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Bodo´s Power Systems®

Electronics in Motion and Conversion

April 2026

HITACHI

IGCT Platform for up to 8.5 kV and advanced Turn-Off Current Capability

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KEY FEATURES

Measurement of the

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- **Amplitude inductance** $L_{amp}(i)$ and $L_{amp}(\int Udt)$
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www.ed-k.de

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Power Systems!

March is of course APEC time, so why did I visit the Embedded World show in Nuremberg/Germany in March? The reason is quite simple: I wanted to get an overview of what's going on in the world beyond power, about the applications as well as the needs of these applications for today and tomorrow. At such a trade show you can see an incredible amount of computing boards, computing solutions and computing systems – extremely small ones up to relatively high-performance but still compact computing systems. However, computing blades for server farms were not covered in Nuremberg at all.

And now I'll tell you the main reason why I attended Embedded World: I visited some booths that were embedded between the numerous booths showing embedded computing systems; I visited these power-related companies and talked to them about their systems. One of the most fascinating concepts I saw was presented by the Swiss company EM Microelectronic: They showed a speedometer for bicycles, where the sensor (mounted at the fork) does not need a battery anymore to send the speed data to the display unit (mounted at the handlebar). Up to now these sensors needed lithium batteries like 2032 or 2035 (or a cable, which has lots of disadvantages), and following Murphy's law these batteries were always empty when you were far away from the next shop selling button cell batteries. EM Microelectronic uses its ultra-low power analog semiconductor technology in the context of energy harvesting, which means that the energy of vibration, temperature gradient etc. is used to power an electronic circuit.

Talking about power circuits: For the first time ever, the Austrian company Recom Power now offers some of the deciding ingredients of their secret sauce used to manufacture Recom's DC/DC converter solutions for sale by presenting e. g. several custom transformer driver ICs to engineers who want to build their own discrete DC/DC power supply.

Something else: Having seen an incredible number of solutions I realized that "analog" standard transformers running at 50/60 Hz were almost invisible while switch-mode power supplies and DC/DC converters were almost everywhere. It is very good that inefficient LDOs are more and more replaced by highly-efficient SMPS and DC/DC solutions.

Bodo's magazine is delivered by postal service to all places in the world. It is the only magazine that spreads technical information on power electronics globally. We have EETech as a partner serving our clients in North America. If you speak the language, or just want to have a look, don't miss our Chinese version at bodospowerchina.com. An archive, of every issue of the magazine, is available for free at our website bodospower.com.

My Green Tip of the Month: Try to avoid using disposable batteries whenever it makes sense. Unfortunately batteries are way too often disposed of improperly which can cause environmental problems even though proper recycling allows us to return the scarce raw materials back into the product cycle.

Alfred Vollmer

Events

electronica India 2026
Greater Noida, India April 8 – 10
www.electronica-india.com

PEMD 2026
London, UK April 13 – 15
https://pemd.theiet.org

The Battery Show South 2026
Charlotte, NC, USA April 22 – 23
www.thebatteryshowsouth.com

SEMICON Southeast Asia 2026
Kuala Lumpur, Malaysia May 5 – 7
https://expo.semi.org/southeastasia2026

EnerHarv 2026
Madrid, Spain May 27 – 29
www.enerharv.com

ECCE Asia 2026
Nagasaki, Japan May 31 – June 4
https://ipec2026.org

PCIM Expo & Conference 2026
Nuremberg, Germany June 9 – 11
https://pcim.mesago.com/nuernberg

Sensor+Test 2026
Nuremberg, Germany June 9 – 11
www.sensor-test.de

EV Tech Expo Europe 2026
Stuttgart, Germany June 9 – 11
www.evtechexpo.eu

Silicon Power Semiconductor for high-voltage Modules

Hitachi Energy announced a collaboration to advance shared value creation and sustainable growth. Hitachi Energy will incorporate Pakal Technologies' Insulated Gate Turn-Off (Thyristor), IGTO(t)™, silicon power switch into its portfolio of high-voltage power modules, beginning with devices used in essential applications such as rail, renewables, energy storage, AI, and data center infrastructure. The collaboration addresses one of the most significant challenges in large-scale electrification: reducing energy losses and improving overall efficiency in high-voltage power conversion. By combining Hitachi Energy's expertise in power module design with Pakal Technologies' IGTO(t) innovation the collaboration aims to contribute to cumulative daily efficiency gains across energy infrastructure. Together, the companies intend to produce the highest-performing ≥3.3 kV power semiconductor modules for Hitachi Energy to offer to its large and growing global customer base, delivering higher performance, lower operating costs, and greater long-term reliability across critical electrification projects.

www.hitachienergy.com

Full ISO/IEC 17025 Accreditation for AC Calibration Services achieved

The in-house calibration laboratory of Danisense has achieved full ISO/IEC 17025 accreditation for AC calibration services. This follows the laboratory's ISO/IEC 17025 accreditation for DC current transducer calibration up to 21 kA, obtained in September 2022. This calibration laboratory is now equipped to handle e. g. DC calibration from 1 A to 21 kA as well as AC calibration (53 Hz) from 1 A to 1.2 kA for gain error and phase shift. This capability enables the calibration of a range of current transducers with either current or voltage outputs, supporting applications across power electronics, energy, automotive, rail, and industrial sectors. Danisense's standard AC calibration report is performed at 10%, 25%, 40%, 55 %, 70 %, 85 % and 100 % of nominal AC current. The DC standard calibration is performed at +/- 10 %, +/- 25 %, +/- 40 %, +/- 55 %, +/- 70 %, +/- 85 %, +/- 100 % of nominal DC current. Results are presented with and without offset, with linearity analysis and statement of conformity (for Danisense transducers only) on all test points. Custom calibration points are also available. The service operates with typical lead times of approximately 10 working days, while accepting and calibrating both Danisense as well as third-party AC and DC current transducers. Customers receive a DANAK-accredited calibration certificate, ensuring that every calibration report fully complies with ISO/IEC 17025 requirements and provides complete confidence in measurement traceability and quality. All calibration services can be booked through the company's online calibration portal, which provides e. g. with regular online and email updates during the calibration process, calibration reports, detailed order tracking etc.

www.danisense.com

Strengthening its Electrification Business

Danfoss has acquired 100% ownership of power electronics leader Semikron Danfoss, moving from a joint venture to fully owned subsidiary of Danfoss enabling Danfoss to accelerate the company's electrification business. As part of the continued portfolio optimization, Danfoss intends to divest their automotive business. Danfoss announces the acquisition of the remaining shares in Semikron Danfoss, increasing its ownership from 62% to 100% and gaining full ownership of the global leader in power electronics. The acquisition reflects Danfoss' refocused electrification priorities and is aligned with the execution of the LEAP 2030 strategy. "As part of our strategy, LEAP 2030, we are prioritizing investments in high-value opportunities, such as electrification, within our core businesses. The full acquisition of Semikron Danfoss allows us to fully accelerate our investments in technology leadership, in advanced power modules, and industrial-scale power electronics solutions that create maximum value for our customers," said Kim Fausing, President & CEO of Danfoss. With full ownership, Danfoss moves from a joint setup to full autonomy. This strengthens Danfoss' ability to serve customers with industrial-scale power electronics solutions and sharpens focus on core businesses including industrial drives, renewables, data centers, energy storage solutions, off-highway and construction as well as commercial on-highway vehicles beyond electric passenger cars.

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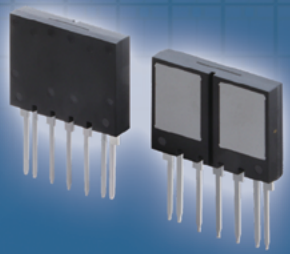

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- Half-bridge/source common

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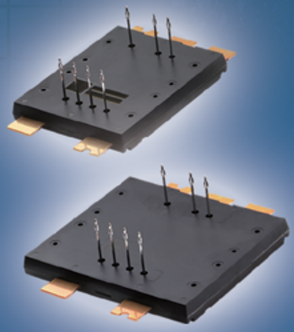
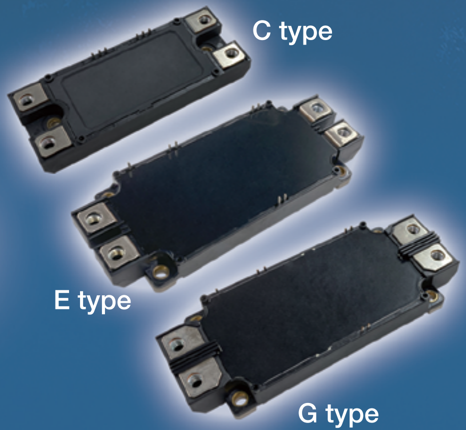


- Parallel multi-chip configuration provides high current capability
- Low Ls improves switching performance
- Reduced size through improved heat dissipation performance

Case type



- Parallel multi-chip configuration provides high current capability
- Gel encapsulation in case

www.rohm.com

Distribution Partnership for Silicon Carbide Solutions

SemiQ has announced a distribution agreement with NAC Semi, a global electronic component design services and distribution company. This partnership is expected to accelerate the adoption of SemiQ's SiC technology across North America markets, providing engineers with access to high-efficiency power modules, MOSFETs, and Schottky diodes. NAC Semi bridges the gap between catalog houses and large fulfillment distributors by offering "demand creation" services, including dedicated Field Applications Engineer (FAE) support. By adding SemiQ to its line card, NAC Semi enhances its ability to provide comprehensive SiC solutions for applications such as EV charging stations, solar inverters, and high-voltage power supplies.

www.semiq.com

Contract extended ahead of Schedule


Jochen Hanebeck

Infineon Technologies plans to extend the contracts of Chief Executive Officer Jochen Hanebeck and Chief Financial Officer Dr. Sven Schneider ahead of schedule. Jochen Hanebeck's contract is to be extended until the end of March 2032, while Dr. Sven Schneider's contract is to run until the end of April 2032. Without the planned extension, the contracts would have expired on 1 April 2027 and 1 May 2027, respectively. The Supervisory Board will pass the formal resolution in May. "Infineon Technologies is in very capable hands, which is why we are establishing clarity about the company's long term direction at an early stage," says Dr. Herbert Diess, Chairman of the Supervisory Board of Infineon Technologies. "With important investments in technological strength and a consistent focus on competitiveness, Jochen Hanebeck — together with Sven Schneider and the entire Management Board team — has successfully positioned Infineon for the future. The company will continue on this path of profitable growth in the years ahead." "We are determined to seize future opportunities — for example in the fields of artificial intelligence, software defined vehicles and humanoid robotics," says Jochen Hanebeck. "Infineon is exceptionally well positioned to benefit from the defining growth trends of our time. The key to success is the ability to rapidly turn innovation into customer value. I would like to thank the Supervisory Board for its confirmation to continue consistently on this path."

www.infineon.com

Strategic Semiconductor Manufacturing Partnership in India

ROHM and Suchi Semicon have established a strategic semiconductor manufacturing partnership in India. By combining ROHM's device technology expertise with Suchi Semicon's manufacturing capabilities and operational execution, the companies aim to build a reliable and scalable manufacturing framework aligned with evolving industry needs. The collaboration aims to enhance supply chain resilience and provide customers with trusted manufacturing solutions. Specifically, ROHM is considering the outsourcing of back-end processes for power devices and IC products to Suchi Semicon and has begun technical evaluations toward potential mass production shipments starting in 2026. Through these efforts, ROHM aims to build, in collaboration with Suchi Semicon, an early-stage manufacturing framework in India that aligns with the expected industry ramp-up in the coming years. Furthermore, ROHM and Suchi Semicon will share a roadmap to expand the range of locally manufactured packages.

www.rohm.com

Intensified Distribution Agreement on Power Supplies

RECOM Power and electronics distributor Bürklin Elektronik are intensifying their collaboration, which has been in place for more than twelve years. The aim of expanding the partnership is to provide customers even faster and more comprehensively with DC/DC and AC/DC power supply solutions from RECOM for industrial, medical, and railway applications.

www.recom-power.com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3D Power Electronics Integration Conference

The 3D-PEIM 2026 conference is focused on 3D power electronics packaging and heterogeneous integration. Sponsored by PSMA and IEEE EPS it will convene researchers, manufacturers, and industry leaders at the Arizona State University Skysong Complex in Phoenix, Arizona, from 16th – 19th November 2026. The event will highlight emerging technologies and manufacturing approaches addressing the performance, reliability, and scalability challenges facing next-generation 3D power electronics heterogeneous integration. The 2026 technical program includes six plenary presentations, seven technical sessions, expert-led tutorials, and poster and industry partner sessions. Topics span the full integration stack, including advanced packaging and 3D integrated modules, thermal management, design modeling and simulation, reliability and failure analysis, power delivery and energy storage, passive components, and materials for advanced packaging. Together, these sessions emphasize both fundamental research and practical implementation for automotive, aerospace, data center, and energy applications. Attendees will be able to participate in guided tours of ASU’s MacroTechnology Works, a manufacturing facility. The site hosts industry-scale capabilities, including a 300 mm Fan-Out Wafer-Level Packaging pilot line. The Call for Papers is now in progress.

www.3d-peim.org

Shenzhen Conference focusing on Power Electronics

The PCIM Asia Shenzhen Conference 2026 will focus on the domain of power electronics applications in artificial intelligence (AI) and data centers, and it will be held from 26 – 28 August 2026 at the Shenzhen World Exhibition and Convention Centre. This event bridges industry, academia and research across the full value chain. Held in conjunction with the exhibition, the conference links technology from the research stage to industrial deployment and has become a principal forum for tracking technical developments and building the cross-sector partnerships that carry technology from the lab to the market. Alongside data center infrastructure, the program also addresses the application of AI technologies in other aspects of the power electronics field, from renewable energy control and power quality monitoring to motor drive optimization and electric vehicle systems. The conference covers all areas of the power electronics field, from foundational research and novel technologies through to industry applications, with sessions to be organized under three thematic tracks: Power electronics core technologies, Innovative applications and system integration as well as AI and data centre energy technologies. The latter track is new for 2026 addressing AI applications across power systems, renewable energy, and electric machines. It focuses on power quality monitoring and electric vehicle systems, reflecting the areas of fastest-growing areas of technological development and industry investment. PCIM Asia Shenzhen is jointly organized by Guangzhou Guangya Messe Frankfurt and Mesago Messe Frankfurt.

www.pcimasia-shenzhen.com

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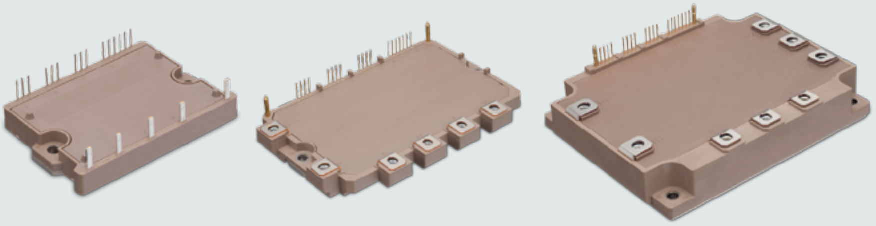

MAIN FEATURES

- Reduction of losses and improvement of energy efficiency by optimizing 7th generation IGBT technology for IPM
- Embedded driver IC for optimum control and protection functions
- Single wire provides three alarm signals: over-current, over-heating, under-voltage
- 6in1 and 7in1 topology (inverter + brake)
- High temperature operating (T_j=175 °C)
- Reduced turn-on loss at high temperature operation by drive control
- Power range from 20 A to 450 A at 650 V and 10 A to 300 A at 1200 V

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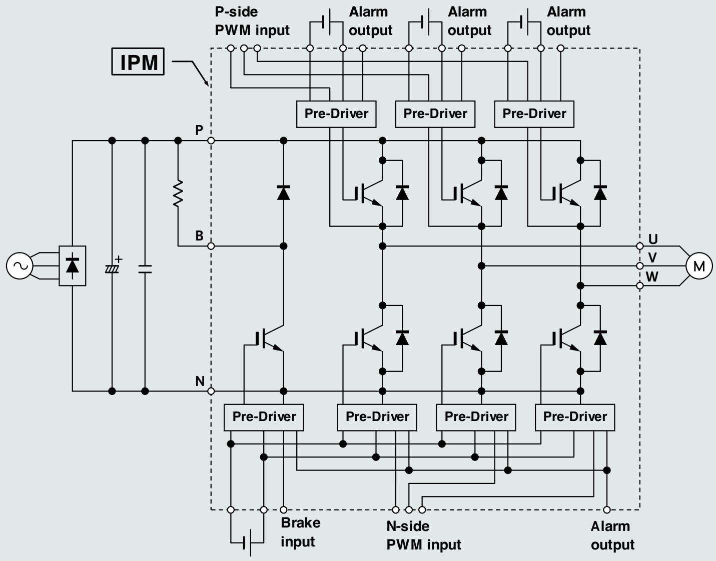


www.fujielectric-europe.com

Power Analysis for Converters, Inverters, and Motors

In applications such as DC-DC converter efficiency evaluation, inverter analysis, and motor efficiency measurements, power is rarely steady or easy to measure. Regenerative operation, distorted waveforms, and high-voltage DC systems demand power measurements that remain reliable under changing conditions.

High DC Accuracy for optimized DC-DC Converter efficiency Testing

Modern DC-DC converters operate with high currents, have challenging efficiency targets and fast switching behavior. This makes DC measurement accuracy a decisive factor in development validation, end-of-line production testing and on-site system commissioning, where even small errors can distort loss calculations and efficiency results.

High frequency noise on the DC bus is often the cause of overheating and eventually failure of components, servers or systems and must be reduced to a minimum. So, capturing the full power on the DC bus requires not only high accuracy for DC, but also for higher frequencies to identify the power fluctuations.

High-precision Power Measurement: Only possible with the right Current Sensors

Power measurement accuracy depends not only on the analyzer, but also on how well current sensors are matched. At higher current rates and switching frequencies, the phase error introduced by the current measurement, is affecting the accuracy of the power measurement. HIOKI pass-through and clamp-on current sensors, are designed for accurate power measurement and share phase error data directly with the power analyzer when they are connected. This makes an effective phase error correction possible over a wide frequency range, leading to accurate, stable and reproduceable results.

For quick and easy connection to the device under test, the accurate clamp-on current sensors ranging from 2 A up to 1000 A are often chosen, but when the highest accuracy and measurement frequency band is required, pass-through current sensors ranging from 50 A up to 2000 A are the best fit.

Efficiency Evaluation with a Fixed Four-Channel Design

The fixed four-channel design of the PW4001 Power Analyzer is optimized for efficiency testing where input and output power must be captured at the same time. Operating modes such as charging, discharging, and regeneration are detected automatically. The analyzer adapts its efficiency calculation accordingly, avoiding false results, such as efficiencies above 100% that would occur during regenerative operation.

Built for Long Tests and Field Operation

Power measurement is not always done in the test lab. During commissioning of high-power DC chargers, Electrical Storage Systems (ESS) or Solar power converters, accurate power measurements are essential to judge the performance of the installation. At such remote locations, temperatures can vary a lot and grid power might not always be available all the time. For these kinds of conditions, the PW4001 can operate at temperatures from −20 to +50 °C, while being powered by a DC power source like a 12 or 24 V battery. The 16 Gb internal memory allows measurement data to be saved for days or even weeks, depending on the number of selected items and the data save interval.

The PW4001 combines its high DC precision with a frequency measurement band of 600 kHz, ensuring stable and accurate power calculations even when voltage and current signals are distorted, exactly the conditions found in modern power electronic applications like industrial drives, renewable Power Converters and Energy Storage Systems. It is designed for engineers who need power measurements that remain reliable across different operating modes, test durations, and environments, without adding unnecessary complexity to the measurement setup.

https://shop.hioki.eu

IGCT Platform for up to 8.5 kV and advanced Turn-Off Current Capability

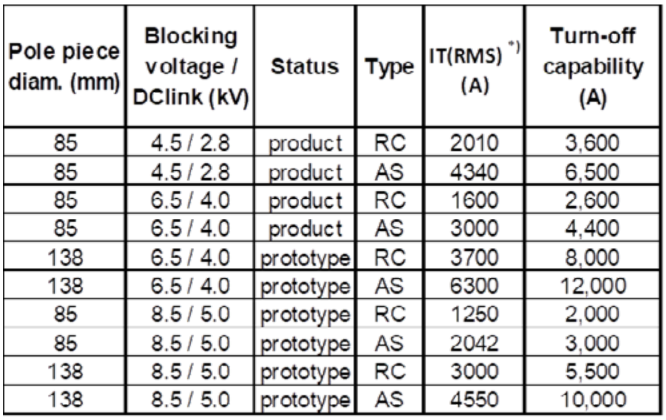
High power semiconductor applications are more and more evolving into higher power ratings. At the same time there is increasing pressure on cost. High voltage IGCT enable to design these applications significantly more cost efficient e.g. by reducing number of series connected cells in a MMC topology. The new platform applies latest technologies what results in unprecedented turn-off capability at high voltage ratings up to 8.5 kV. On top, the IGCT circuit offers advantages in respect to converter protection e.g. fault current limitation, SCFM and case rupture.

By Tobias Wikström, Hitachi ABB Power Grids; Umamaheswara Vemulapati, Urban Meier, Mark Frecker, Thomas Stiasny, Christian Winter, all Hitachi Energy, Semiconductors, Switzerland; and Zuzana Ptakova, Hitachi Energy, Semiconductors, Czech Republic

Power semiconductors are used in many demanding high-power applications like HVDC, Medium Voltage Drives, offshore wind turbines or rail-interties. For these applications, the trend goes towards higher voltage and current ratings. The new IGCT platform with voltage ratings up to 8.5 kV and outstanding thermal and dynamic behavior, addresses these demanding requirement. Thanks to the robust and hermetic housing, the IGCT is ready to deal with demanding protection requirements.

IGCT power handling scalability

The IGCT is a mature component used in demanding applications like industrial motor drives, offshore wind turbines, and rail supply, all of which demand highest availability, efficiency, and power handling scalability. IGCT technology is evolving to support higher power applications with elevated current and voltage ratings. The IGCT device currently used in majority of the applications in the field is the L-type, Reverse conducting (RC) or Asymmetric (AS) IGCT with a 85 mm diameter pole piece and 4.5kV or 6.5 kV blocking voltage. Smaller power requirements can be met with RC IGCT devices. To enhance power handling capabilities, an AS IGCT with a discrete antiparallel freewheeling diode or increased device area can be employed. Addressing applications with highest power demand, devices with increased area are required. Hitachi Energy is developing a device platform with a pole piece diameter of 138 mm. The development activities focus on high voltage devices with 6.5 and 8.5 kV blocking capability. High voltage devices offer some advantages particularly for applications using multilevel topologies. These applications can be designed with reduced number of series connected multilevel cells and consequently reduced cost by applying HV IGCT devices. The Table 1 provides RMS and turn-off current capability overview for Hitachi Energy's 85 mm and 138 mm IGCT platform.



