifiers, capacitors, resistors, NTC and PTC thermistors, as well as input filters (inductors and EMI filters). The 48 V traction inverter has a continuous power output of 10 kW and a peak power output of 15 kW. The single PCB design reduces the complexity of the overall system.

The reference design demonstrates the circuit structure (Fig. 2) and the suitability of the selected components for the application (Table 1). As such, it serves as a customer guide for selecting components when developing a similar charger.

**Figure 1: Prototype of the traction inverter (source: Vishay)**

## Traction inverter offers new opportunities

The effects of traction inverter technology extend well beyond individual vehicles, shaping the entire landscape of electric mobility. As electric vehicles become more prevalent, economies of scale and technological advancements will lower the

| Type/Series | Description | Properties | Advantages |
|---|---|---|---|
| SQJQ184ER | TrenchFET Automotive N-Channel MOSFET | 80 V, low $R_{DSon}$, low $R_{thJC}$, top-side cooling, AEC-Q101 | Automotive quality, low power loss, direct heat dissipation from the top, no heat dissipation through the PCB required, simple printed circuit board material, fewer vias |
| WSLP5931, Power Metal Strip | Shunt resistor | AEC-Q200, low TCR (temperature coefficient of resistance), low thermoelectric voltage | Automotive quality, direct measuring principle with linear transfer function, insensitive to stray magnetic fields, no saturation effects during/after overcurrent |
| SiPQ32433B | eFuse IC with adjustable and precise overcurrent limitation | AEC-Q100, short response time, adjustable switch-on edge | Automotive quality, resettable fuse, fast triggering characteristic protects voltage source and electronic loads |
| 183CPHT | Hybrid polymer aluminum capacitor | AEC-Q, 125 °C, vibration resistance up to 30G, low ESR | Automotive quality, suitable for harsh environments, low self-heating, SMD can be populated |
| VOMA617A | Optocoupler with phototransistor output | AEC-Q101, high current carrying capacity, small flat package, 3,750 V RMA isolation voltage | Automotive quality, direct control by microcontroller possible, low space requirement on the printed circuit board |

**Table 1: Properties and advantages of the components used for the reference design**

costs of traction inverters and make electric drives more accessible to consumers. At the same time, there is increasing demand for specialized traction inverters tailored to the unique needs of micromobility vehicles, including size, weight, efficiency, and costs, while delivering the performance and reliability necessary for urban traffic.

Moreover, the electrification of transport opens up new opportunities for grid integration and demand management. Bidirectional charging functions enabled by traction inverters allow electric vehicles to act as mobile energy storage devices, feeding energy back into the grid during peak load periods or providing backup power in emergencies.

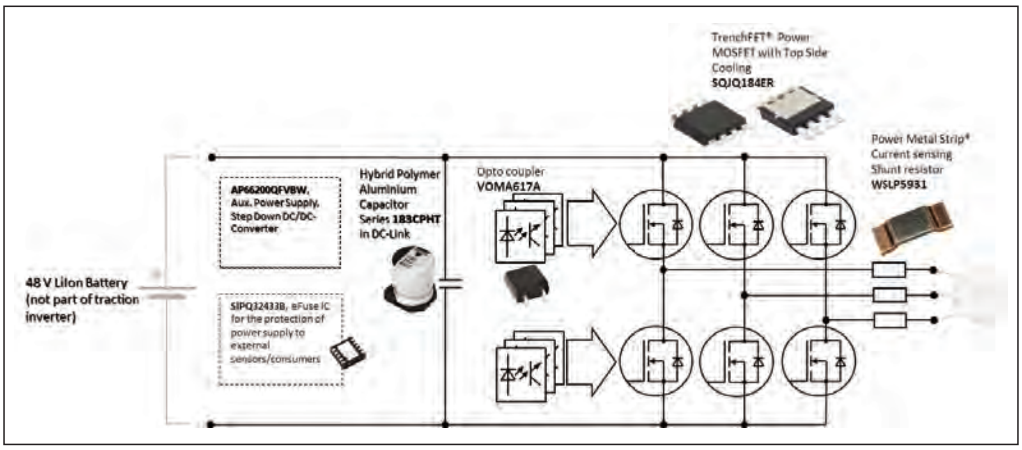


**Figure 3: Design of the traction inverter (source: Vishay)**

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