Pole piece diam. (mm)	Blocking voltage / DClink (kV)	Status	Type	IT(RMS) *) (A)	Turn-off capability (A)
85	4.5 / 2.8	product	RC	2010	3,600
85	4.5 / 2.8	product	AS	4340	6,500
85	6.5 / 4.0	product	RC	1600	2,600
85	6.5 / 4.0	product	AS	3000	4,400
138	6.5 / 4.0	prototype	RC	3700	8,000
138	6.5 / 4.0	prototype	AS	6300	12,000
85	8.5 / 5.0	prototype	RC	1250	2,000
85	8.5 / 5.0	prototype	AS	2042	3,000
138	8.5 / 5.0	prototype	RC	3000	5,500
138	8.5 / 5.0	prototype	AS	4550	10,000

Table 1: Overview of selected IGCT types with 85 mm and 138 mm pole piece diameter
**) IT(RMS): RMS on-stat current at half sine wave, semiconductor case temperature 85 degC.*

Device Design

An IGCT device is made up of three intimately meshing parts: semiconductor, housing and gate unit. Scaling current handling capability with device area is a known challenge, see, for example, [5]. At present, the state of the art is manufacturing a single IGCT device on a 150 mm, "6 inch", silicon wafer (see, for example, [1] through [4]). Accounting for loss of wafer real estate due to flats and notches, production margins and junction termination, approximately 150 cm² remains available for active, cooled, device area. Applying water cooling and reasonable pumping effort, the device area potentially represents massive power handing capability, suitable for the highest power applications – also if the device area is shared with a free-wheeling diode alongside the IGCT switch in the Reverse-Conducting (RC-) IGCT. Here, results for an RC-IGCT with A_{GCT} / A_{Diode} ≈ 1.35 are presented. The choice of area ratio is ultimately a question for the customer, whose wishes will vary depending on application. Testing of RC-IGCTs with different area ratios is planned.

The platform described here was improved over the one presented in 2014 [2]. The GCT segment layout of the switch part of the wafer was adapted to the state-of-the-art [6], the diode has been fitted with segmented cathode [7] for improved switching behavior. In addition, the platform's performance at higher voltage has been improved by applying the high-voltage vertical design already presented for smaller device sizes [8]. To meet increased insulation requirements anticipated for the high voltage (≥ 6500 V) branches, the housing was increased to 35 mm.

In terms of scaling the controllable current, the AS poses the challenge due to the increase of the physical size of the gate circuit that is an unavoidable consequence of the increase of the switch's active area. To compensate for this, testing the maximal controllable current with improved gate circuit is investigated.

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RC 6.5 and 8.5kV

Both the 6.5 and 8.5 kV RC-IGCT prototypes were tested beyond the requirements on maximal current controllability (MCC). The appreciation of MCC requirements originates in application simulations that indicate a T_{vj}-dominated performance limit rather than MCC. Figure 1: shows waveforms from both voltage classes, switching currents above the anticipated MCC ratings.

The corresponding loss trade-off curves are shown in Figure 2.

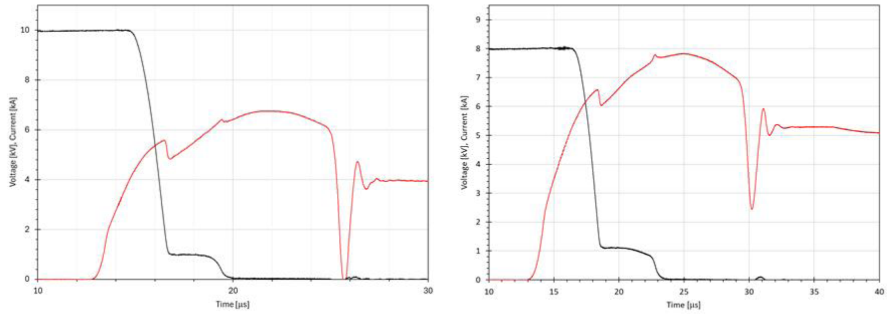

Figure 1: Illustration of probing the current controllability for the 6.5kV (left, 10000 A) and 8.5 kV (right, 8000 A) RC-IGCT prototypes.

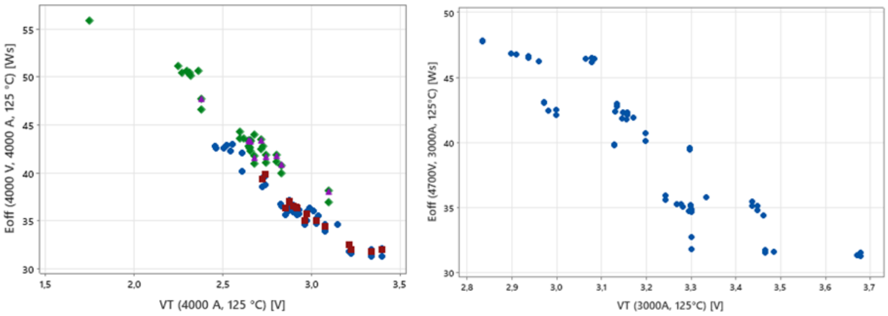

Figure 2: Trade-off between dynamic and static losses for the 6.5kV (left) and 8.5kV (right) GCT-part of the RC-IGCT prototypes.

Outlook AS IGCT

It is sensible to strive for the maximal challenge during technology development. For this reason, the 4.5 kV and 6.5 kV voltage classes were selected for the first prototype series. It is expected that the current controllability limit will be dictated by either the gate circuit impedance or its current capability. The aim is to verify significantly higher current controllability than 10 kA, ideally beyond 14 kA for the 4.5 kV AS-IGCT. Getting better information on what aspect of the device poses the limit is also a target for the test series on the AS-IGCT prototypes. However, as already mentioned above, at present there are only results available at lower currents. Figure 3: shows such a sample waveform.

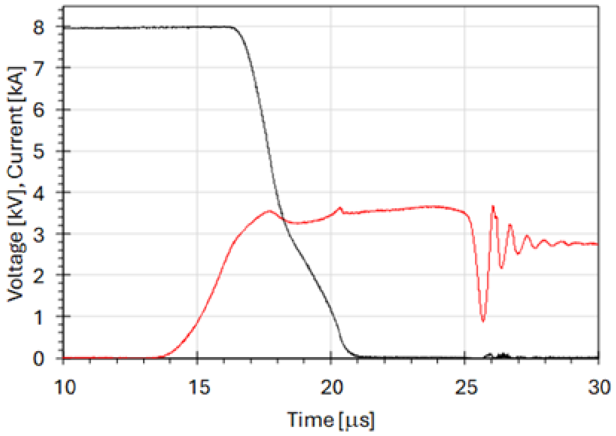

Figure 3: Illustration of the 4.5 kV AS-IGCT prototype switching 8 kA at 140°C for Eoff-characterization

Application

Overview

IGCTs are used in high power applications. As the IGCT is based on a Thyristor structure, the device can be tailored to lowest on-state losses to be the perfect match for low frequency applications, like DC breakers [9] or MMC topologies [10], concerning system losses.

The turn-on dI/dt control is achieved by a dI/dt choke in combination with a clamp circuit. This leads to a nearly full elimination of the turn-on losses in the IGCT. Additionally, the dI/di choke limits fault current peaks in case of device or system failures and can therefor prevent case ruptures and severe damage. Together with the SCFM capability of the press pack construction of the device package, the IGCTs offers significant advantages in application using the MMC topology.

Unpowered dV/dt capability for startup

The IGCT with a powered gate unit shows a remarkable dV/dt capability in blocking state. During dV/dt events the displacement current is extracted through the gate and the very low inductive gate path of the gate unit. This prevents latch-up of the thyristor structure, even with dV/dt above 10kV/ms.

In applications like MMC, auxiliary power for controllers and gate units are often generated out of the DC-link capacitor voltage. During system start-up the auxiliary power in not available in the beginning until the capacitor is charged to a certain voltage. With an unpowered gate unit, for dV/dt events the displacement current extraction through the gate unit is not available. Here the extraction of the displacement current is managed though anode shorts as also well-known from GTOs. In this regime the dV/dt capability is significantly lower than for a powered gate unit. The dV/dt capability of 4.5kV and 6.5kV IGCTs without gate unit is shown in Figure 4: The dV/dt capability of an IGCT is strongly temperature dependent (lower temperature – higher dV/dt capability). During system startup, power semiconductors are at cooling water temperature. As the voltage rise during system power up is typically limited, the unpowered IGCT can easily cope the period until the DC-link capacitor voltage is high enough to supply auxiliary power.

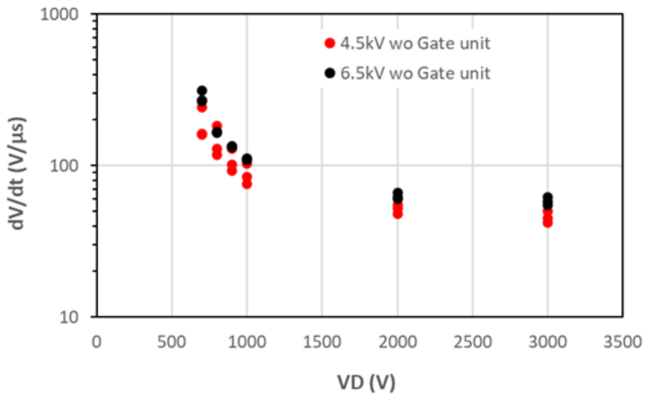

Figure 4: dV/dt capability at T_j = 60°C of a 4.5kV and a 6.5kV IGCT with unpowered Gate unit

Conclusion

- IGCT offers excellent possibility to scale in voltage and area.
- Design for large size IGCTs for several voltage classes have been presented with unprecedented thermal and dynamic performance.
- Ideal for high power applications like MMC e.g. used in HVDC.

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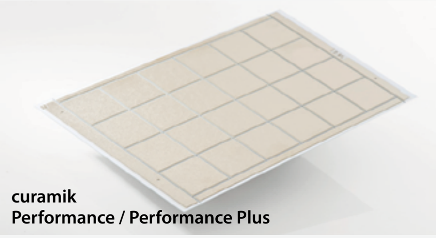

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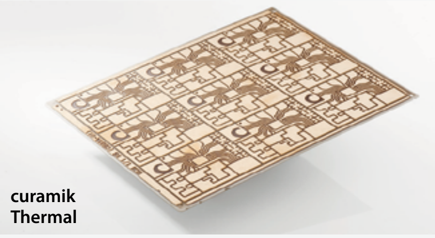

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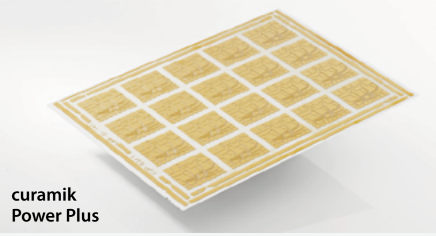

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Inside the Silicon Carbide JFET: Specs, Stability, and the new Performance Frontier

JFETs have advantages over MOSFETs for specialized applications such as high-voltage SSCBs

Global electricity consumption continues to rise sharply across regions, sectors, and end-use systems. Electrification of transport, heating and cooling, industrial equipment, and data center expansion are among the strongest contributors to this trend (IEA, 2025) [1]. As demand grows, so does the pressure on distribution infrastructure to operate faster, safer, and more efficiently.

By Rene Mente, Principal Engineer Technical Marketing, and
Fagbemi Elijah, Product Marketing Manager, both for HV MOSFETs, Infineon Technologies

Traditional electromechanical switching, designed for a different era, cannot meet the microsecondscale response times and longlife reliability now expected. The shift toward solidstate architectures reflects this need for speed, precision, and durability.

As power systems evolve, so does the semiconductor technology enabling them. Widebandgap (WBG) materials, especially silicon carbide (SiC), have become foundational for highvoltage, highcurrent switching thanks to their thermal performance, low losses, and voltagehandling capability. SiC MOSFETs are wellestablished, but recent advancements highlight another device class whose time has come again: the silicon carbide junction fieldeffect transistor (JFET). Fabrication maturity, improved packaging, and the emergence of high-voltage solidstate power distribution (HV SSPD) make the SiC JFET newly relevant and powerfully differentiated.

From market pressures to material choice

Today, the world faces not only increasing power consumption but more volatile demand profiles, driven by fastcharging systems, industrial automation, distributed generation, and highpower digital loads. Highspeed fault isolation is critical in these applications but electromechanical circuit breakers typically take more than 10 ms to interrupt a fault, whereas solidstate approaches can achieve response times under 5 µs. This dramatically reduces current overshoot and stress on downstream equipment.

These systemlevel requirements have elevated the role of SiC, now the primary WBG material enabling (HV SSPD). In this context, SiC JFETs stand out for their ability to pair extremely low conduction losses with high robustness, making them a compelling fit for faulttolerant, highcurrent distribution architectures.

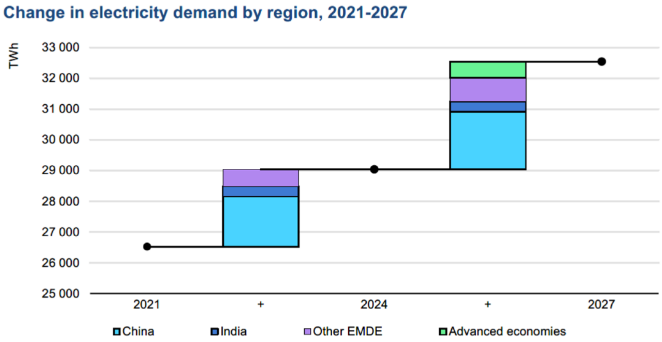

Figure 1: Change in electricity demand by region, 2021–2027. Note: EMDE = Emerging Markets and Developing Economies [1]

Why the SiC JFET is reemerging

Several industry trends have converged to lift the SiC JFET back into prominence.

1. SiC manufacturing has improved significantly, reducing variability and enabling larger die with consistent performance
2. Modern packaging - especially thermally optimized, topsidecooled designs - supports higher current densities
3. The rise of HV SSPD has created demand for devices with ultralow $R_{DS(on)}$, stable linearmode behavior, and high avalanche robustness

These characteristics are the JFET's natural strengths. Devices now achieve bestinclass typical $R_{DS(on)}$ values such as 1.6 mΩ at 750 V and 2.3 mΩ at 1200 V. This makes them ideal for currentintensive applications where conduction loss dominates total system loss.

Device construction and operating principles

Modern SiC JFETs typically use a trenchbased structure with a ptype gate region sculpted into the ntype drift zone. This creates a vertical channel whose conductivity is modulated by gate voltage. The structure is optimized to minimize the $R_{DS(on)}$ × A figure-of-merit (FOM) while maintaining thermal stability and robust avalanche behavior.

During onstate conduction, current flows through the volume channel, while in the offstate the spacecharge region expands to pinch off conduction. Because the device is normallyon, it provides extremely low resistance when conducting but requires careful control to ensure a safe turnoff. These characteristics can be managed either through gatedrive schemes or through cascode configurations where a lowvoltage MOSFET controls the JFET gate indirectly.

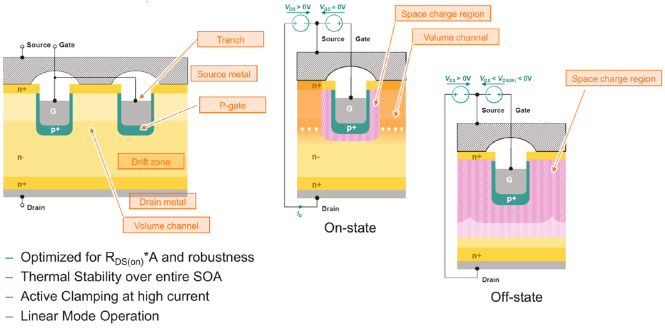

Figure 2: Cross-section of trench-based SiC JFET showing P-gate, drift region, and channel


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Ultralow $R_{DS(on)}$: Scaling efficiency and density

In highcurrent distribution and protection systems, designing components to manage conduction loss becomes a dominant contributor to footprint, thermal design effort, and cost. SiC JFETs currently deliver some of the lowest devicelevel $R_{DS(on)}$ values available in their voltage classes, with typical ratings such as:

- **1.6 mΩ (750 V)**
- **2.3 mΩ (1200 V)**

This performance supports system designs operating at 32 A to 63 A and above, within compact footprints—levels that would require significantly larger silicon or MOSFET-based stages.

Lower conduction loss also reduces heatsink mass and cooling requirements, improving system compactness and lowering overall cost.

Improved linearmode stability for safe inrush handling

A defining strength of the SiC JFET is its improvement in stability in linear mode, compared to a SiC MOSFET. When a system powers a capacitive load, the device can safely operate in a highresistance regime, naturally limiting inrush current without additional circuitry.

This simplifies the implementation of “connect” functions such as precharging, hotswap operations, and soft starts. It also reduces stress on both the device and the surrounding system during highcurrent transients.

Avalanche robustness for inductive disconnect

Disconnecting inductive loads can generate large overvoltage spikes. SiC JFETs are rated for; and productiontested in; highcurrent avalanche conditions, allowing them to clamp these events safely.

This high avalanche energy handling:

- Reduces the need for external clamping networks
- Improves current sharing during paralleling
- Enhances reliability during repeated inductive switching cycles

Some JFETbased implementations still need metal oxide varistors (MOVs) or transient voltage suppression (TVS), but they reduce the MOV + RC snubber combinations required by MOSFET architectures, reducing BOM complexity and potential failure points.

Packaging and system integration: The role of QDPAK

Packaging is crucial for realizing device potential. The QDPAK form factor used in CoolSiC™ JFETs incorporates:

- Large drain and source interface areas for low electrical resistance
- A large, topsidecooled heatslug for low Rth
- Internal diffusion soldering for high current capability
- Extendable thermal capacitance to adapt overload behavior

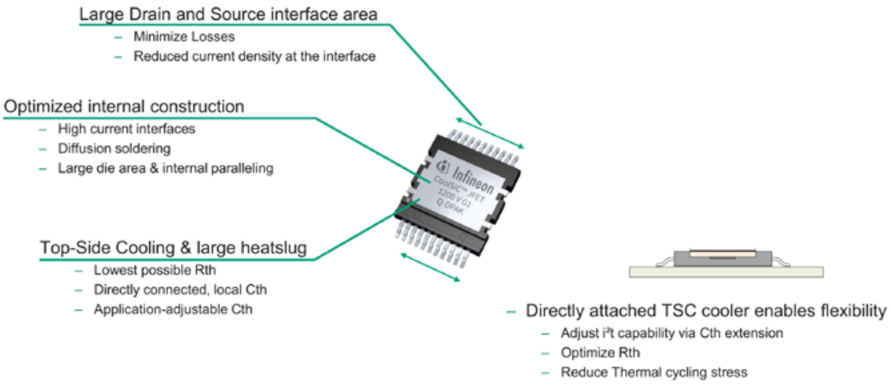

Figure 4: Q-DPAK package layout illustrating drain/source pads and heatslug

This approach directly supports highcurrent SSPD designs by minimizing temperature rise and reducing interface bottlenecks.

Driving concepts: Normally on and cascode options

Although the JFET is inherently normally on, several practical driving strategies exist:

- Direct drive with negative gate bias
- Classic cascode using a lowvoltage MOSFET for normallyoff behavior
- Adapted cascode with additional gatenetwork tuning

These options improve compatibility with existing MOSFEToriented architectures, giving system designers flexibility to integrate JFETs without major architectural redesign.

JFET vs. MOSFET: A comprehensive comparison

Dimension	SiC MOSFET	SiC JFET
Conduction mechanism	Channel conduction	Bulk conduction
Gate structure	Fully isolated	Non-isolated p-gate
Normal state	Normally off	Normally on
$R_{DS(on)}$	Higher for same voltage class	Lowest per device
Temperature coefficient	Lower	Higher but stable SOA
Linear-mode capability	Limited	Improved, inrush-limiting
Avalanche behavior	Good, but requires clamping	Highly rugged, simplifies clamping
Control complexity	Simple	Requires drive strategy or cascode
System implications	Best for legacy -friendly designs	Best for maximum power density and protection

Table 1: JFET vs. MOSFET comparison across critical dimensions

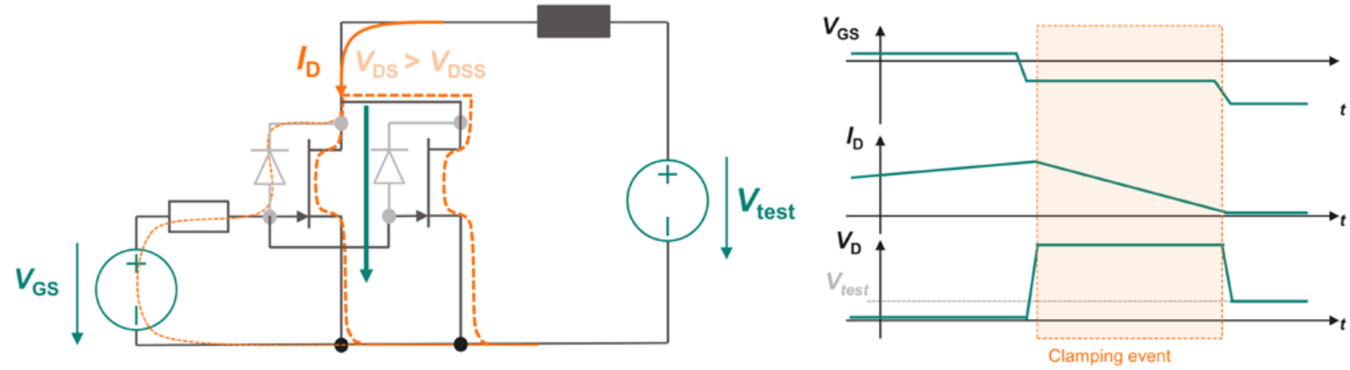

Figure 3: Overvoltage clamping waveform demonstrating stable avalanche behavior

Business implications

While technical differentiation matters, evaluating SiC device choices focus on system-level outcomes. Several implications stand out:

- Lower TCO from miniaturization and reduced cooling requirements
- Simplified architecture from reduced clamping components and fewer failure modes
- Higher reliability through stable linear-mode operation and robust avalanche capability
- Scalability in improved thermal performance using advanced packaging like Q-DPAK

These advantages translate directly into operational efficiency, long-life performance, and reduced downtime for critical infrastructure.

Conclusion

The SiC JFET has returned to prominence not because it replaces MOSFETs, but because it excels in domains where ultralow conduction loss, linear-mode stability, and avalanche resilience are essential. Today's power-distribution landscape demands precisely these characteristics, particularly as systems evolve toward solid-state protection, compact power stages, and long-lifetime operation.

With manufacturing improvements, advanced packaging, and flexible control strategies, modern SiC JFETs present a compelling option for high-current, high-reliability designs. For businesses rethinking their next generation of power architectures, exploring what CoolSiC™ JFETs can offer is a strategic step toward meeting the demands of an increasingly electrified world.

To learn more about the CoolSiC™ JFET family, visit:
https://www.infineon.com/product-information/power/silicon-carbide-jfets

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Meeting Compact Inverter Design Demand with Small Size While Maintaining Insulation Distance

In recent years, power density of a power inverter stages are increasing by providing low power losses as well as compact size so that the demand of environmentally friendly, efficient, and light inverter stages could be designed. To meet the challenges of these small and light inverter design, COMPACT DIPIPM have been developed in a smaller package still maintaining the insulation distance compared to conventional products.

By Dr. Mustafa Cem Ozkilic, and Keisuke Kawamoto, Mitsubishi Electric Europe B.V.,
and Akiko Goto, Mitsubishi Electric Corporation, Fukuoka, Japan

Back in 1997, Mitsubishi Electric introduced the very first DIPIPM Concept in the power electronic industry, which integrated power semiconductors (3 phase inverter stage with IGBT and FWD), LVIC (Low Voltage Integrated circuit) and HVIC (High Voltage Integrated Circuit) gate drivers with protection logic circuits for cost-effective inverter applications [1]. Since then, development of different types of DIPIPM Families with 600V and 1200V rating for various output current ratings and additional topologies has continued [2]. Main target of DIPIPM development has always been to increase power density of a power stage by providing DIPIPM with low power losses as well as compact size so that the demand of environmental friendly, efficient, and light inverter stages could be designed [3].

A new Family of COMPACT DIPIPM Series with current/voltage rating of 30A-50A / 600V, which have recently been introduced to the power electronics industry to mainly address PAC (Package Air Conditioner), Heat Pump Compressor Drive, and motor drives for industrial machines, maintain same isolation voltage (2500Vrms/1min) as Mini DIPIPM Family whilst reducing the package size requirement 43% , hence it is able to cover a wide range of inverter output power capacity with small package size and lower cost. COMPACT DIPIPM incorporates, 6 pieces of RC-IGBT, 1 piece of HVIC, 1 piece of LVIC and 3pieces of BSD (Bootstrap Diodes) [4].

Internal Schematic and Package Concept of COMPACT DIPIPM

In order to reduce the size and cost, COMPACT DIPIPM has been implemented with RC-IGBT technology, which integrates an IGBT and an FWD (Free Wheeling Diode) in a single chip. HVIC and LVIC incorporated in the package are not only responsible for driving the power switches but are also used protection and feedback such as UV (Under Voltage), SC (Short Circuit implemented only for low sides), VOT (Analogue Temperature Output), interlock circuit to prevent short circuit between P-N arms, and Fo Output (activated only for low side UV and SC protection). Integrated Bootstrap diodes allow the operation of the device with a single 15V power supply.

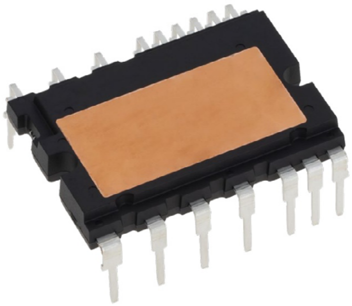


Figure 1: Outline of COMPACT DIPIPM

Outline, Internal Schematic and Internal Cross-Section Structure of COMPACT DIPIPM are illustrated in Figure 1, Figure 2 and Figure 3 respectively.

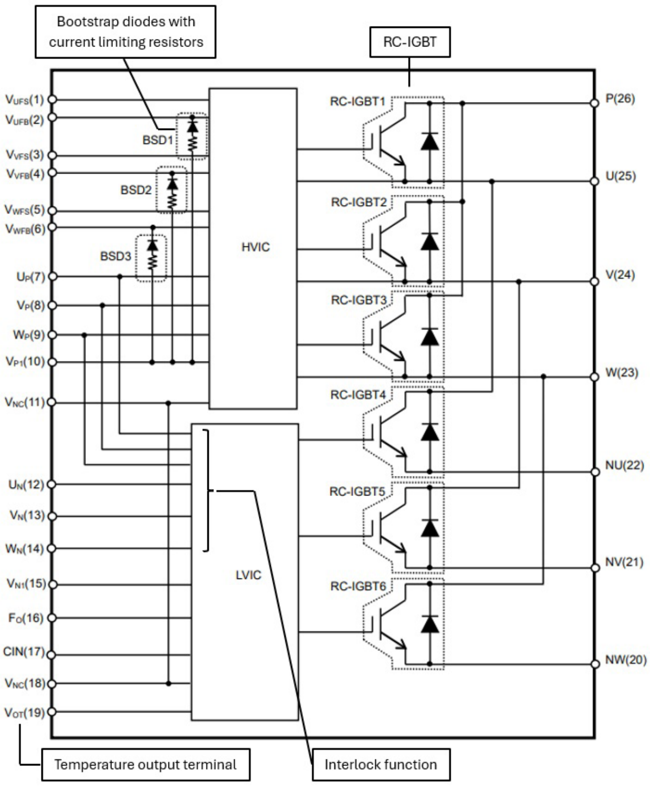


Figure 2: Internal schematic

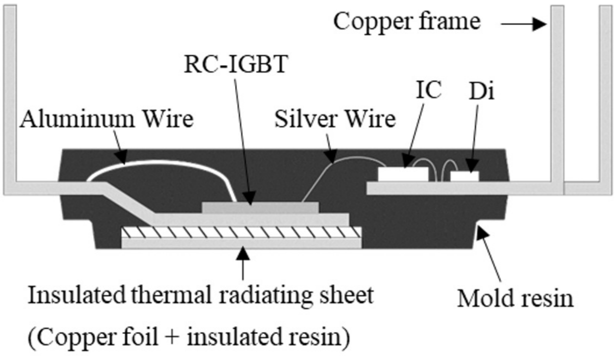


Figure 3: Internal cross-section structure

Features of COMPACT DIPIPM

Reduction of the Package size

COMPACT DIPIPM has been implemented with RC-IGBT technology that integrates an IGBT and an FWD in a single chip so that the total number of power chips could be halved (Figure 4). Compared with Mitsubishi Electric Mini DIPIPM, which is the conventional DIPIPM of Mitsubishi Electric with voltage ratings of 600V and 1200V, COMPACT DIPIPM needs only 43% less package size to deliver the same current level at the same voltage ratings, as shown in Figure 5.

Even though the package size of COMPACT DIPIPM has been reduced, the design of the package with deep step cross-sectional structure between the heat dissipation surface and terminals ensures the creepage (4mm) and clearance (3.2mm) typical distance so that same isolation voltage (2500Vrms/1min) as of Mini DIPPM could be maintained (Figure 6).

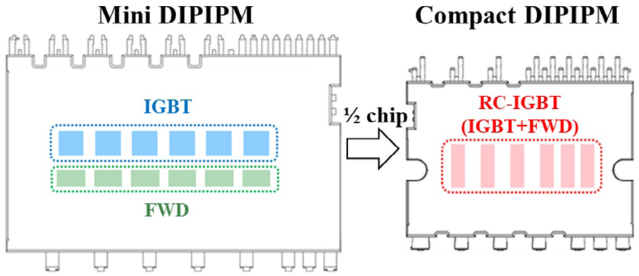


Figure 4: Chip layout comparison

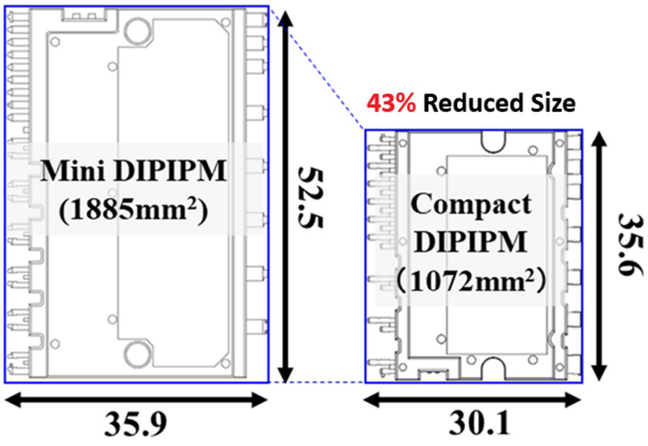
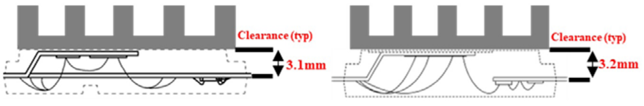


Figure 5: Package size comparison



(a) Mini DIPIPM **(b) Compact DIPIPM**

Figure 6: Typical distance from terminals to heat sink

Simplified Layout Pattern

Mini DIPIPM, which contains 3pieces of HVICs to drive each P-side power switches individually, needs individual wiring of power supply pattern for each of high side. On the other hand, state-of the-art HVIC design of COMPACT DIPIPM covers all of P-side driver stages in single element so that the pattern wiring of the high side power supply could be simplified. Thus, BSC circuit design is further simplified and enhanced without having the control power supply terminals, GND terminals as well as the input signal terminals cross each other as illustrated in Figure 7.

Reduction of Thermal Resistance

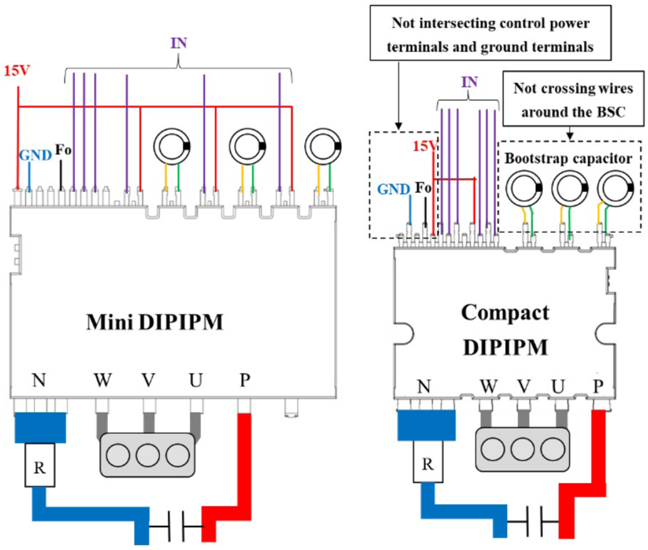
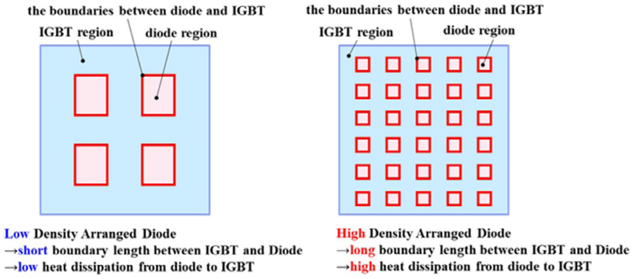


Figure 7: PCB layout

COMPACT DIPIPM integrates the 3rd generation RC-IGBT (3rd RC-IGBT). IGBT and diode portions of an RC-IGBT mutually dissipates the heat so that power density could be increased whilst the thermal resistance decreases [5][6]. Diode layout of 2nd generation RC-IGBT (2nd RC-IGBT) and 3rd RC-IGBT have been illustrated. In 3rd RC-IGBT, the heat dissipation could be improved by two aspects compared with 2nd RC-IGBT which are i. arrangement of diodes more densely in an island pattern, ii. increased boundary length between the IGBT and the diode (Figure 8).

Reduction of thermal resistance is not only limited to chip level improvement but also due to the insulation sheet structure used in COMPACT DIPIPM which has about 70% higher thermal conductivity compared with that of Mini DIPIPM insulation sheet.

Additional Functionalities



(a) 2nd RC-IGBT **(b) 3rd RC-IGBT**

Figure 8: Diodes arrangement on RC-IGBT

COMPACT DIPIPM comes with BSD functionality and VOT function of monitoring LVIC temperature which could be used for generating control supply for high sides from a single 15V power supply and for enabling control system to monitor LVIC temperature to set-up over temperature protection, respectively.

Moreover, integrated interlock function contributes to safe operation of the system by preventing simultaneous turn-on of both P and N sides by turning off the corresponding N-side without outputting Fo signal (Figure 9).

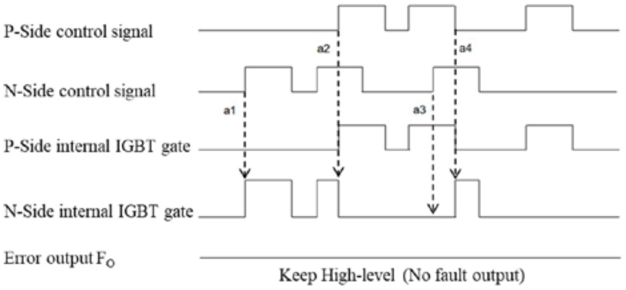


Figure 9: Timing chart of interlock function

Electrical Characteristics

Turn-on and Turn-off waveforms of COMPACT DIPIPM have been illustrated in Figure 10 and Figure 11 respectively. As can be seen from the figures, during turn-on, no oscillation has been observed whereas during turn-off the tail current falls smoothly in a fast fashion.

In the meantime, loss simulations of 50A COMPACT DIPIPM (PSS50SF1F6) and 50A Mini DIPIPM with BSD (PSS50S71F6) were conducted with following conditions, modulation method SVPWM, V_{cc}=390V, I_O=25Arms, P_F=0.97, M=1, f_c=6.6kHz, f_o=60Hz, V_D=V_{DB}=15V. As shown in Figure 12, the total loss of COMPACT DIPIPM could be reduced by 8.5% compared with that of Mini DIPIPM with BSD by reducing the package size whilst thinning the chip and optimizing the driving capacity.

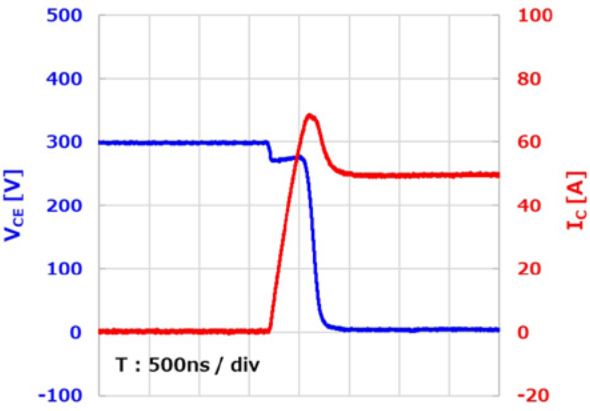


Figure 10: Compact DIPIPM turn-on waveform

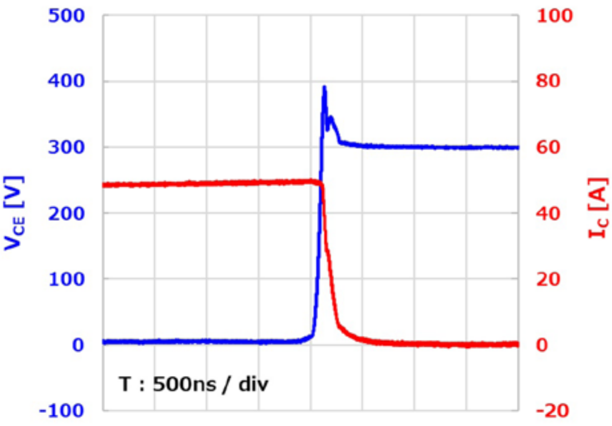


Figure 11: COMPACT DIPIPM turn-off waveform

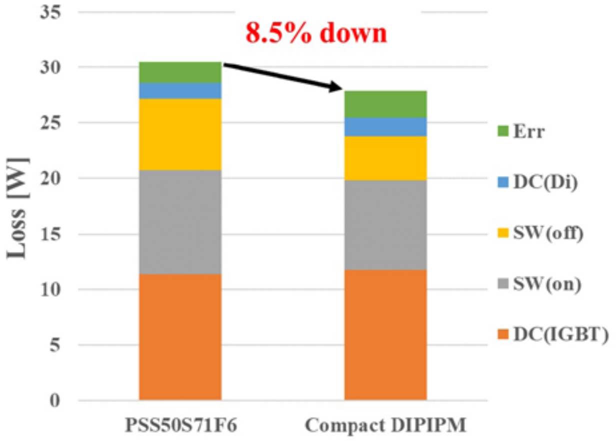


Figure 12: Loss simulation result

Conditions: SVPWM, V_{cc}=390V, I_o=25Arms, P_F=0.97, M=1, f_c=6.6kHz, f_o=60Hz, V_D= V_{DB}=15V

Conclusion

COMPACT DIPIPM, embedding RC-IGBT technology, allows smaller package implementation and lower or similar level of power losses compared with that of previous generation Mini DIPIPM Series, while simplifying board layout design by providing optimal pin placement. COMPACT DIPIPM is the perfect DIPIPM match for compact power inverter stage design of PAC and low power industrial drives.

* SLIMDIP and DIPIPM are trademarks of MITSUBISHI ELECTRIC CORPORATION.

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Powering AI with reliable SiC-based Solid-State Transformers

Why are Solid-State Transformers such a hot topic? How can SST designers move to an even simpler cell architecture for HV designs with >5 kV blocking voltage by using a 10 kV SiC power MOSFET? How do you achieve a conversion efficiency of 99 %? Here are some answers.

By Ashish Kumar, Ph.D., MVHV Research Scientist at Wolfspeed

NVIDIA's 800 V HVDC architecture — announced at Computex 2025 — fundamentally transforms AI factory power delivery with direct benefits to GPU density and efficiency[1]. By distributing power at higher voltage, wiring requirements are significantly reduced, freeing rack space for additional GPUs and enabling the emerging 1-MW rack designs. The architecture delivers up to a 5 % improvement in end-to-end power efficiency and a 70 % reduction in maintenance costs. Silicon Carbide is the critical enabling technology: the 800 V DC bus requires 1200 V SiC MOSFETs for AC/DC rectification and DC/DC conversion, delivering a 25–40 % reduction in conversion losses.

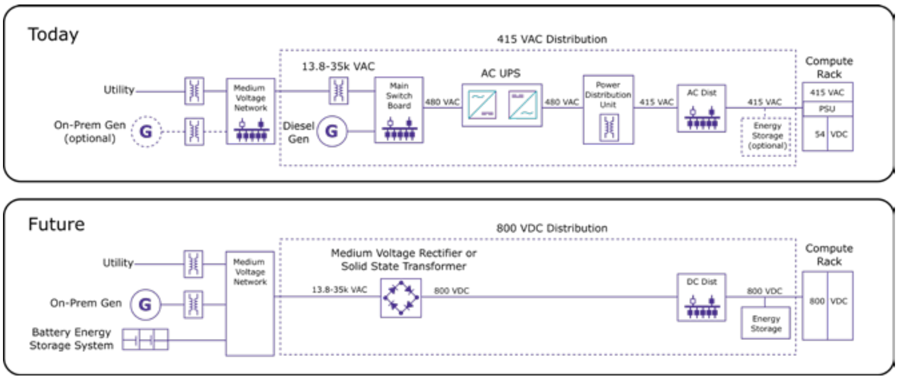


Figure 1: NVIDIA's 800 V DC power distribution in next-generation AI data centers[1]

However, realizing this vision requires solving an upstream problem. In Figure 2, the IEA warns that approximately 20 % of planned data center projects are at risk of delays due to electrical grid constraints and supply chain bottlenecks on conventional transformers[2]. Reducing AI data center build-out duration is essential to mitigate this risk. Accelerated global deployment is increasing procurement and installation lead times for the medium-voltage (MV) transformers that connect the data center facilities with the utility grid. The availability of medium-voltage transformers is emerging as one of the primary constraints on AI data center expansion, with lead times stretching up to 3 years[3].

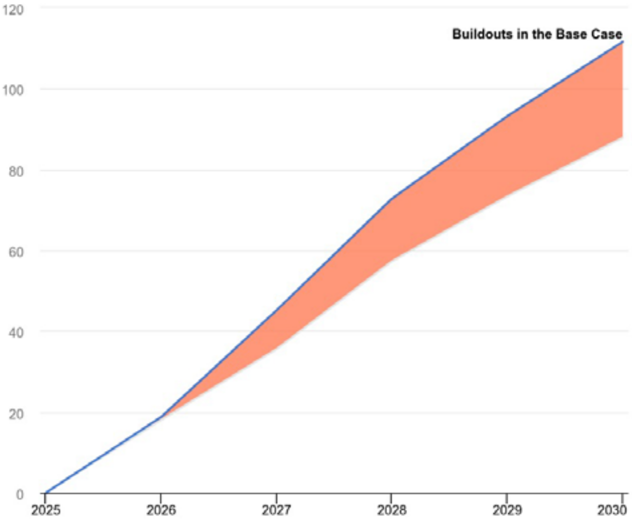


Figure 2: GW hours of data center buildouts facing connection delays[2]

The solution lies in Solid-State Transformers (SSTs) — power electronics-based alternatives to conventional iron-core transformers that can convert medium-voltage grid power directly to 800 V DC, dramatically compressing deployment timelines and enabling modular, scalable grid interconnection.

Once again, Silicon Carbide is the enabling technology: medium and high-voltage SiC devices are the key semiconductor breakthrough accelerating SST development, enabling higher switching frequencies, superior thermal performance, and compact form factors that conventional silicon cannot achieve. In this light, SiC's role in the AI datacenter revolution extends far beyond the rack — it is foundational to the entire power delivery chain from the grid to the GPU.

Grid-tied renewable energy sources are being leveraged in more of the infrastructure powering today's data centers. But as power levels increase, and hyperscalers elbow their way into the larger grid – or create their own microgrid – ensuring that power conversion remains stable and reliable throughout rapidly shifting load profiles is an immediate engineering barrier to overcome. In short, power availability is paramount, and the solid-state transformer might be AI's white horse.

Why do transformers matter?

Traditional transformers are commonplace, and at their foundation exist to buck or boost AC input voltage, and transmit power from point A to point B. They can be huge, albeit relatively simple in nature, including heavy copper windings and magnetic cores to "transform" to the appropriate output voltage. Electronics manufacturers are re-thinking the transformer concept, moving to a solid-state transformer (SST), replacing the heavy copper coils by light-weight solid-state semiconductor devices. Unlike conventional transformers a SST can respond to changing demands faster and adjust its power flow and output smartly. Early SST concepts may consolidate functions traditionally provided by switchgear and UPS/battery systems, enabling DC compute loads to be powered directly from the utility grid or an alternate source.

At a minimum, a SST is valuable if it can meet the variable power ranges that the 800 V DC rack architecture will bring in the future. But a power dense SST brings enormous value for data center original equipment manufacturers (OEMs) who are trying to make the most of AI campus's very valuable floor space, without sacrificing power uptime. Some manufacturers are finding unique ways to integrate smarter protection and control algorithms alongside robust isolation to achieve predictive maintenance, with the intent to avoid any power downtime.

SST pilot deployments are occurring while procuring traditional transformers is a commercial challenge. Data suggests that in 2025 data center expansions and kickoffs might be responsible for years-long lead times and a nearly 30 % shortage of the necessary transformers[4].

Two-ways to achieve a reliable SST enabled by medium to high-voltage SiC devices

Power inputs of AI data centers typically connect near the 13.8 - 35 kV AC power level. A SST converts the high voltage AC input to 800 V DC output connected to the compute rack. Figure 3 shows a simplified building block of a typical SST architecture made of several cascaded converter cells based on the DC bus of the cells and voltage rating of the power devices.

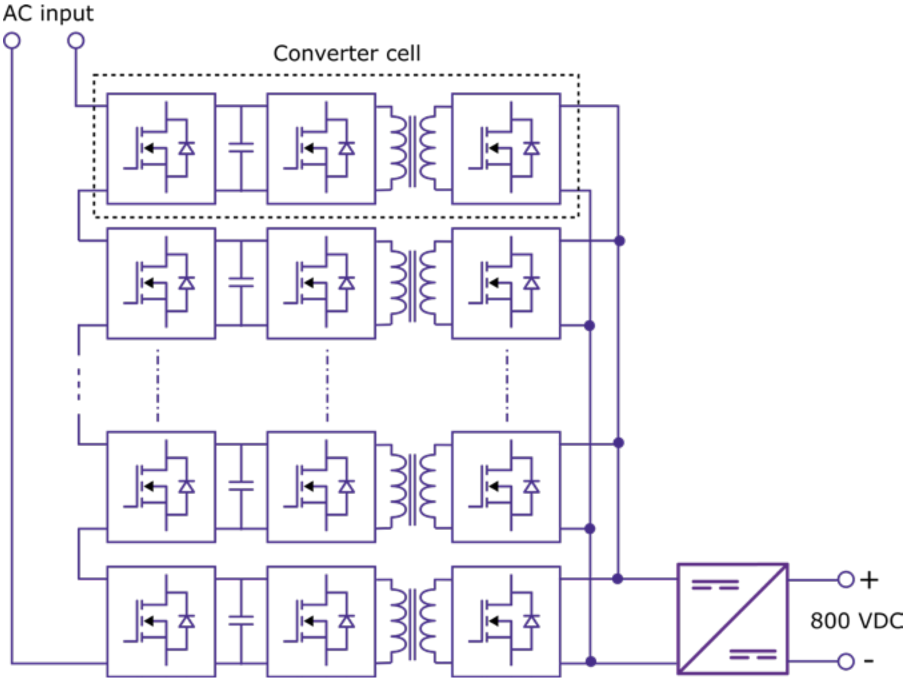
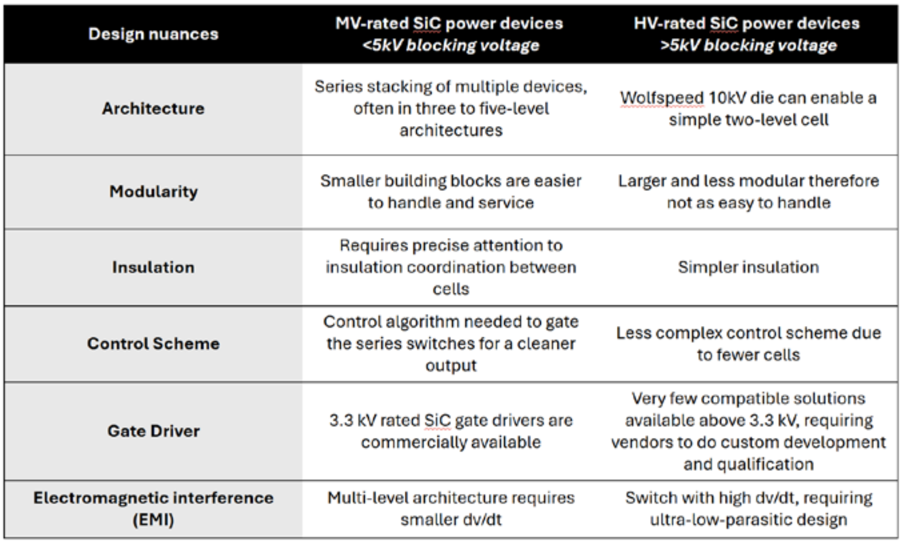


Figure 3: A typical SST architecture made of several cascaded cells

Wolfspeed has been partnering with leading SST manufacturers to understand their core constraints. Wolfspeed's medium-to high voltage die and module portfolio is expanding with silicon carbide options that enable scalable implementation of silicon carbide to achieve multiple factors of greater density over traditional solutions. Table 1 summarizes some of the tradeoffs between a MV and HV SiC-based SST design.



Design nuances	MV-rated SiC power devices *<5kV blocking voltage*	HV-rated SiC power devices *>5kV blocking voltage*
Architecture	Series stacking of multiple devices, often in three to five-level architectures	Wolfspeed 10kV die can enable a simple two-level cell
Modularity	Smaller building blocks are easier to handle and service	Larger and less modular therefore not as easy to handle
Insulation	Requires precise attention to insulation coordination between cells	Simpler insulation
Control Scheme	Control algorithm needed to gate the series switches for a cleaner output	Less complex control scheme due to fewer cells
Gate Driver	3.3 kV rated SiC gate drivers are commercially available	Very few compatible solutions available above 3.3 kV, requiring vendors to do custom development and qualification
Electromagnetic interference (EMI)	Multi-level architecture requires smaller dv/dt	Switch with high dv/dt, requiring ultra-low-parasitic design

Table 1: Key nuances between SSTs designed using MV and HV-rated SiC devices

The good news is that several SiC technology nodes are ready for integration into designs now, offering a flexible path to a variety of SST architectures. For those who are prioritizing a medium voltage device based-SST, WolfPACK™ power modules' switching performance enables passive reduction, and the devices' 15 % greater voltage headroom compared to 2 kV devices gives system designers the flexibility to power a full 1500-V DC bus.

But power is only as good as it's available, hence why every medium voltage Wolfspeed module is designed with durability in mind. These WolfPACKs perform predictably at a variety of altitudes thanks to their low cosmic ray failure-in-time (FIT) rate performance.

A clear path to HVDC cell-based SSTs

For high-voltage (>5 kV blocking voltage) designs, SST designers can move to an even simpler cell architecture with Wolfspeed's 10 kV silicon carbide power MOSFET. The CPM3-10000-0300A achieves a conversion efficiency of 99 %, which provides a means to a 50 % reduction in thermal cooling system compared to conventional HV-rated silicon IGBT based-designs.

Higher switching frequency in SSTs directly reduces the size and weight of the magnetic components, because the required magnetic coils and core size decrease as frequency increases. To keep magnetics compact, SST power stages typically target switching frequencies higher than 10,000 Hz. Conventional 6500 V silicon IGBTs have high switching losses and are generally limited to a few hundred Hertz switching, making HVDC cell-based SSTs impractical with high-voltage Si IGBTs. In contrast, Wolfspeed 10 kV SiC MOSFETs can operate above 10,000 Hz with substantially lower switching loss and faster transitions, making compact, lightweight SSTs feasible.

Bipolar degradation is one of the major causes of failure of HV SiC devices operating for long periods of time. The Wolfspeed 10 kV MOSFET is also the first known commercial SiC device in its class whose bipolar stability has been established by the body diode operating life (BDOL) testing with zero bipolar degradation over 1,000 hours. Additionally, the CPM3-10000-0300A exceeds the industry's cosmic ray FIT rate requirement by 4X at a typical 6,000 V_{DC} operation, ensuring fewer single points of failure throughout the operating life of SST.

While these might feel like bold claims to make for a new technology node, it is now time to explain why you can trust the figure. Wolfspeed has a long history of wide bandgap materials development and has been demonstrating > 5 kV SiC power devices for nearly 20 years now. As a research scientist in our medium and high-voltage business unit I feel like I've come full circle and am proud of technology that I've had a front-seat to in more than one capacity. In 2021 I presented my PhD dissertation on "High Voltage SiC Power Devices in Medium Voltage Power Converter Applications." The majority of my doctoral research was based on Wolfspeed's 10 kV SiC MOSFETs. Medium and high voltage SiC has been Wolfspeed's domain for quite some time!

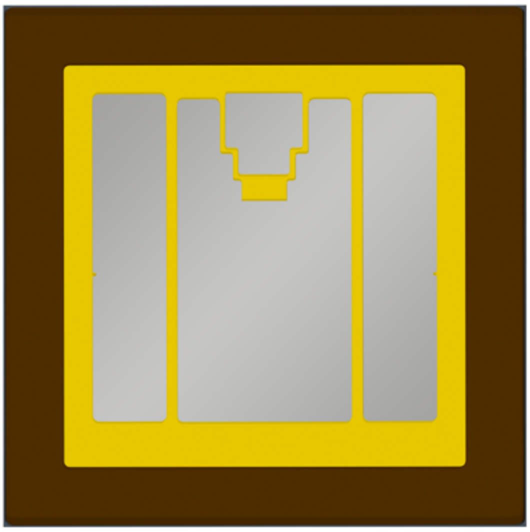


Figure 4: CMP3-10000-0300A, a 10,000 V 305 mΩ SiC MOSFET die

Where do we go from here?

If SSTs are the answer, and I believe they are, it will take more than just acceleration from SiC MOSFET manufacturers to enable a quicker path to market. SST design isn't trivial, and essential components aren't broadly available at the right voltage ratings, which may require custom development by SST vendors and makes dual-sourcing a challenge.

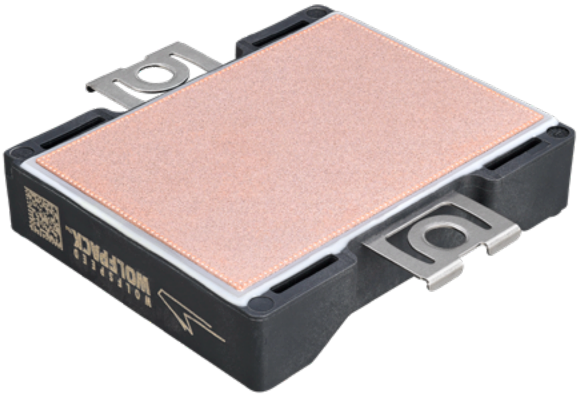
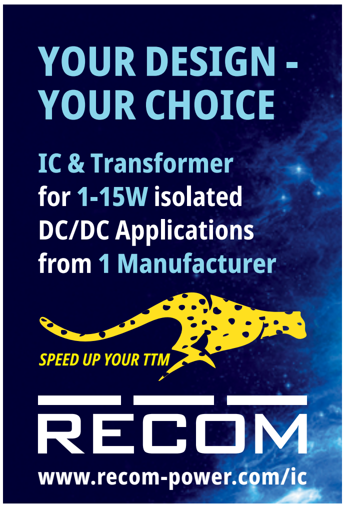


Figure 5: The CAB5R0A23GM4/T 2300V is a 5 mΩ half-bridge module with optional pre-applied thermal interface material



Given the power SSTs are handling, safety is critical. Protection schemes must be carefully architected, and millisecond class DC fault clearing is required for high voltage nodes. Gone are the days of utilities customers using converter efficiency as the target benchmark. Efficiency is table stakes – but safety and durability are the differentiators.

While gate drivers for SiC devices rated at 3.3 kV and below are commercially available, compatible gate drivers for high voltage SiC are few and far between. Medium frequency magnetics and insulation systems compatable with HV SiC devices also aren't widely commoditized yet, which puts the onus of device design on the SST vendor. I'm certain with the right partnership that SiC MOSFET IDMs can deliver the performance that SSTs mandate, but we need a collective push from electronics manufactures of all stripes to fill the gaps.

Power and passive electronics manufacturers are perhaps facing a once in a lifetime chance to shape the pace and extent to which a life-changing technology like AI is deployed. To other suppliers, I'm asking for your help. Let's all buckle down and deliver the components that are essential to powering a more reliable AI infrastructure.

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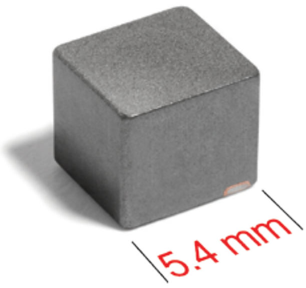

Gallium Nitride in Professional Audio: From Early Adoption to System-Level Advantage

The professional audio industry has traditionally prioritized reliability, predictable lifecycles, and long-term product stability when evaluating new semiconductor technologies. As a result, emerging device platforms are typically introduced only after their electrical performance and robustness are well understood.

By Maurizio Di Paolo Emilio, Marcom Director, Efficient Power Conversion – EPC

Against this backdrop, Markus Bätz, CEO and co-founder of Innosonix, made the decision to transition from silicon to gallium nitride (GaN) power devices as early as 2020 - several years before GaN became widely discussed within professional audio circles.

Early Adoption and EPC Partnership

At the time, Innosonix was looking for a new platform for mid- to low-power professional amplifiers, roughly 50 to 300 watts per channel. They needed something that would work well with their ±60 V rails, and that's when they found EPC's 150 V devices. The EPC2059 proved to be a perfect electrical fit.

What followed was not only a technology transition, but a shift in how the company approached amplifier design. Unlike many traditional semiconductor vendors, EPC provided open access to datasheets, application notes, and detailed reliability reports. Everything was online, everything was documented, which mattered a lot for a small company like Innosonix.

That openness, combined with direct engagement from EPC's engineering team, created the confidence needed to adopt GaN at a time when many audio manufacturers were still hesitant.

Technical Advantages of GaN in Class-D Audio

In high-performance Class-D audio, the choice of switching device directly impacts key sonic metrics. eGaN FETs offer several critical advantages over silicon MOSFETs:

- Lower conduction losses
- Much faster switching transitions
- Zero reverse-recovery charge
- Significantly lower gate charge for given on-resistance
- Very low output capacitance

These characteristics allow designers to raise PWM frequency, shorten dead time, and more closely approximate the ideal digital power waveform at the output stage. This combination reduces open-loop distortion caused by propagation delay, dead-time, and diode recovery effects, while simultaneously cutting switching losses that would otherwise demand larger heatsinks.

The shorter turn-on and turn-off delays and steeper edges enable both lower THD+N and reduced transient intermodulation distortion (T-IMD) with lighter overall feedback. EPC's published reference designs demonstrate THD+N figures below 0.005% and SNR above 120 dB using GaN-based Class-D stages.

At the heart of the Innosonix's success is an engineering philosophy focused on real-world performance. GaN technology didn't just improve one parameter - it changed the entire design approach. The main advantage is that one can operate at higher switching frequencies without huge losses. That allows to shrink size, increase efficiency, and improve loop performance, which in turn helps audio quality. While total harmonic distortion (THD) improvements were modest - since installation-grade speakers often dominate perceived quality - the gain in efficiency, thermal management, and density was significant.

Design Choices and Trade-offs

The design strategy deliberately prioritizes minimizing switching losses rather than conduction losses, leveraging the very low output capacitance and essentially zero reverse-recovery charge of GaN devices. This approach matches the high crest-factor nature of audio signals, where peak currents are short-lived and the average thermal load is comparatively moderate.

Because audio has such a high crest factor, optimizing purely for conduction losses doesn't make sense. Switching losses dominate, so devices like the EPC2207 actually perform better overall.

As a result, EPC2207 has become the preferred choice for lower-power channels, while EPC2307 supports higher-power designs in the kilowatt range.

However, the intrinsic speed of GaN devices requires careful management. Engineers actually had to slow the devices down a bit with additional gate resistance. Otherwise, the switching edges were polluting the analog modulator. In the end, they gave up some raw speed to make the whole system behave.

Another deliberate trade-off involved dead time. While hard-switching with minimal dead time could have improved distortion figures, it would have significantly increased idle losses. Idle consumption was far more important! A green solution was the goal, not just a great datasheet.

On the PCB integration side, the shift from chip-scale (wafer-level) packages to QFN variants in more recent projects simplifies assembly and improves thermo-mechanical robustness while preserving the low parasitic inductance needed for fast, clean switching. EPC's guidelines on stencil design, solder paste volume, and thermal-cycling behavior have been critical to achieving high long-term reliability (Figure 1).

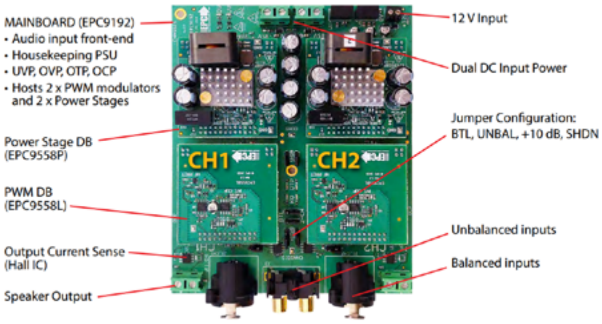

Figure 1: EPC9192: 2 x 700 W/4 Ω Class-D Amplifier Evaluation Board using EPC2307

System-Level Benefits and Markets

Today, every amplifier product in the company's portfolio is GaN-based, the LP² range for example delivers 32 amplifier channels in a single 1U rack enclosure - a level of density that would be extremely difficult to achieve with silicon. That density is not a nice-to-have - it's the whole value proposition. With all channels active, total idle power consumption remains below 100 W, dramatically reducing heat dissipation and cooling requirements.

This capability has unlocked new markets. High-channel-count, space-constrained environments such as superyachts, luxury residences, and large theaters have emerged as key application areas. On a yacht for example, rack space is incredibly expensive. No one wants to dedicate more room than absolutely necessary to technical equipment. In theaters and large installations, the benefits are equally tangible. Lower heat output reduces HVAC demands, simplifies retrofits, and lowers total cost of ownership. These amplifiers now power high-end systems aboard luxury yachts, as well as professional commercial audio visual installations worldwide.

The company's Micro Maxx Series, recently launched in both PoE and mains-powered versions, uses the same GaN-based amplifier core but targets broader, more cost-sensitive markets (Figure 2).

Reliability Lessons

The transition to GaN was not without setbacks. Early reliability issues emerged - not due to device weaknesses, but because of process-related factors unfamiliar to teams accustomed to silicon packages. There was some pretty bad reliability in the first years. Stencil design, solder paste selection, exact paste volume - everything matters with chip-scale GaN devices.

Thermal stress management also required a new mindset. Once these factors were addressed, long-term testing showed excellent robustness, even under aggressive overload conditions.

While the company's installed base - around 25,000 audio channels so far - is still too small to derive statistically meaningful failure rates in ppm, field experience has been encouraging. EPC's detailed reliability reports played a key role in accelerating this learning process. If you actually read and understand the documentation, most of the pitfalls are already described.

Future Outlook

Looking ahead, devices such as EPC2304 are opening doors to GaN-based power supplies, including LLC converters and multi-level PFC architectures. This is where things get really interesting, GaN isn't just about the amplifier anymore - it's about the entire power architecture.

EPC will still be very important to Innosonix's future plans. Innosonix shows what happens when engineering curiosity meets next-generation semiconductor innovation. They make exclusive marine sound systems and push the limits of efficiency in professional audio. For professional audio, GaN may not be about the numbers that show how much distortion there is. Instead, its real effect is that it makes systems smaller, cooler, and more efficient, which is slowly changing how amplification is designed, built, and used.

Figure 2: Micro Maxx Series

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Beyond Compliance: Sustainability and Energy Efficiency Benefits of Lead-Free Soldering

This story investigates the transition from high-lead (PbSn5Ag2.5) to Pb-free solder in power module assembly in response to anticipation of the currently scheduled RoHS Exemption 7(a) expiry in 2027, subject to possible future extension or renewal. The results confirm that Pb-free soldering offers an energy-efficient alternative, supporting both regulatory alignment and sustainability targets.

By Mani Krishna Swami Puppala and Sonja Madloch, Littelfuse

Introduction

High-lead (PbSn5Ag2.5) solder alloys containing more than 85% lead by weight have long been utilized in power module assembly due to their ductility and mechanical robustness under cycling conditions. Their high melting point allows multiple soldering steps without reflowing previously formed joints, while their intrinsic ductility helps absorbing the thermal stress during power cycling. These characteristics have made high-Pb solders the standard choice for demanding applications such as die-attach, terminals, clips, and substrate-to-baseplate bonding in power semiconductor modules. However, the use of lead presents significant environmental and health risks, which has led to increasing regulatory restrictions across global markets.

In the European Union, the Restriction of Hazardous Substances (RoHS) Directive limits the use of lead in electrical and electronic equipment to a maximum concentration of 0.1% by weight in homogeneous materials [1]. Until now, widespread use of high-Pb solder in power modules has been permitted under Exemption 7(a), which allowed lead in high-melting-point solder (≥85% Pb). This broad exemption, originally adopted in 2003, has enabled the continued use of high-Pb solder in industrial power electronics. RoHS Exemption 7(a) expires on 31 December 2027, though it is subject to possible future extension or renewal [1].

In response to these regulations, market adapted in a way by offering more Pb-free solutions (SAC alloy system, SnSb system, Transient liquid phase sintering). This article presents a case study evaluating the transition from high-Pb to Pb-free solder across two representative power modules (M1&M5). The investigation compares both processes in terms of lead consumption, soldering reflow profiles, energy consumption, and CO_2 emissions reduction potentials. The study was conducted under real-world manufacturing conditions, using a calibrated energy monitoring system during reflow soldering in a vacuum furnace. Figures and tables support the discussion of experimental results and highlight the sustainability and economic advantages of the Pb-free assembly process. The findings are discussed in the context of upcoming regulatory deadlines and offer practical insights into the readiness of Pb-free technology for industrial power module production.

Experimental Methods

Two power semiconductor modules were selected for this study, named as M1 and M5. Module M1 was chosen as its complex design and high thermal mass, whereas module M5 was selected for high-runner product. These modules are representatives of high-volume industrial production and similar assembly processes. Conventional soldering of these module assembly was done using a PbSn5Ag2.5 solder alloy. These modules were examined to assess energy consumption differences between soldering processes, both subject to the same vacuum soldering furnace (Budatec VS320). In the new assembly process, this high-Pb solder was replaced with a Pb-free alternative such as SAC alloy. All other materials, including substrates, terminals, baseplates, and dies, remained unchanged.

Module	Capacity per run	Solder	Reflow temp [°C]
M1	max	Pb	410
M1	max	Pb free	255
M5	max	Pb	380
M5	max	Pb free	255

Table 1: Reflow Soldering Conditions for M1 and M5 Modules

Table 1 summarizes the soldering conditions and reflow temperatures applied to the two representative module families. The Pb-based reference was soldered at reflow temperatures of 380 °C and 410 °C as shown in Figure 2.

Figure 1: Eltako DSZ180CEE-32A MID 28032128 three-phase meter digital 10 A


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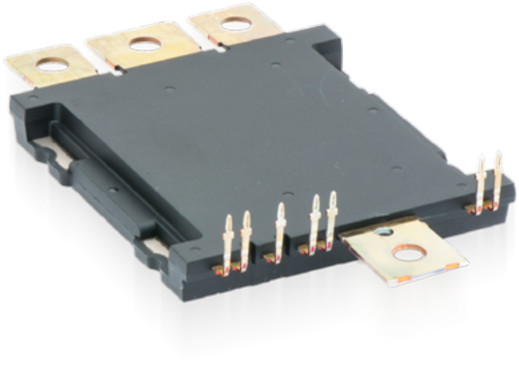

These profiles involved direct ramp-up to peak temperature and extended time-above-liquidus (300 s). For the Pb-free soldering process, a controlled thermal profile was used with reflow temperature of 255 °C. A preheat step at 160 °C with 120 s dwell time was introduced to activate flux and remove volatiles. The temperature was then ramped to peak, followed by a short vacuum stage (1 mbar) to support void reduction and flux residue removal. Final cooling was carried out under nitrogen to minimize thermal stress and intermetallic growth.

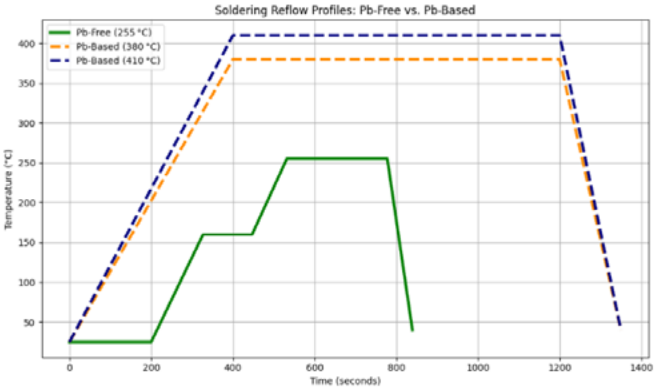

Figure 2: Soldering reflow profiles for Pb-based (380 °C and 410 °C) and Pb-free (255 °C) processes

Electrical energy consumed by the furnace during each reflow run was recorded using a three-phase plug-in MID-certified electricity meter, shown in Figure 1. This portable metering device was connected directly to the furnace's 400 V/50 Hz power supply and allowed precise logging of active energy consumption (kWh) per batch.

For each module and soldering condition, the average energy per run was determined by multiple measurement runs to ensure repeatability. The annual energy consumption and CO_2 emissions for each module family can be calculated using the following equations. Exemplarily, Germany's 2025 grid emission factor is given as 0.328 kg CO_2/kWh [2]. Electricity costs can be calculated based on an industrial tariff e.g. 0.151 €/kWh [3].

1. Annual energy consumption potential

   $Energy\ consumption\ (E_{total})=\left(\frac{E_r}{C_{run}}\right)*N$

   E_r=energy consumption per run

   C_r=capacity(no.of modules) per run

   N=annual production

2. Annual CO_2 emission potential

   $CO_2=(E_m*EF)*N$

   E_m=Energy consumptio per module

   $E_F=CO_2$ emission factor

3. Energy consumption reduction potential

   $\Delta E= E_{Pb}-E_{Pb\ free}$

4. CO_2 reduction potential

   $\Delta CO_2=CO_2^{Pb}-CO_2^{Pb\ free}$

Together, this methodology allowed direct comparison of energy, emissions, and cost between the high-Pb and Pb-free soldering processes under real production-scale conditions. The results of this comparison are presented and analyzed in the following Results and Discussion section.

Results and Discussion

Two energy metrics were used to assess the effect of switching from high-Pb to Pb-free soldering, (i) electricity consumption per run and (ii) energy consumption and CO_2 emissions per module. The per-run values represent the total electricity consumed by the soldering furnace during one complete operating cycle, measured while the process was operated at maximum loading capacity.

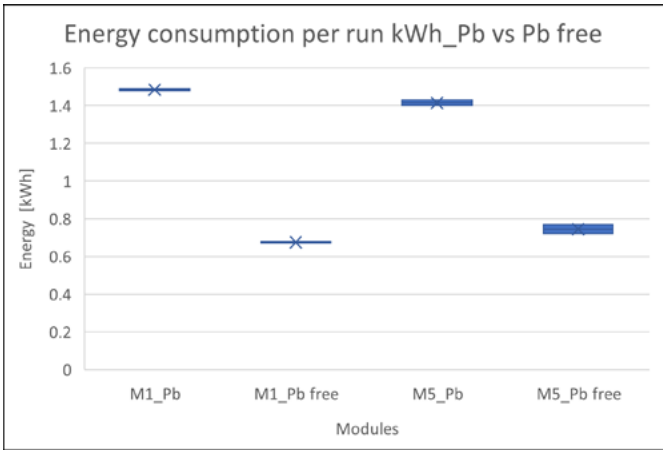

Figure 3: Energy Consumption per furnace Run for Modules M1 and M5 Under Pb and Pb-Free soldering

Figure 3 illustrates that under these max-capacity runs, a major decrease was observed with the Pb-free process. For module M1, the per-run electricity demand drops from approximately 1.49 kWh with the high-Pb solder to 0.68 kWh with the Pb-free solder. Similarly, module M5's energy requirement decreases from about 1.42 kWh to 0.75 kWh per run, indicating that Pb-free soldering requires approximately half the run-level energy compared with the high-Pb process.

	Module	Solder material	Reflow temp[°C]	Energy consumption [kWh]	CO_2 [kg]
1	M1	Pb	410	0.165	0.054
2	M5	Pb	380	0.118	0.039
3	M1	Pb free	255	0.075	0.025
4	M5	Pb free	255	0.062	0.020

Table 2: Energy Consumption and CO_2 Emissions, for High-Pb and Pb-Free Soldering Processes (M1&M5)

As shown in Table 2, energy consumption and CO_2 emissions were evaluated per module for M1 and M5 under both Pb-based and Pb-free soldering conditions. Module M1 showed a decrease in energy consumption per module from 0.165 kWh in the high-Pb process to 0.075 kWh after switching to Pb-free solder, corresponding to an energy saving of more than 55%. Similar trends were observed in M5 from 0.118 kWh to 0.062 kWh reduction energy saving around 48%. This corresponds to reductions in CO_2 emissions from 0.053 kg to 0.024 kg for M1, and from 0.038 kg to 0.020 kg for M5, based on Germany's 2025 average grid emission factor of 0.32 kg CO_2/kWh. The measured data revealed that M1 exhibits its higher energy consumption in the same Pb-free process (peak T=255°C) compared to M5. This difference is primarily attributed to the higher thermal mass of M1. Heavier module designs and higher material volume require additional heat input to reach target soldering temperatures.

The main driver in energy reduction between M1 and M5 is primarily attributed to the differences in their original Pb-based reflow temperatures. For module M1, the high-Pb process operated at reflow temperature of 410 °C, whereas for M5, the peak was 380 °C. Since both were transitioned to the same Pb-free process at 255 °C, M1 experienced a larger absolute temperature drop (155 °C) compared to M5 (125 °C). This reduction of over 125 °C significantly reduces furnace energy demands [4]. Studies have shown that even a modest 35 °C reduction in peak reflow temperature can yield around 10% energy savings in industrial furnaces [4]. The 125–150 °C decrease achieved in this case explains the nearly 50% energy reduction observed. Despite these lower temperatures, the Pb-free process maintained full compatibility with production quality requirements. All modules passed standard optical inspection, isolation tests, and electrical validation after soldering. These findings reinforce the practicality and industrial relevance of transitioning to Pb-free soldering in power module assembly, combining process optimization with regulatory readiness and sustainability-driven innovation.

Conclusion

This study demonstrates that Pb-free soldering has the potential to be a reliable and sustainable alternative for power module assembly. The transition eliminates significant lead usage (several tons/year dependent on production volume), lowers reflow temperatures and achieves a 48% reduction in energy consumption and reduction in CO_2 emissions along with meaningful cost savings. As RoHS Exemption 7(a) approaches its scheduled 2027 expiry, adopting Pb-free processes supports regulatory compliance while advancing environmental and operational efficiency in power electronics.

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Designing More Robust Battery-Powered Motor Drives with MOSFETs

Battery-powered motor drives are becoming the dominant architecture across a wide range of applications, from micromobility and power tools to agricultural machinery and industrial electrification. As system power levels increase and battery voltages climb from legacy 48V architectures toward 72V, 96V, and even 144V platforms, designers face tradeoffs between efficiency, robustness, size, and cost.

By Ryan Manack, VP of Marketing, iDEAL Semiconductor

While low on resistance and high current handling remain fundamental performance metrics, real-world motor drive reliability is rarely defined by steady-state efficiency alone. Instead, long-term field performance is dictated by how well power devices respond to transient stress, fault events, and repeated overload conditions. In this context, MOSFET robustness becomes a primary design consideration rather than a secondary constraint.

The Reality of Battery-Powered Motor Drive Operation
Unlike line-powered systems, battery-powered motor drives must deliver high peak currents from limited voltage rails. Rapid acceleration, regenerative braking, locked-rotor events, and abrupt load changes are inherent to normal operation rather than rare corner cases. These events push inverter stages close to their electrical and thermal limits, often within compact, thermally constrained enclosures.

Short-duration fault conditions are particularly challenging. During locked-rotor events and fault conditions, current can rise to extreme levels within microseconds. Protection circuitry has a finite detection and response time, during which MOSFETs must remain electrically stable. If the device fails before the fault is cleared or the system can safely shut down, damage frequently propagates beyond the original failure point, resulting in catastrophic inverter loss.

As motor drive power scales upward, from e-bikes and scooters to electric mowers, tractors, forklifts, and industrial equipment, the frequency and severity of these stress events increase. Designing for real-world motor behavior, therefore, requires devices with meaningful electrical margin, not just optimized conduction losses.

SuperQ™ Robustness Starts at the Silicon Level
SuperQ MOSFET robustness is not achieved through conservative derating or oversized packaging. Instead, it is built directly into the silicon architecture. The SuperQ structure employs a fully charge-balanced trench design that preserves a wider conduction region than competing approaches that aggressively scale feature sizes to minimize resistance.

By preserving a wider current-conduction path while maintaining charge balance, SuperQ MOSFETs achieve low on-resistance without concentrating current into localized regions of the silicon. The combination of wider mesa regions, higher silicon efficiency, and optimized trench geometry spreads current more evenly across the die, reducing localized heating and improving tolerance to high peak currents and fault-induced electrical stress (Figure 1).

This architectural approach allows SuperQ devices to operate safely under electrical and thermal stress levels that would exceed the practical limits of many conventional silicon MOSFETs.

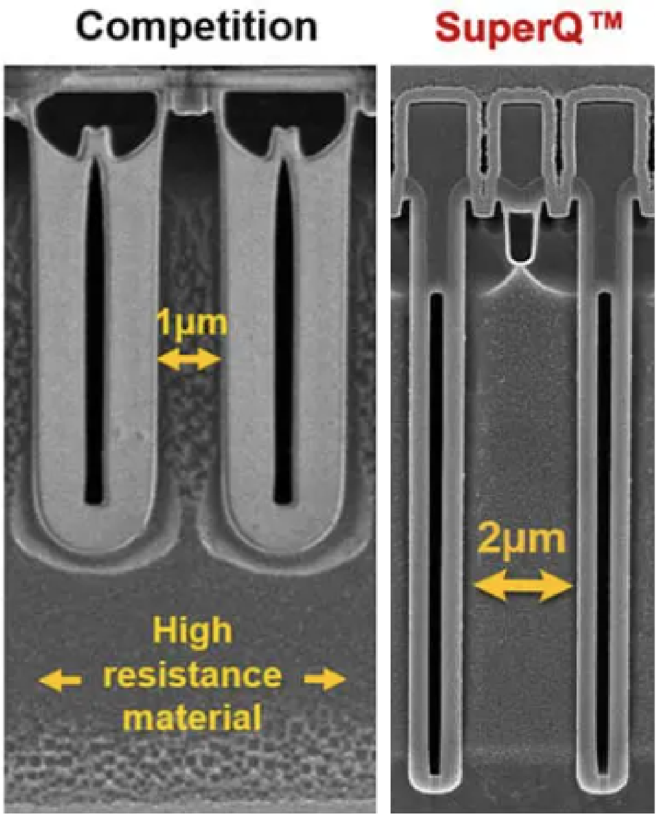


Figure 1: Comparison of traditional silicon architecture vs. SuperQ architecture

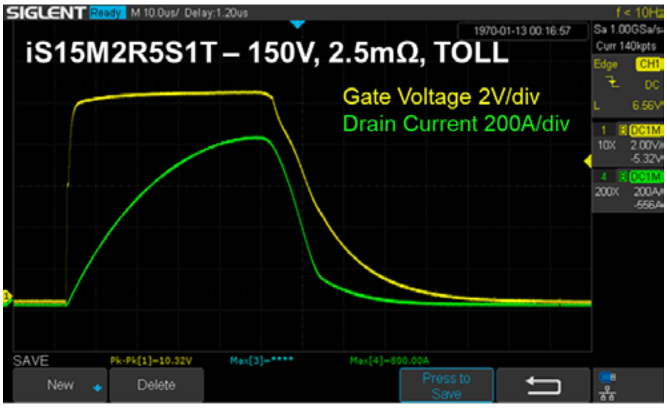
Short-Circuit Withstand Capability Under Real Fault Conditions
Short-circuit withstand capability (SCWC) is a critical but often underappreciated metric in battery-powered motor drives. During a short-circuit event, MOSFETs must sustain extremely high current while maintaining gate control long enough for protection mechanisms to respond.

To characterize real-world behavior, SuperQ MOSFETs are evaluated using controlled short-circuit testing that drives devices to failure, rather than relying solely on static datasheet ratings. In this methodology, progressively increasing short-circuit current pulses are applied while monitoring drain current and gate voltage response. Adequate cool-down time between pulses ensures that results reflect intrinsic electrical robustness rather than cumulative thermal effects.

In comparative testing of 150V TOLL-packaged devices (shown in Table 1), a SuperQ MOSFET with a typical on-resistance of 2.5mΩ sustained peak short-circuit currents approaching 800A before failure (Figure 2). Under identical conditions, a leading competing device with a similar voltage rating and on resistance failed at approximately 580A, indicating that the SuperQ device withstood a peak short-circuit current roughly 1.4× higher.

Parameter	Units	iDEAL iS15M2R5S1T	Comp I
Max $R_{DS(on)}$	mΩ	2.5	2.5
Q_{SW}	nC	8.9	38
SC Current per MOSFET	A	792	584

Table 1: Comparison of leading MOSFETs for $R_{DS(on)}$ and SCWC



iDEAL Semi Passes 800A Current

Figure 2: Short Circuit Withstand Current (SCWC) testing of 150V SuperQ MOSFET

From a system perspective, this additional margin translates directly into longer fault-detection windows, reduced sensitivity to protection timing tolerances, and improved immunity to nuisance or delayed fault response. For motor drives operating near their safe operating area limits, this margin can significantly reduce the likelihood of catastrophic inverter failure.

Battery Disconnect and Protection Roles

In battery-powered systems, inverter robustness alone is not sufficient to guarantee system safety. Battery disconnect and protection circuits must safely interrupt extremely high fault currents, often before significant thermal rise occurs.

During an external short-circuit event, discharge MOSFETs are frequently the only elements capable of protecting the battery pack. These devices must turn off while carrying very high current, placing severe electrical stress on the silicon.

SuperQ 150V and 200V MOSFETs combine low conduction loss with high short-circuit withstand capability, making them well suited not only for motor inverter stages but also for battery disconnect, inrush control, and pack protection applications within high-power battery systems.

The Bonus Benefit of Lower Component Count

An additional practical consequence of the trend to higher battery voltages is a reduction in the number of parallel devices required. In 48V systems operating at several hundred amperes, multiple MOSFETs are often paralleled in each switching position to reduce conduction losses and distribute thermal load. Paralleling devices increases PCB area, gate drive complexity, current-sharing sensitivity, and layout parasitics.

As voltage increases, reduced phase current lowers the current requirement per device. When combined with the very low $R_{DS(\text{on})}$ in the 150 - 200V SuperQ MOSFET family, designers can often reduce the number of devices in parallel per phase leg while maintaining or improving thermal performance. This reduction simplifies gate-drive routing, lowers total gate charge, reduces PCB copper area, and improves overall system reliability by minimizing parasitic interactions. Importantly, these benefits are achieved without sacrificing efficiency, enabling designers to balance cost, size, and performance more flexibly.

Scaling Across Battery-Powered Motor Drive Applications

The benefits of SuperQ technology extend across a wide range of motor drive power levels. In compact applications such as e-bikes and drones, improved transient robustness and reduced MOSFET count support higher efficiency and longer operating time within tight thermal constraints. At higher power levels, including electric motorcycles, mowers, and industrial equipment, the ability to survive repeated overloads and fault events becomes a key determinant of uptime and warranty performance.

Even in high-power systems exceeding 100kW, such as electric tractors and heavy machinery, long-term reliability is ultimately defined by survivability during abnormal conditions rather than nominal operating points.

Designing for Real-World Motor Drive Behavior

Battery-powered motor drives operate through continuous transitions, startup, acceleration, braking, load changes, and faults. Designing for these realities requires power devices that deliver more than low resistance; it requires genuine electrical and thermal margin.

By embedding robustness at the silicon level, SuperQ MOSFETs shift fault tolerance from a system-level burden to a device-level feature. This enables simpler, more compact motor drive architectures while improving reliability under real operating conditions.

For designers developing the next generation of battery-powered motor drives, this approach enables greater design freedom, allowing efficiency, size, cost, and robustness to be optimized simultaneously rather than traded against one another.

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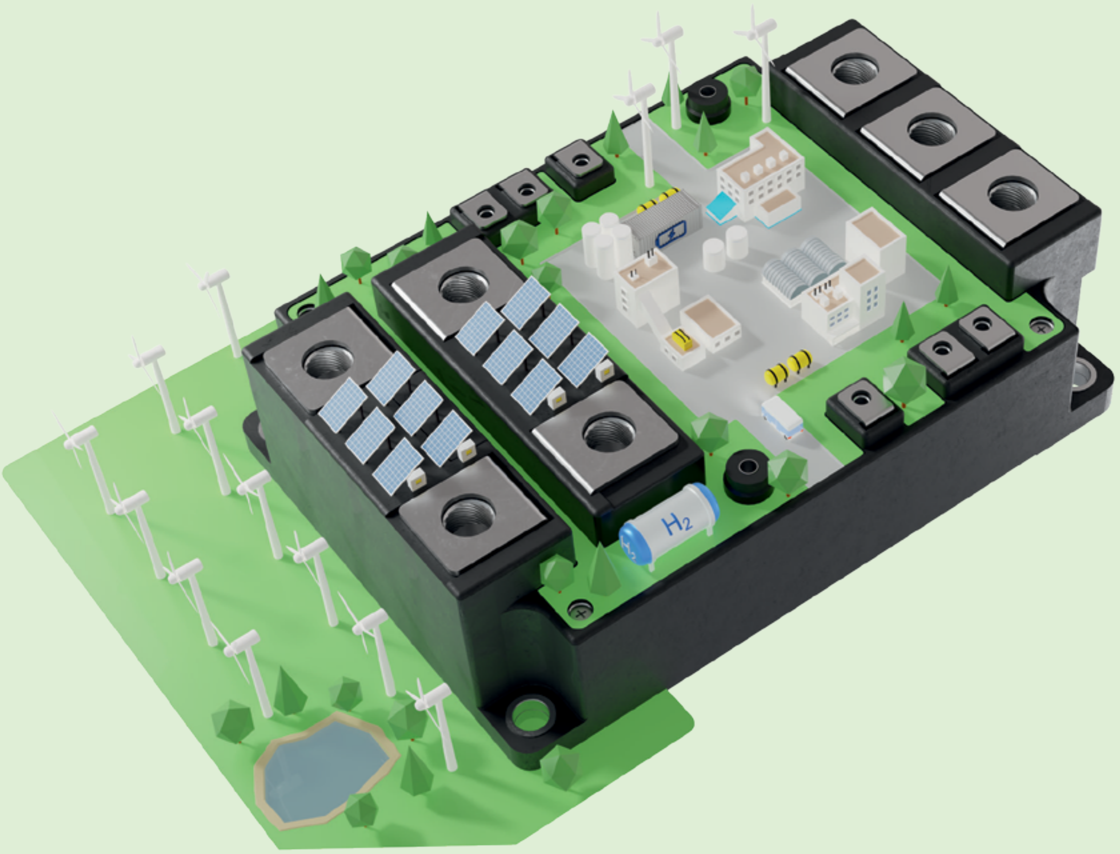
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Formic Acid Soldering – Enabling the Next Generation of Power Devices (Part 2)

What are the advantages that formic acid soldering can offer for assembling power devices in terms of performance and cost-of-ownership? Having described the basics of this process in part 1 in Bodo's Power Systems 11/2025, this part 2 of the story will focus on application considerations and take a deeper look at case studies for prevailing solder material alternatives, including solder preforms and emerging solder paste technology.

By Joseph Hertline, Product Manager for Engineered Solder Materials, Indium Corporation

The targeted mission profile (environmental, electrical, and thermal operating conditions) and reliability expectations are key considerations in packaging design. While engineers seek to squeeze out as much efficiency as possible by pushing the performance boundaries in devices, cost is still equally important to enable the scale-up necessary for electrification in the automotive, energy infrastructure, and industrial sectors.

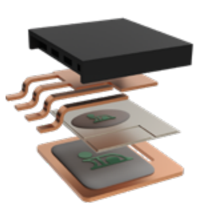
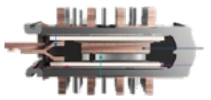
Discrete	Molded Package	Baseplate Module	Dual-Side Cooling
			

Figure 1: Common Power Device Form Factor Types

There are several device form factor types that exist in the market, for example: discrete, molded package, baseplate, and dual-sided cooling. As such, unique characteristics exist for each type. However, the general construction or stack-up of these devices are common, and the performance and cost factors influence material selection for packaging, regardless of the device type.

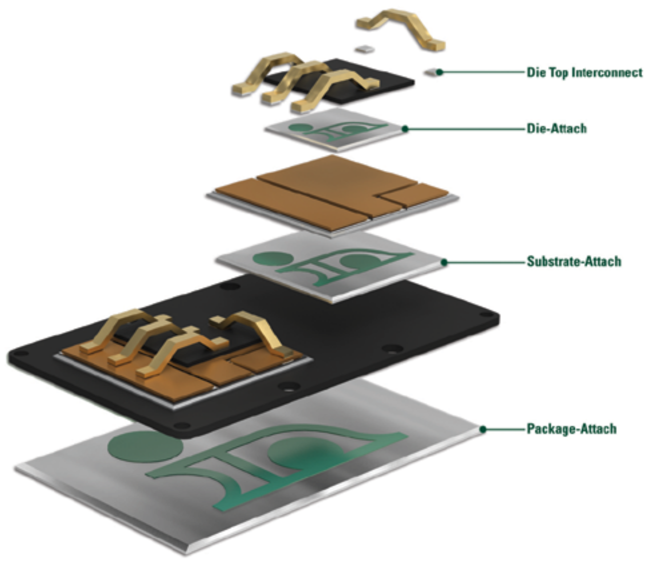


Figure 2: Typical Power Device Packaging Construction Stack-up

Each interface—die top interconnect, die-attach, substrate-attach, package-attach—imposes distinct constraints on functional performance due to mechanical properties, thermal dissipation, and CTE mismatch. The corresponding metallization choices also have a direct influence over the wettability of the soldering material and the configuration parameters in the formic acid/vacuum reflow profile that are required for success. For example, nickel finishes generally have a narrower soldering process window compared to copper or silver/gold-plated and may require extended formic acid soak time to remove oxides for effective solder wettability. Table 1 provides a summary of common packaging materials used in device stack-ups, and constraints that must be considered in selecting the soldering alloy and reflow parameters.

Soldering Alloys

With regards to soldering alloy alternatives, it is worth noting that no single solution exists that will universally satisfy all mission profiles and packaging constraints. Therefore, trade-offs in both process-ability and performance must be considered by Design Engineers during selection:

- **Metallization Compatibility,** which affects wettability, reflow profile configuration parameters, and process window for formic acid soldering
- **Minimizing Voiding,** to achieve consistent thermal performance
- **Process Temperature,** which may influence sensitive materials in the device packaging, such as encapsulation, or affect reliability in multiple reflow stages
- **Reliability Performance,** considering the operating temperature and mission profile
- **Environmental Sustainability**, to reduce the use of lead in manufacturing (Pb-free)

Figure 3 lists commonly used alloys for power device soldering with formic acid:

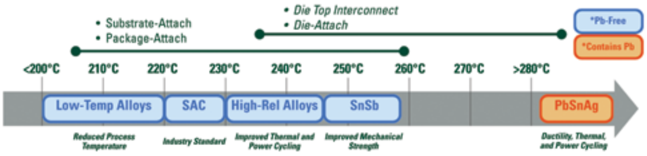
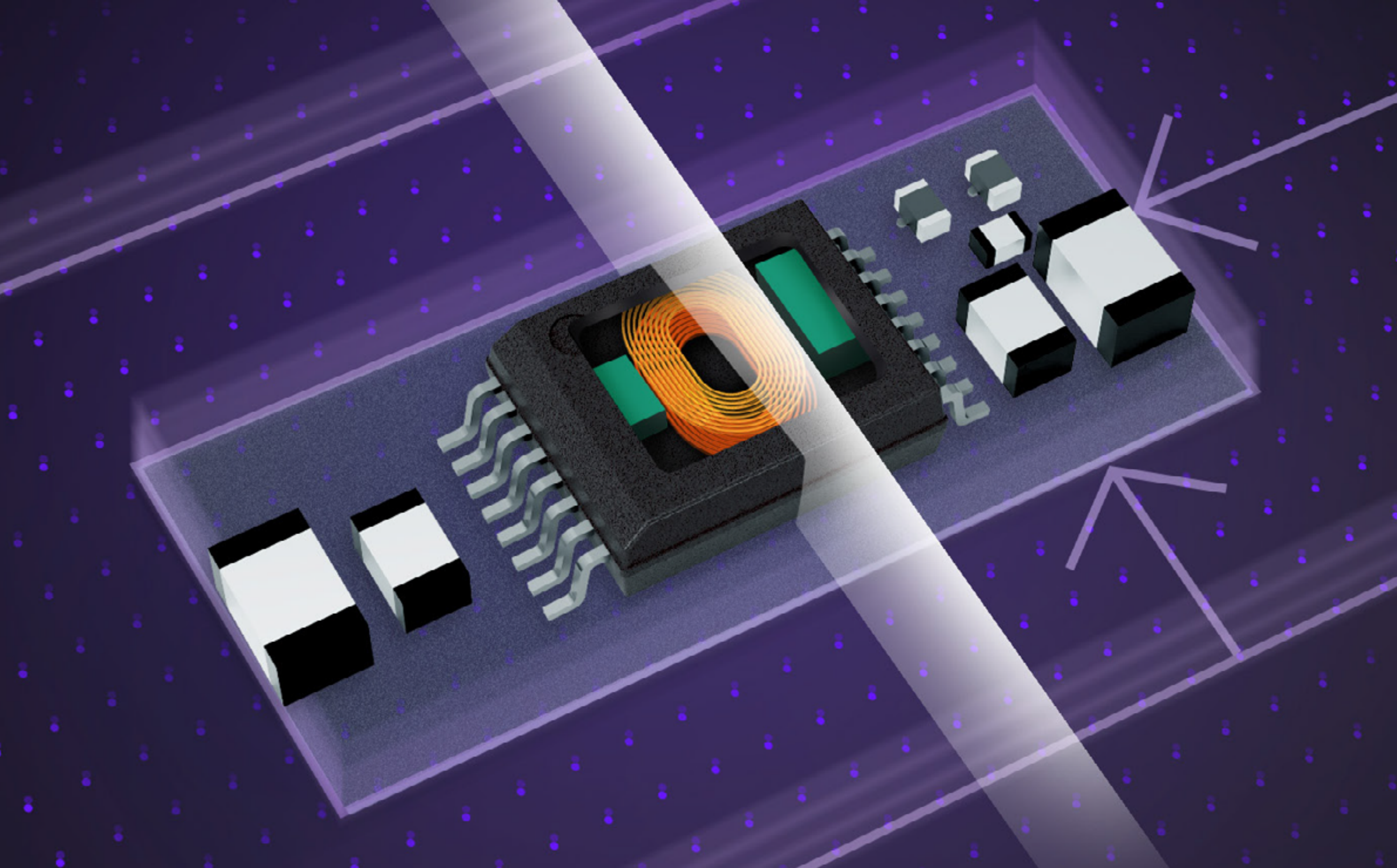


Figure 3: Common Solder Alloys used in Power Electronics Applications



	Packaging Component	Common Materials	Constraints
Die Top Interconnect	Clip/Lead Frame	Bare Cu	Bondline Thickness
	Die Top Metallization	Ti-NiV-(Au or Ag) or Ni-Pd-(Au/Ag)	CTE Mismatch
Die-Attach	Semiconductor Die	Si, SiC, GaN	Junction Temperature
	Die Bottom Metallization	Ti-NiV-(Au/Ag) or Ni-Pd-(Au/Ag)	Bondline Thickness
Substrate-Attach	Ceramic	Al2O3, ZTA, Si3N4, AlN	Strength, Reliability
	Substrate Metallization	DBC, AMB; Cu, ENIG, Ag-plated	Warpage
	Baseplate	Cu, AlSiC *Aluminum Graphite (emerging)*	Thermal Conductivity, Warpage, Thermal Mass
	Baseplate Metallization	Ni-plated	Solder Wettability
Package-Attach	Heat-Sink/Cooler	Cu, Al	Thermal Conductivity, CTE Mismatch
	Metallization	Ni-plated, Ag-plated *Selective Cu (emerging)*	Warpage, Solder Wettability

Table 1: Typical Power Device Packaging Construction Stack-up

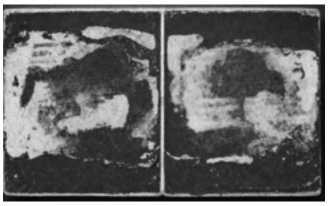
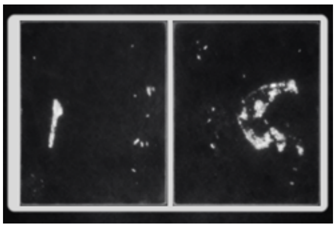
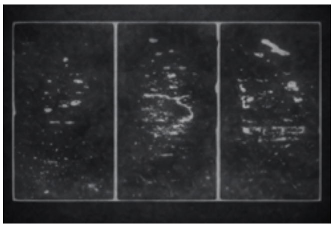
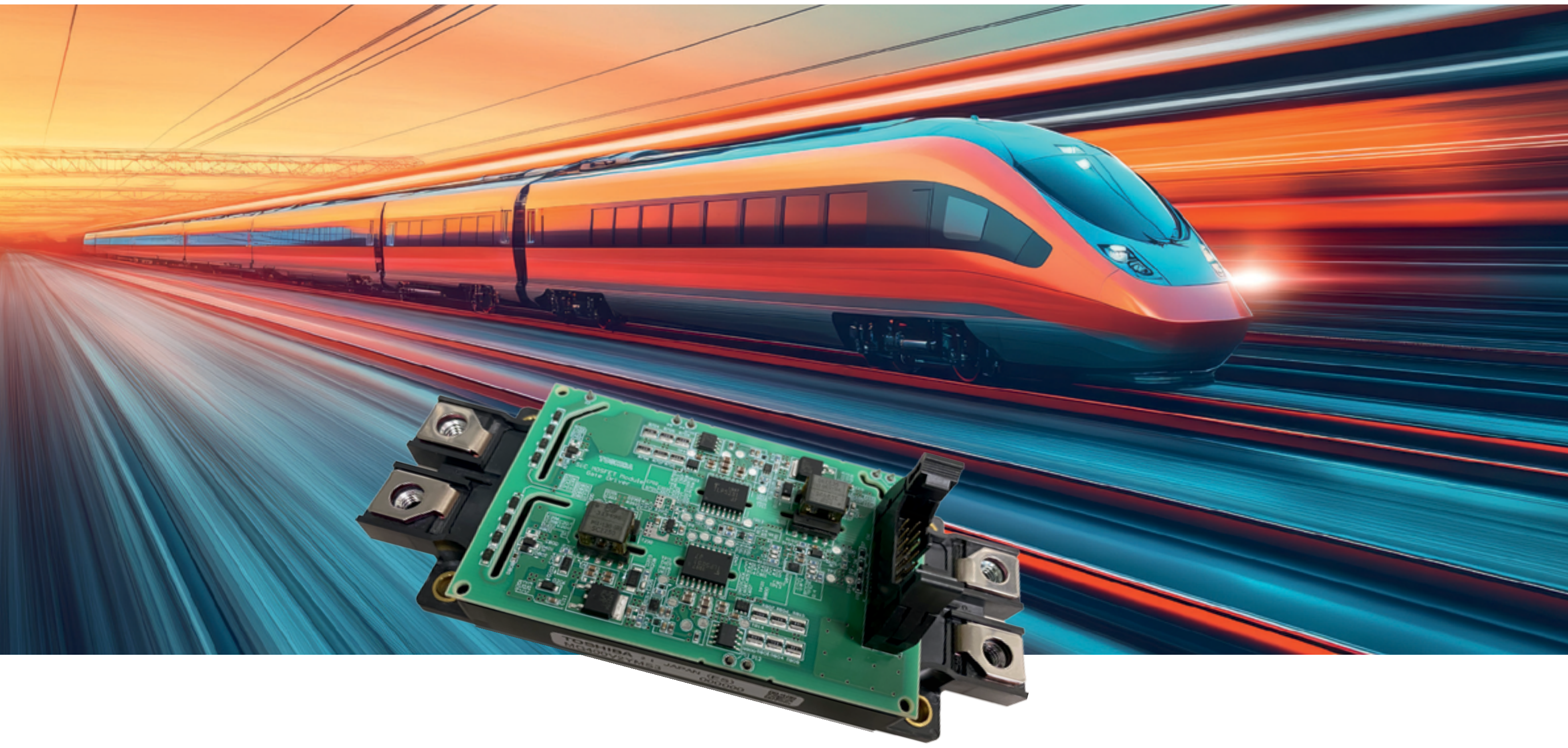
Substrate-Attach Failure	Failure Mode Description	Resolution Steps
	Non-wetting, delamination due to excess surface oxidation.	Increase formic acid temperature (180-250 °C) Increase formic acid soak time Verify formic acid flow rate, concentration
 	Preform discoloration due to significant surface oxidation caused in forming operations Corresponding non-wetting on baseplate	Preform manufacturing not optimized for formic acid reflow Increase formic acid soak time
	Organic contamination on preform surface increases localized voiding	Preform manufacturing not optimized for formic acid reflow Excess manual handling prior to assembly
	Marginal voiding caused by increased oxidation Packaging weaknesses and/or environmental conditions in storage, temperature/humidity	Preform packaging not optimized to maintain shelf life

Table 2: Common Failure Modes in Formic Acid Soldering with Preforms and associated Actions for Improvement

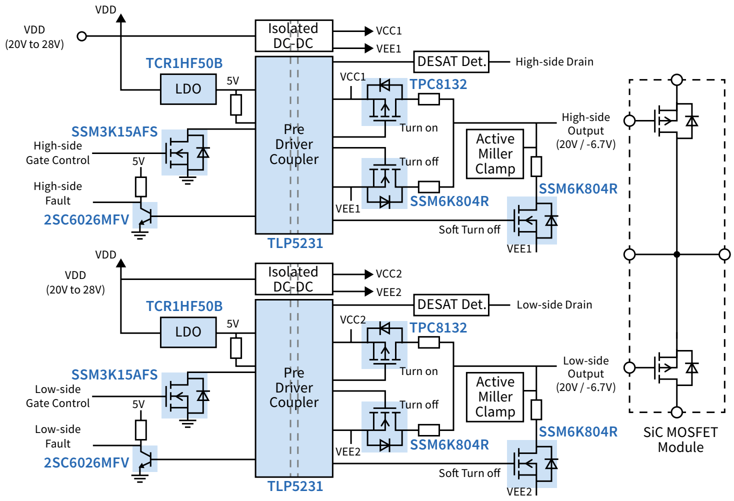
TOSHIBA

Gate Drive Circuit Solution for SiC MOSFET Module



Highlights

- Built-in implementation on a SiC MOSFET Module
- Output voltage +20V (typ.) / -6.7V (typ.)
- Output current ±9.8A (max.)
- Max. PWM frequency 50kHz
- Independent open-collector fault signal output of high-side and low-side



Featured Products

- **TLP5231** – isolated pre-gate driver
  - Split output
  - UVLO protection
  - Over current protection using DESAT
  - Fault signal feedback
  - Soft shutdown
  - Active Miller clamp
- **SSM6K804R** – n-ch MOSFET
  - 40V, 18mΩ @V_{GS} = 4.5V, 1.5W, TSOP6F package
- **TPC8132** – p-ch MOSFET
  - -40V, 20mΩ @V_{GS} = -10V, 1.9W, SOP-8 package
- **TCR1HF50B** – LDO Regulator
  - V_{IN}=4~36V, V_{OUT} = 1.8V to 5.0V, V_{OUT} = ±1% (T_a = 25°C)
  - Overcurrent protection, thermal shutdown, inrush current reduction
- **SSM3K15AFS** – n-ch MOSFET
  - 30V, 3.6Ω @V_{GS} = 4V, 100mW, SOT-416 package
- **2SC6026MFV** – npn transistor
  - 50V, 150mA (max.), SOT-723 package

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Solder Preform Applications

Solder preforms are custom-sized, solid, fabricated parts consisting of a given solder alloy, and can be produced to precise dimensions to closely match the targeted geometry in the device stack-up. For formic acid soldering applications, solder preforms are purely metal and contain no flux—this makes preforms the clear choice for larger area soldering, including substrate- and package-attach, where voiding and thermal performance are factors. Further, the engineering customization available with solder preforms allows for the precise tuning of solder volume that is consistent over mass production.

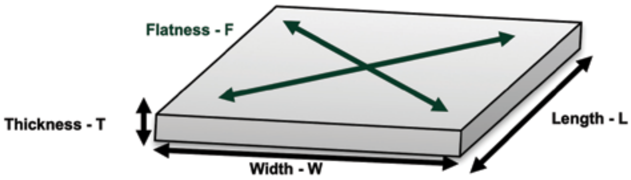


Figure 4: Solder Preform Configuration

While formic acid soldering with preforms offers performance, quality, and scalability advantages, vulnerability to material contamination and excess oxidation narrow the process window for success and pose challenges to solder preform manufacturing. To illustrate these challenges, this story will dig further into the substrate-attach application. In this case, the relatively larger area of the soldering interface means more surface area to reduce oxidation and greater risk for contamination due to manufacturing methods. Table 2 shows common failure modes in formic acid soldering with preforms and associated actions for improvement.

Indium Corporation has developed specialized solder preforms designed specifically for use in formic acid reflow, to minimize surface oxidation and growth over time, prevent any possible contamination, and maximize shelf life. This approach has been proven to deliver really low voiding and maintain a stable shelf life for robust wetting over time, as shown in figures 5 and 6.

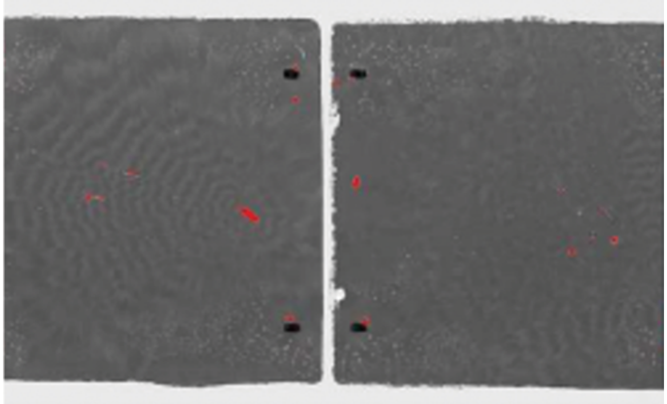


Figure 5: Specialized SnSb Preform results in <1 % Voiding in Substrate-Attach with Formic Acid/Vacuum Soldering.

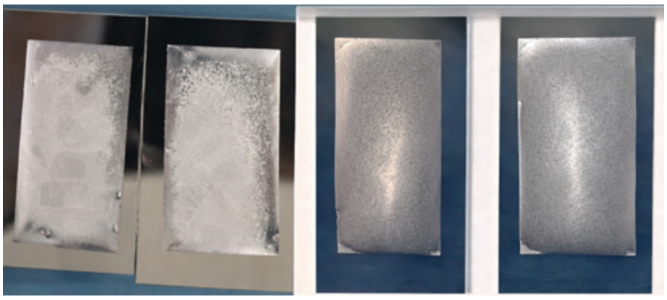


Figure 6: Robust Wetting of SnSb Preforms on Ni Baseplate: Month 1 (Left) Compared to >12 Months (Right).

Emerging Fluxless Solder Paste Technology

Conventional solder pastes leverage a flux vehicle, consisting of rosins, resins, and activators, to both reduce oxides during reflow and maintain the necessary rheology to apply the solder through printing or dispensing. In a formic acid reflow environment where flux is not required, these components in conventional solder paste produce residues that can contaminate the material integrity and often require post-process cleaning. Ongoing innovations in fluxless solder paste have resulted in new technologies that leverage a complex solvent system as a binder with thixotropic agents that enable dispensing and printing, while leaving virtually no residue after reflow.

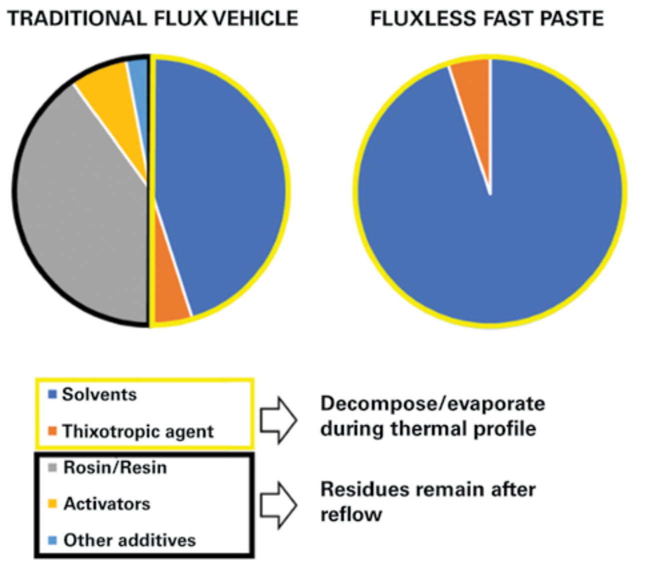


Figure 7: Comparison of Flux and Fluxless Binder

The evaporation of the fluxless paste binder components during reflow is a critical design characteristic to promote solid wettability and eliminate residue in formic acid reflow. Thermogravimetric analysis (TGA) is a technique used to measure the change in mass of a material as a function of temperature and/or time under a controlled atmosphere. The comparison bin figure 8 demonstrates the absence of residues with fluxless paste after reflow compared to conventional solder pastes.

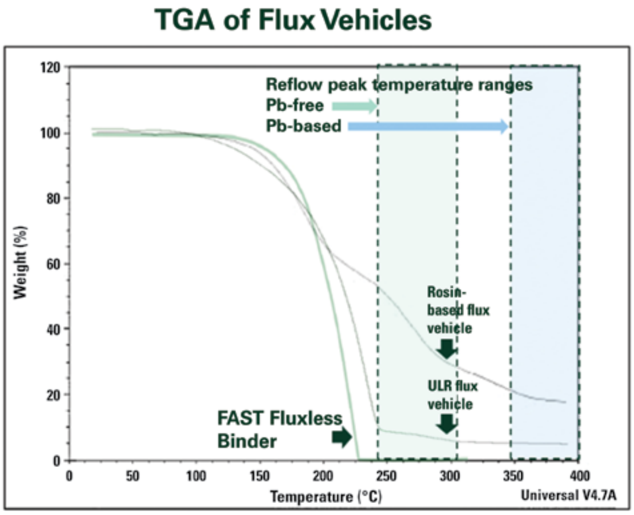


Figure 8: TGA of Fluxless Solder Paste Compared to Conventional Solder Paste

This technology offers a compelling solution for die and component-level soldering in the power device stack-up to reduce equipment footprint and improve voiding for overall performance gains. A case study was performed to characterize solder wettability, voiding, and delamination for die-attach (10 mm x 10 mm, 5 mm x 5 mm) and component-attach, i.e., thermistors using open samples, as well as die-capped samples inspected via acoustic microscopy. The results below indicate solid wetting, consistent edge quality, and ultra-low voiding for the fluxless paste.

Figure 9: Reflow Results for High-Pb Fluxless Solder Paste – Component-Attach

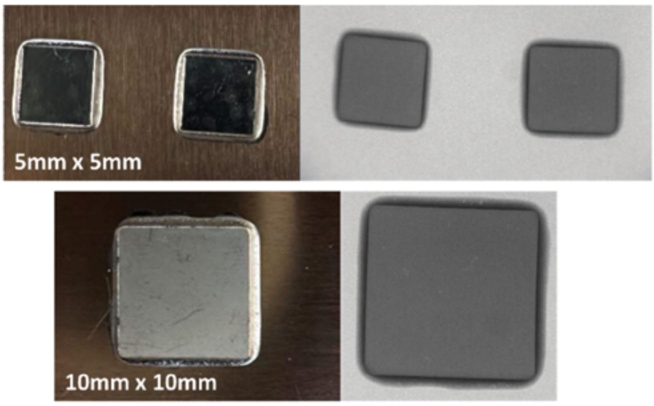


Figure 10: Reflow Results for High-Pb Fluxless Solder Paste – Die-Attach

Die shear, a commonly used technique to determine the quality of the die-attach process, was also carried out to compare the bond strength for fluxless solder paste with formic acid reflow vs. typical values expected from standard high-lead solder with a conventional reflow process. Die shear was carried out at time zero (post reflow) and after both 500 cycles and 1,000 cycles of thermal cycling between -65°C and 150°C. Typical die shear values for high-lead solder are between 20 - 40MPa, depending on other factors such as surface finish or process conditions, and this was the case for the fluxless paste reflowed with formic acid. The average die shear strength at time zero was 31.7MPa, after 500 cycles the average was 28MPa, and after 1,000 cycles the average was 28.3MPa. This showed that the die shear strength for fluxless paste reflowed with formic acid was comparable to traditional solder paste with a conventional reflow for the same alloy system.

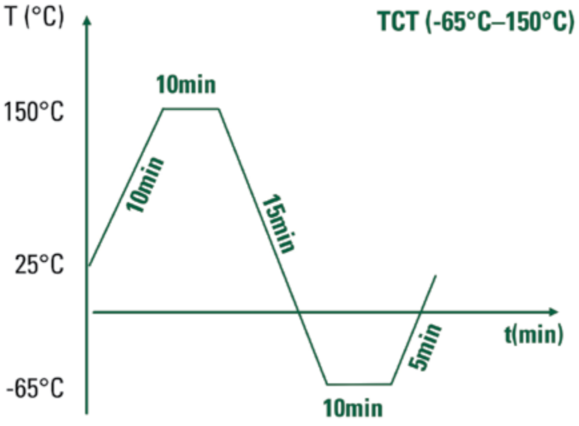
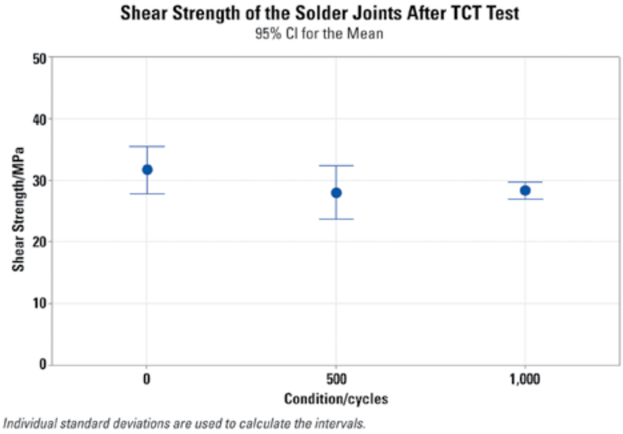


Figure 11: Thermal Cycling Profile



Individual standard deviations are used to calculate the intervals.

Figure 12: Die Shear Results

Conclusion

Formic acid soldering has transitioned from a niche process to a mainstream solution, especially in power electronics manufacturing. It rests on three pillars:

- **Material Cleanliness and Stack-up Design** – metallization and surface oxide/contamination characteristics influence the process window
- **Reflow Process Control** – careful consideration of factors affecting formic acid fluxing activity, temperature, and vacuum
- **Solder Material and Quality** – specially developed materials for formic acid soldering maximize yields and enable increased device performance

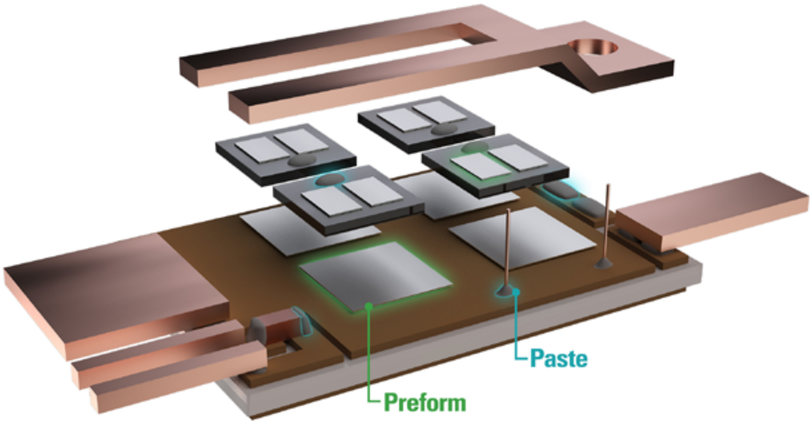


Figure 13: Future Power Device Architectures Can Leverage both Fluxless Solder Preforms and Paste.

With mature formic acid soldering processes, proven solder preform solutions, and emerging fluxless paste technology, engineers have more choices than ever to balance the performance and cost-of-ownership goals for future power device designs. With the progression of materials technologies, both solder preforms and fluxless paste can be incorporated into a single packaging design. This offers a completely fluxless solution for the entire device stack-up to achieve unprecedented flexibility and efficiency with formic acid reflow processes, enabling the Next Generation of Power Electronics devices.

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Multilevel 3-Phase Rectifier for Increasing AI Server PSU Output Power in Data Centers

5LANPC topology for high efficiency at high power density by reduction of passive components

The rise of artificial intelligence (AI) has resulted in a significant increase in power demand in data centers, with AI server racks power levels expected to reach MW range. Accordingly, the server rack architecture will evolve to separated IT rack and sidecar power rack, as shown in Figure1.

By the System Solutions Boards Team: David Meneses, Principal System Application Engineer, and Alex Rossi, Staff System Application Engineer; all at Infineon Technologies

This separation allows the PSU in the sidecar power rack to increase its power up to ranges far exceeding the tolerance of the IT sidecar, reaching even 30 kW with 3-phase AC input and high voltage DC (HVDC) output.

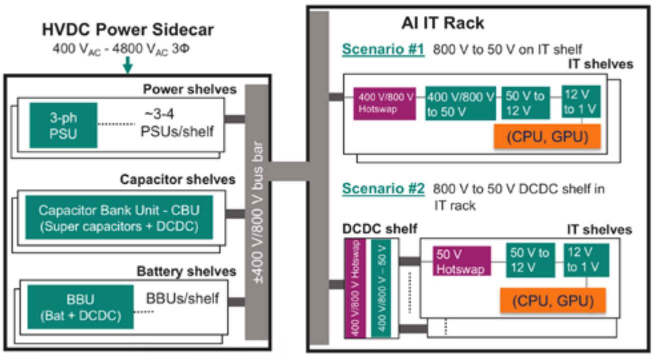
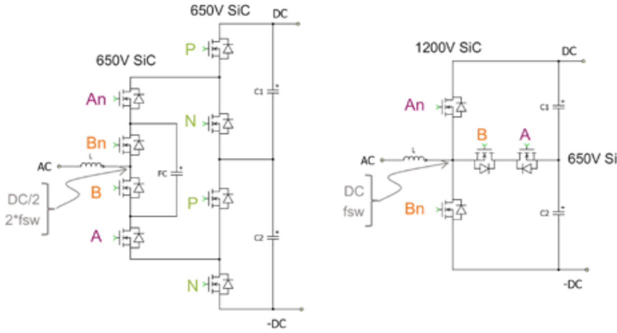


Figure 1: Next generation AI server rack architecture.

Since the input voltage for the PSU reaches 3-phase territory, it is natural that the PSU's topologies also need to change accordingly. The T-type Vienna rectifier is a well-known 3-phase rectifier topology in industrial applications (Figure 2, right), which can be used in these PSUs as well. In the T-type Vienna rectifier, A-An and B-Bn are modulated during the AC's positive and negative respectively at a high switching frequency. Therefore, a 3-level voltage (DC/0 V/-DC) with a switching frequency component is applied to the PFC choke switching node. To enable this, 1200 V switches are required for connecting the switching node to the DC rails, while 650 V devices are needed for the back-to-back switches implementation.



5LANPC PFC T-type Vienna Rectifier

Figure 2: 3-phase topologies for AI server power supplies.

However, in the search for higher powered PSUs, an emerging alternative for 3-phase rectifiers in AI server PSU is the 5-level active neutral point clamped (5LANPC) PFC, in which efficiency and power density are the key highlights. Figure 2 (left) presents the 5LANPC topology in which the stacked devices on the DC side (P/N) are switched according to the AC polarity. The flying capacitor (FC) component of the 5LANPC phasing the AC side implements 180 degrees out-of-phase PWM (A-An versus B-Bn) similar to a single-phase 3-level FC PFC. As a result, all the devices required for the topology implementation are rated for 650 V. In addition, the switching node voltage is half of each of the DC capacitor voltage, at double of the switching frequency. Therefore, the PFC choke volt-second is 4 times lower than that of the T-type Vienna PFC. The consequent size reduction, together with an expected performance improvement, makes the 5LANPC a very good topology for AI PSUs, which can be evaluated using the REF_18KW_HFHD_3P_PSU . The FC modulation in the 5LANPC choke provides a ripple reduction as well, which enables a reduction in the differential mode EMI filtering effort.

Choke and EMI component size comparison in 5LANPC and T-type Vienna

Figure 3 (top) presents the PFC choke current and ripple in a 5LANPC for 398 V L-L AC and ±445 V DC, with a switching frequency of 35 kHz and an output power of 18 kW. The choke is implemented using 2 cores CH270060GT with 28 turns and an AWG14 wire. This specific design is used as a base for comparison with the T-type converter.

The phase-shift modulation of the FC converter enables a ripple reduction effect and doubling the switching frequency in the inductor, which provides a maximum current ripple of around 8 A to be considered for the differential mode (DM) EMI design.

If the same choke is used in a T-type Vienna with 70 kHz switching frequency (same inductor frequency), the higher volt-second of the topology considerably increases the inductor current ripple, as well as core losses which jeopardize the performance, as described later in this article. The resulting maximum current ripple, as shown in Figure 3 (middle), considerably increases the DM EMI effort, which directly translates to a size increase as more capacitance or stray inductance is needed.

The design choice to reduce the inductor ripple, and to keep an EMI filter size similar to 5LANPC in the T-type converter, is to increase the PFC choke inductance. Figure 3 (bottom) shows the current ripple when double the number of cores are used in the T-type design, with the correspondent increase in PFC choke volume.

Therefore, it is clear that the lower volt-second of the 5LANPC, together with the ripple cancellation effect, provides a huge advantage in terms of size compared to the T-type Vienna – a smaller PFC choke with reduced differential-mode EMI filter effort. The size difference could then be used for more bulk capacitors, or for implementation of new cooling concepts, such as liquid cooling.

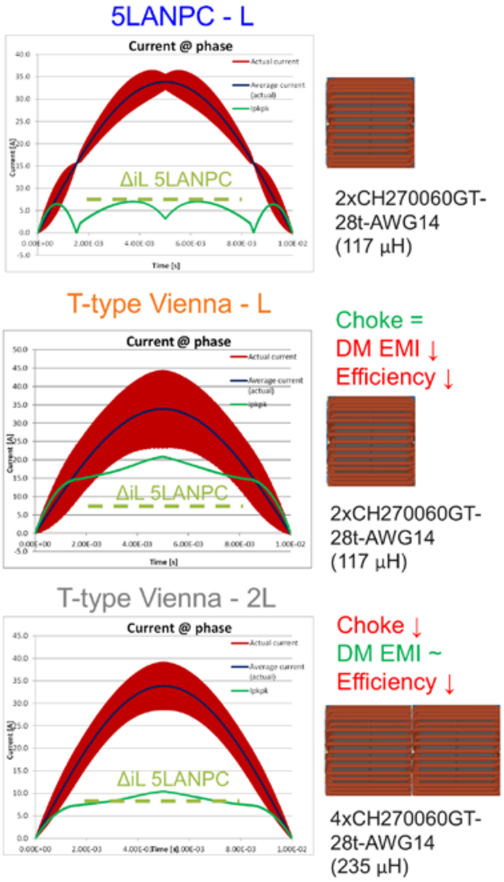


Figure 3: Choke size and current ripple comparison.

5LANPC and T-type Vienna performance comparison

Using the previous PFC choke designs and considering 10 mΩ on-resistance in the different devices used (paralleling of devices is only considered in the low-frequency MOSFETs of 5LANPC), the efficiency of the three different solutions have been estimated (Figure 4). The 5LANPC clearly outperforms the T-type Vienna designs, which are also expected to be bigger in volume either because of the PFC choke or the EMI filter.

Figure 4 also presents the loss breakdown of the three proposed designs for 18 kW operation (100% load). As seen, the inductor losses are the main contributor in the T-type Vienna designs. This is either because of considerably high core losses, or because of the increase in winding losses when trying to reduce the former.

This tendency is also expected in higher power designs, in which a single choke could still be implemented in 5LANPC. However, the T-type Vienna rectifier might benefit from the ripple cancellation effect of interleaving, and by splitting losses and the choke. Nevertheless, the choke losses and the size are issues to consider as well in interleaved solutions.

5LANPC control block diagram

Another benefit of the 5LANPC is that most of the control implementation of a 5LANPC is common to a T-type Vienna PFC, which reduces the complexity of redesigning. Figure 5 shows the block diagram of a DQ control for a 5LANPC. The blue colored blocks in Figure 5 are common for both topologies. Apart from PWM modulation, the main difference is the need of FC control loops, shown in orange in Figure 5.

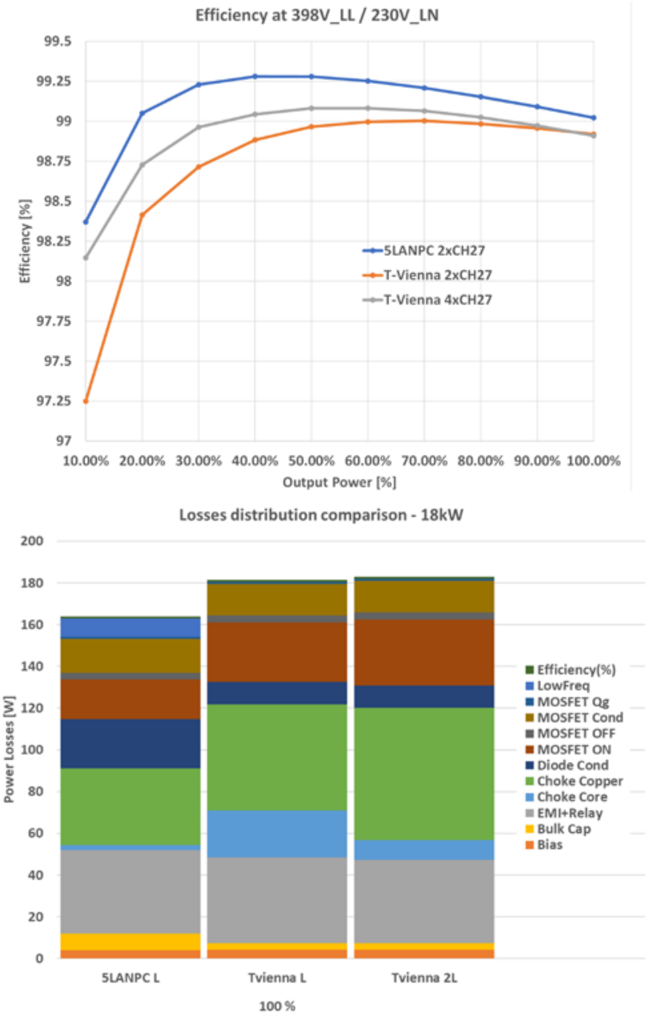


Figure 4: Efficiency comparison of T-type Vienna and 5LANPC and losses distribution for 18 kW operation.

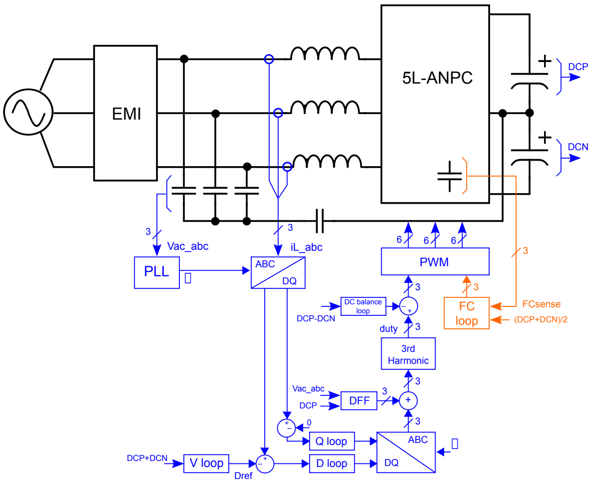


Figure 5: Control block diagram of 5LANPC.

Summary

The speed of AI advancements and their adoption will depend directly on the corresponding growth of data centers and the infrastructure that powers them. Therefore, for hardware designers of these critical systems, the 5LANPC multilevel converter offers advantages in performance and size, making the topology very attractive for AI server PSUs where efficiency and power density are key design parameters. To help with a faster design-to-launch of high-power AI PSUs, see Infineon’s REF_18KW_HFHD_3P_PSU and other reference designs at www.infineon.com/aipsu.

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Advancing Power Efficiency with SiC Merged-PiN Schottky (MPS) Diodes

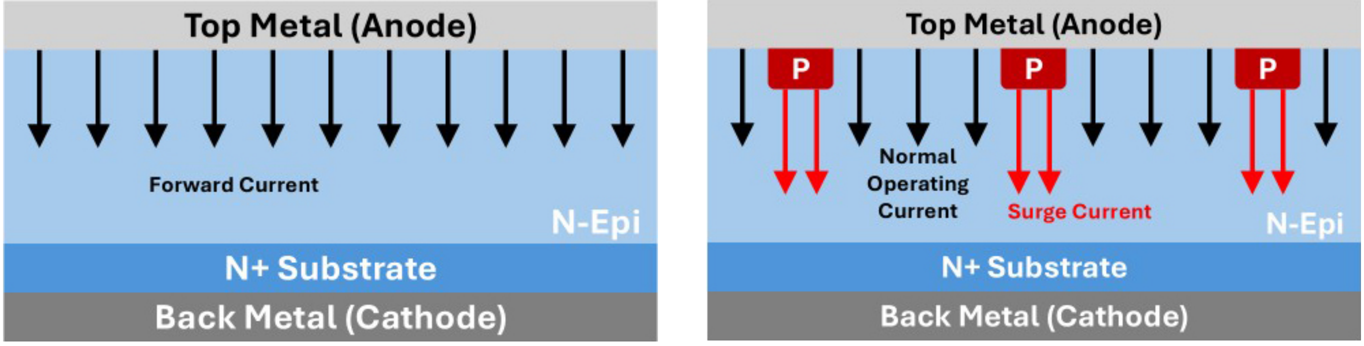
Within the SiC diode family, Merged-PiN Schottky (MPS) diodes represent a critical evolution beyond conventional SiC Schottky Barrier Diodes (SBDs). By combining Schottky and PiN diode structures in a single, monolithic device, SiC MPS diodes overcome the historical trade-offs between low conduction loss, high blocking capability, and ruggedness.

By Perry Schugart, CMO & Head of Business Development, RIR Power

Conventional SiC Schottky Barrier Diodes (SBDs) are majority-carrier devices that offer near-zero reverse recovery charge (Q_{rr}), extremely fast switching and low switching losses. However, at higher voltages and temperatures, traditional SiC Schottky diodes face inherent limitations like increased leakage current, reduced surge current capability and higher sensitivity to overload and short-term fault conditions. These factors can constrain their robustness in demanding applications such as traction inverters, grid-connected converters, and industrial power supplies.

SiC Merged-PiN Schottky (MPS) Diodes

The Merged-PiN Schottky (MPS) structure integrates a PiN diode region within the Schottky architecture. Under normal forward operation, the device behaves like a Schottky diode, maintaining low forward voltage and fast switching. Under high current or high voltage stress (surge current), the PiN regions become active, dramatically enhancing device ruggedness. This intelligent self-adapting behavior allows MPS diodes to deliver the best attributes of both Schottky and PiN devices—without their traditional drawbacks.



Pure Schottky Diode (SBD)

Merged PiN Schottky Diode (MPS)

Figure 1: Structural differences between SBD and MPS.

Comparison of SiC MPS and SiC Schottky diodes

MPS diodes remove the need to choose between efficiency and ruggedness.

Parameter	SiC Schottky Diode (SBD)	SiC Merged-PiN Schottky (MPS) Diode	Customer Value
Conduction Mechanism	*Majority carrier (Schottky)*	*Majority carrier with PiN assist*	*Best of both worlds*
Reverse Recovery	*Near-zero*	*Near-zero*	*High-frequency efficiency*
Forward Voltage (Nominal Load)	*Low*	*Low*	*Comparable efficiency*
Forward Voltage (High Current / Surge)	*Increases rapidly*	*Stabilized via PiN conduction*	*Improved overload handling*
Leakage Current @ High Temperature	*Higher*	*Significantly lower*	*Better high-temp reliability*
Surge Current Capability	*Limited*	*High*	*Robust against inrush & faults*
Avalanche Capability	*Limited*	*Enhanced*	*Grid and industrial resilience*
Thermal Stability	*Moderate*	*Superior*	*Extended operating range*
System Derating Required	*Higher*	*Lower*	*Smaller, lower-cost systems*
Typical Use Case	*Light to medium duty*	*Mission-critical, High stress*	*Broader applicability*

Table 1: Characteristic differences between SBD and MPS.

Key Performance Advantages of SiC MPS vs. SiC Schottky Diodes

One of the key advantages of SiC MPS diodes is in the forward conduction loss curve. These SiC MPS diodes closely match SiC Schottky diodes at low to nominal current, maintaining low forward voltage and high efficiency during normal operation. At higher current and overload conditions, MPS diodes exhibit lower incremental conduction loss as the embedded PiN regions conduct, stabilizing forward voltage and reducing thermal stress compared to conventional SiC Schottky diodes.

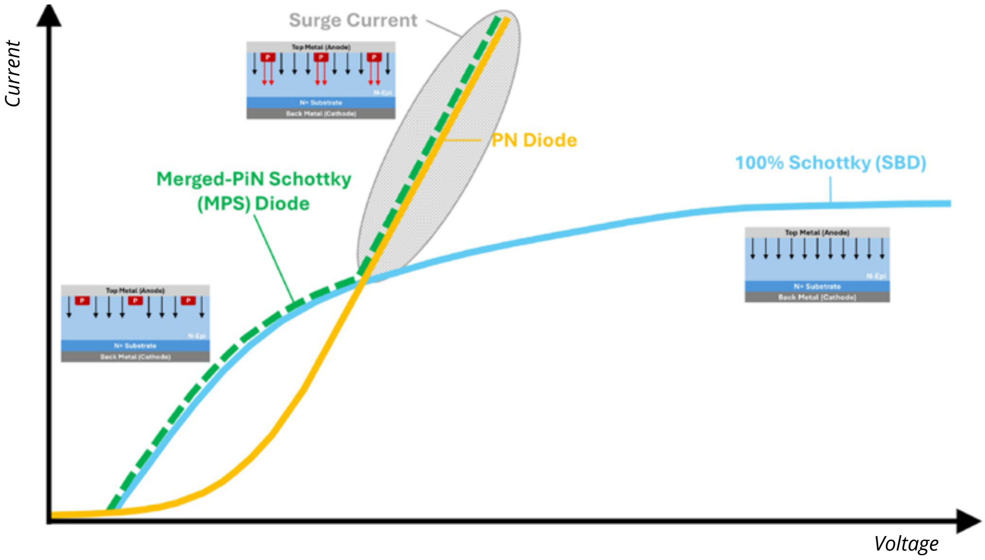


Figure 2: Forward Surge Capability (I_{FSM}) of SBD and MPS Diodes

MPS diodes can safely conduct significantly higher surge currents due to the activation of PiN regions during overload events. This makes them far more robust in real-world systems exposed to inrush currents, short circuits, and grid disturbances. While standard SiC Schottky diodes experience rapidly increasing leakage current as junction temperature rises, MPS structures suppress leakage through their PiN regions—enabling stable operation at elevated temperatures.

The merged structure enhances high-voltage blocking stability and avalanche capability, making MPS diodes better suited for high-voltage DC-link and grid-tied applications. Like Schottky diodes, SiC MPS diodes remain majority-carrier devices during normal operation, preserving ultra-fast switching and negligible reverse recovery losses—critical for high-frequency power conversion. By combining efficiency with fault tolerance, MPS diodes reduce the need for over-design, snubber circuits, and excessive derating, improving overall system reliability and lowering total cost of ownership.

Application Impact

RIR's SiC MPS diodes enable higher system efficiency and reliability across demanding applications by combining Schottky-like switching performance with enhanced surge, thermal, and high-voltage robustness. This makes them well-suited for EV traction inverters, renewable energy systems, industrial drives, aerospace, and green hydrogen applications where high-power density, efficiency, ruggedness, and thermal performance are equally critical.

Who is RIR?

RIR is India's only company with existing high-power semiconductor fabrication capability, with experience in devices rated up to 20,000 V and 12,000 A. Through its U.S. development operations and its forthcoming first-of-its-kind SiC manufacturing facility in Odisha, RIR is building a vertically integrated SiC ecosystem spanning wafer processing, device design, packaging, and application support. This foundation enables RIR to deliver high-voltage, high-reliability SiC MOSFETs and diodes, optimized not only for electrical performance, but also for manufacturability, long-term reliability, and system-level value.

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Modern AC Electric System Blackouts Hypothesis

As a consequence of ever-increasing percentage of generated power by renewable power sources as photovoltaics (PV), wind energy conversion systems (WECS), electric vehicle (bidirectional) charging stations and similar power sources or electric energy storages properties of electric power system are changing. Recent blackouts recorded in Southern Europe appearing during warm days could be supported by smart power converter transients in distribution network and specific conditions in their communication and control circuits. In this paper a brief phenomenology of such occurrence has been investigated.

By Sasa Sladic, Ph.D., sladic@hotmail.com

Blackouts are appearing worldwide. Generally, blackouts in Europe are rare. However, recently an Iberian blackout appeared. Inhabitants from Iberian Peninsula were surprised. It was rare event. Life in numerous cities without electricity was unrecognizable. Traffic lights were out of order; trains stopped on their journeys across the country. Shops and supermarkets were closed in dark. Cities without street lights become undesirable places. Mobile and internet connections were unaccusable [1]. Cose for such extraordinary event was not known. However, renewables were first to blame but officially reason was unknown. Today, several months later situation is not better. Some obvious reason is still missing. It is not unknown that similar event occurred in Southeastern Europe few months earlier [2]. In this case, obvious reason seems to be unknown, again. Officially, that was heat however it was many hotter days that year. So, it seems that some reason is still hidden for a scientific community. In the meanwhile, number of power converters (especially photovoltaic inverters) in electric power system is increased and same trend could be recorded in all European countries. According to one recent hypothesis reason for this blackout was synchronized action of large number of power converters. According to hypothesis both single-phase and three-phase inverters could contribute to this event. Sudden changes of phase-angle or power could create change in temporary power. Simulations could be used in order to show average temporary power.

Temporary Overload – Contribution to fatal Event

According to mentioned hypothesis a temporary power demand appears in electric power system. This occurrence has been hidden since voltages and currents are not out of their boundaries.

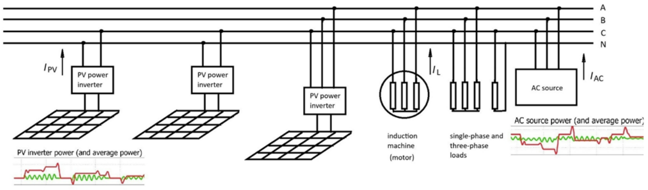

Figure 1: Simplified model of power electric system

Typically, single-phase and three-phase power inverters are generating constant power. However, if some change in solar radiation appear this power is not going to be constant any more. According to simulations power surges appear. It has been known that modern power inverters have "very good" performances. That means, they are generating sine wave current. However, its amplitude and phase could be changed (Figure 2). Current THD could obtain values less than THD<3%. Besides, transients are very fast which means that transient finishes in the same half-cycle of sine wave electric network voltage when the disturbance appear. This means that modern power inverters could be simulated as ideal sine wave current source (Figure 2).

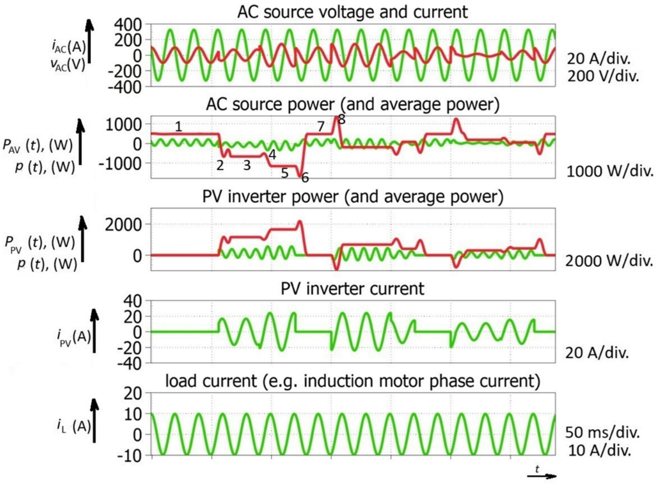

Figure 2: Simulated waveforms of single-phase voltage (v_{AC}), AC source current (i_{AC}), AC source temporary and temporary average power (P_{AV}), PV inverter temporary and temporary average power (P_{PV}), PV inverter current (i_{PV}), and load current (i_L) in frame of simplified power electric system model

According to Figure 2. A several intervals could be identified with different values of power source (system) current (i_{AC}) and power source (system) power (P_{AV}). According to hypothesis intervals with increased power could be dangerous for the electric power system because additional demand on electric power appears.

1. AC power source is suppling load with constant power ($P_{AV}=P_L=500W$). Power inverters are not switched ON and their currents equals zero, $i_{PV}=0$.
2. One power inverter has been turned ON. Depending on its phase shift referring to AC power source (v_{AC}) a different power surges could appear.
3. AC power source is receiving power. That means motor-generator could be used or even bidirectional power converter connected to batteries.

4. AC power source current (i_{PV}) has been increased which results in power surge marked with number 4.
5. In steady state PV inverter brings more power to electric power system. That means AC source would receive 1 kW comparing to 500 W in interval 3.
6. In one moment, solar radiation has been dramatically decreased or PV inverter(s) is turning OFF. In that moment change of temporary average power appears.
7. AC source power during the interval 7 equals to AC source power during interval marked with number 1. That means, AC source is suppling load with 500W.
8. After the appearance of solar radiation, or after the turning on the PV inverter a power surge appears again. In this case AC source increased power could be interpreted as power demand which could reach the power of entire system. That means after the 500 W load, temporary power demand of 1000 W could appear.

This type of overload in system could be dangerous for system stability if the large number of power converters is synchronised. Theoretically, PV inverter is generating sine-wave current, however frequent changes in its amplitude and even phase shift makes a completely different appearance (Figure 2). In case when the large number of PV inverters is synchronized an event known as "black swan" could appear. Such event could result in temporary power demand which could not be supplied in real time. As a consequence, a blackout could appear [3]. It doesn't mean that this particular event could result in massive blackout as Iberian blackout in 2025 however this event could give significant contribution to massive loss of power. According the past experience [3] blackouts are consequence of series of critical events rather than one event. Change of temporary power is not appearing only in photovoltaic (PV) inverters, nevertheless bidirectional power converters used as chargers for electric vehicles or different types of power converters could be source of described power surges.

For this hypothesis single-phase systems [4] are more important than same occurrences in three-phase systems. Theoretically this type of imbalance introduced by different phases could be compensated in three phase system, however asymmetry in driver circuits could prevent such occurrence. So, both single-phase and three-phase PV and other (smart) inverters could be source of overload in electric power system. According to hypothesis, number of PV inverters in such event could be larger or smaller it depends how many devices are synchronized. It could be few devices or even all devices in some region.

Conclusion

It has been shown that PV inverters by their action could produce power surges in system. In case when the large number of power inverters are synchronised (synchronised turning ON-OFF) or some atmospheric event occurs, a large amount of additional power demand could appear. This state could be described as generation of strong currents which are not in phase with system voltage. According to presented hypothesis this event could contribute to massive blackout as recent Iberian blackout. However, final evidence that this hypothesis is correct should came from Spain in the form of forensic serious of events.

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6500 V / 2000 A Press Pack IEGT for HV DC Applications

Toshiba Electronics launched the ST2000JXH35A, a 6500 V / 2000 A press pack injection enhanced gate transistor (IEGT) designed for high-voltage converters used in DC power transmission systems, industrial motor-drive equipment and static synchronous compensators (STATCOM). The device uses trench-type IEGT chips. The ST2000JXH35A is able to streamline the design of high-voltage systems. By adopting this 6500 V-rated product, engineers can reduce the number of series-connected devices required in DC power transmission architectures. This reduction in component count directly contributes to the weight reduction and miniaturisation of overall equipment designs. Consequently, these improvements help reduce construction and transportation costs, offering value for offshore converter stations in wind farms, where installation costs and logistical complexity are significant. The product features a press-pack design that supports double-sided cooling and a hermetic sealing structure to ensure the reliability required for long-term industrial operation. In addition to transmission infrastructure, the ST2000JXH35A enables higher voltage ratings and more compact form factors for industrial motor drives and reactive power compensation devices that stabilize power systems.

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Current Transducers for up to 3200 V and 1500 A

Danisense has expanded its DN1000ID current transducer product family with the introduction of the DN1000ID-CP02 model, which features a significantly increased creepage and clearance distance of 38 mm, compared with 11 mm for the standard DN1000ID version. In addition, the permissible voltage for uninsulated cables has been raised from 1000 V to 3200 V, making them well-suited for power measurement and power analysis in EV chargers, power inverters, and battery energy storage systems. Additional target applications include EV test benches, particle accelerators, MRI systems and medical scanners, battery testing and evaluation equipment, current calibration systems, and other precision current-sensing applications. The DN1000ID-CP02 device incorporates a removable isolation insert and a 40 mm aperture to accommodate wide cable terminals. The transducer is capable of measuring currents up to 1500 A, with continuous measurement of 1000 A achieved with a linearity error of less than 1 ppm. An over-range capability of 1200 A_{RMS} for up to 30 minutes is also supported. Based on Danisense's closed-loop fluxgate technology, the DN1000ID-CP02 delivers an offset of 5 ppm. Noise performance is claimed to be "best-in-class, with sub-ppm RMS noise across frequencies up to 10 kHz".

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AC/DC Power Supplies

The TAD150 series AC/DC power supply from P-DUKE is designed for industrial applications, featuring specific switching topology and high-efficiency conversion. It provides 130 W (natural convection) or 150 W (forced air cooling) continuously, with up to 200 W peak power, which makes it well-suited for surge-starting and intermittent high-power applications. The devices comply with IEC/EN/UL 62368-1 safety standards and offer reinforced insulation with a 3000 V_{AC} input-to-output isolation voltage while meeting EN55032 Class B emissions tests and comprehensive EMI/EMS testing. For high-altitude applications, the TAD150 includes an OVC III (2000 m) option. Its temperature range spans from -40 °C to +85 °C. With synchronous rectification technology it achieves efficiencies of 92-94 % and a power factor of 0.95, meeting EN61000-3-2 Class D standards. Its no-load power consumption of 0.2 W complies with energy-saving regulations. Available in Open Type, Enclosed Type, and Din Rail Type, the TAD150 supports several connector options (Molex, JST, Terminal Block) and operates with an input voltage range from 85-264 V_{AC} / 88-370 V_{DC} for global compatibility. The TAD150 includes multiple protections: Overvoltage Protection (110-135 % V_{nom}), Overload Protection (160 % rated), Short Circuit Protection (Hiccup mode), and Overtemperature Protection (125 °C), while the MTBF is 724,500 hours (MIL-HDBK-217F, 25 °C full load). Typical applications are Programmable Logic Controllers, Motor Drive Systems, Electromagnetic Valve Control, Communication Equipment, Testing and Measurement. Output voltages are 12, 15, 18, 24, 28, 36, 48 and 54 V_{DC}.

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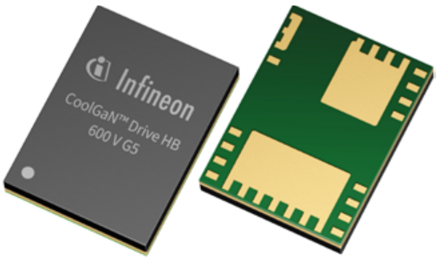
GaN Half-Bridge Solutions including Drivers

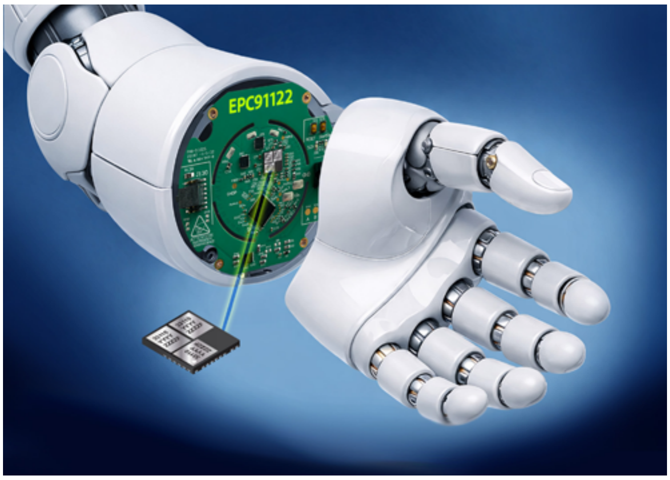


Infineon expands its CoolGaN™ portfolio with the CoolGaN Drive HB 600 V G5 product family. The four devices – IGI60L1111B1M, IGI60L1414B1M, IGI60L2727B1M, and IGI60L5050B1M – integrate two 600 V GaN switches in a half-bridge configuration together with integrated high- and low-side gate drivers and a bootstrap diode, delivering a compact, thermally optimized power stage. By bringing key functions into one optimized package, the family lowers external component count, eases PCB layout challenges typically associated with fast-switching GaN and helps designers shorten development cycles while achieving the core advantages of GaN technology: higher switching frequencies, lower switching and conduction losses, and greater power density. Targeting low-power motor drive systems and switched-mode power supplies, the integrated half-bridge enables smaller magnetics and passive components, higher efficiency across operating conditions, and improved dynamic performance in space-constrained designs. The device achieves switching with a 98 ns propagation delay. For simplified system integration, it offers a PWM input compatible with standard logic levels and operates from a single 12 V gate driver supply, while fast UVLO recovery helps ensure robust behavior during start-up and transient supply events. The products are housed in a 6 x 8 mm² TFLGA-27 package with exposed pads, enabling efficient heat spreading and supporting heat-sink-less designs in many applications.

www.infineon.com

Evaluation Board for Humanoid Robot Joint Applications

Efficient Power Conversion (EPC) has released the EPC91122, a 3-phase BLDC motor drive inverter evaluation board specifically engineered for humanoid robot joint applications. Featuring EPC's EPC33110 3-phase ePower™ Stage module, the EPC91122 delivers up to 20 A_{RMS} (28 A_{peak}) phase current in an adequate form factor optimized for space-constrained robotic joints, integrating all key functions of a complete motor drive inverter, including a microcontroller, motor shaft angular sensor, housekeeping power supplies, accurate voltage and current sense. The EPC91122 is mechanically optimized to fit directly inside humanoid joint motors. The complete GaN inverter occupies a 32 mm diameter inner circle, surrounded by a 55 mm external frame that supports mechanical mounting and lab connectivity. This design lets the inverter fit inside the motor chassis, which lowers loop inductance and makes the power density and dynamic performance higher. The EPC33110 is the main part of the system. It is a three-phase co-packaged module with a maximum voltage of 100 V. It has three monolithic GaN half-bridges with built-in gate drivers, bootstrap circuits, and level shifters. The device has an $R_{DS(on)}$ of 11.7 + 13 mΩ and can switch at frequencies of up to 150 kHz, which means it may use smaller passive components and respond quickly to changes.



The board operates from a wide input range, making it well-suited for battery-powered robotic systems. It integrates all critical subsystems required for a complete motor drive inverter. The EPC91122 comes preprogrammed to operate at 100 kHz PWM with 50 ns dead time, showcasing the high-speed switching capability enabled by GaN technology. Thermal testing under real-world operating conditions confirms the board's capability for continuous and pulsed operation. Complete design support files, including schematic, bill of materials (BOM), and Gerber files, are available.

www.epc-co.com

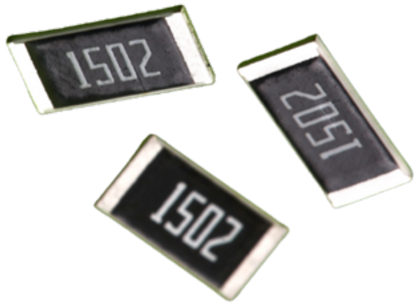
Compact Package for Automotive 40 V/60 V MOSFETs

ROHM has expanded its lineup of low-voltage (40 V/60 V) MOSFETs for automotive applications – such as main inverter control circuits, electric pumps, and LED headlights – by introducing latest products adopting the new HPLF5060 package (4.9 mm × 6.0mm). The HPLF5060 package offers a smaller footprint compared to the widely used TO-252 package (6.6 mm × 10.0 mm) while enhancing board-mount reliability through the adoption of gull-wing leads. Additionally, the use of copper clip junction technology enables high-current operation, making the HPLF5060 suitable for demanding automotive environments.

www.rohm.com

Automotive Grade High Voltage Chip Resistors: Up to 100 MΩ

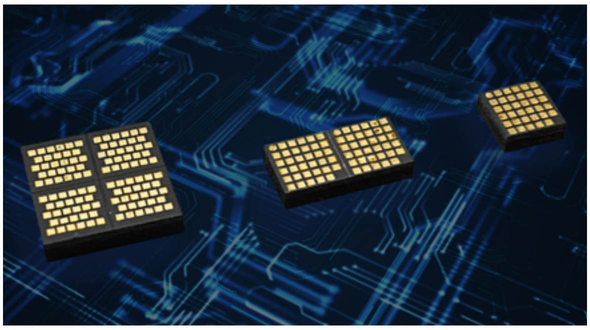
Stackpole's RVCA Series is a thick-film, high-voltage chip resistor family purpose-built to meet the demands of 400 V, 800 V, and higher voltage systems. Designed to simplify high-voltage circuit implementation, RVCA provides engineers with a reliable, compact solution that reduces the need for series stacking while improving long-term stability. The series is automotive grade, AEC-Q200 qualified, and anti-sulfur compliant per EIA-977, ensuring robust performance in harsh, high-stress environments common to EV, industrial, and power electronics applications. The RVCA Series supports voltage ratings up to 3 kV in the 2512 case size, with 0805 and larger packages offering minimum ratings of 400 V. The resistance range spans from 30 kΩ to 100 MΩ further enables implementation of voltage dividers, sensing networks, bleed circuits, and high-impedance nodes across high-voltage platforms.



www.seielect.com

Embedded Silicon Capacitors

Empower Semiconductor launched three embedded silicon capacitors (ECAPs™), designed to meet the power integrity demands of next-generation AI and high-performance computing (HPC) processors. These ECAPs include the EC2005P, with 9.34 μF capacitance in a 2 mm x 2 mm package; the EC2025P, offering 18.68 μF capacitance in a 4 mm x 2 mm package and the EC2006P, providing 36.8 μF capacitance in a 4 mm x 4 mm form factor. As AI processors push the limits of performance, power delivery has emerged as a critical constraint. Achieving the required power integrity for extreme current densities and ultrafast transient response is no longer realistic with board-level mounted components; embedding capacitors into the processor substrate is now essential.



www.empowersemi.com

GaN Devices for Flyback Topology up to 440 W

Power Integrations introduced a flyback solution extending the power range of flyback converters to 440 W—well beyond the limits that traditionally required more complex resonant and LLC topologies. The TOPSwitchGaN™ flyback IC family unites the company's PowiGaN™ technology with its TOPSwitch™ IC architecture. This solution is claimed to reduce complexity, eliminate heat sinks in many cases, shorten design time, improve manufacturability and lower total system cost. TOPSwitchGaN ICs provide 92 percent efficiency across the load range—from 10 percent to 100 percent load—and clearly beats ErP regulations at less than 50 mW power consumption for standby and off modes. The device does this without the need for synchronous rectification. PowiGaN switches deliver much lower RDS(ON) than silicon, significantly increasing the power capability of flyback converters. These devices incorporate 800 V PowiGaN switches which can operate at switching frequencies of up to 150 kHz. No-load consumption is well below 50 mW at 230 VAC including line sense, and up to 210 mW of output power is available for 300 mW input at 230 VAC to run housekeeping functions when units are in stand-by mode. These ICs are available in two styles. For ultra-slim designs, low profile eSOP™-12 surface mount packaging enables 135 W (85 – 265 VAC) to be delivered without a heatsink for applications such as appliances. The vertical orientation of the eSIP™-7 package minimizes PCB footprint and has a thermal impedance equivalent to a TO-220-packaged part. Several reference design materials are available.

www.power.com

1500 V Relays for Energy Storage Systems and EV Fast-Chargers

OMRON is extending its contactor-replacement relay portfolio with the G9KJ to save weight and cost in high-voltage energy storage systems and electric-vehicle fast chargers. With 25 A make current and 5 A carry (0 A break) current, the PCB-mount relays have ratings optimized for pre-charging circuits at DC-link voltage up to 1500 V. As pre-charge control switches, the OMRON G9KJ relays divert capacitive inrush currents through a high resistance to relieve stress on components handling the main charging current, including the main contactor, DC link capacitor, and trip protection. With a critical role in preventing nuisance faults or unwanted system resets, and enhancing long-term reliability of the power stage, G9KJ relays permit greater board integration and faster assembly than traditional contactors. The 37.2 mm x 25.5 mm x 17 mm type 1A (SPST NO) relays address the growing reliance on high-voltage DC switching capabilities as the energy transition redefines grid infrastructures and life essentials like mobility. The contact resistance is 100 mΩ (max.) while the coil power is specified with 530 mW.

www.components.omron.com

Automotive SMT Common Mode Chokes

The CMA family of automotive qualified common mode chokes from Coilcraft are available for current ratings up to 8.2 A. Providing suppression of high frequency common mode noise up to 100 MHz they are suitable for inverters, motor drives, onboard chargers, as well as telecom and industrial applications. The AEC-Q200-qualified surface mount toroids provide isolation (hipot) up to 1500 V_{rms}. The CMA series complements the Cx common mode choke series with AEC qualified reliability.

www.coilcraft.com

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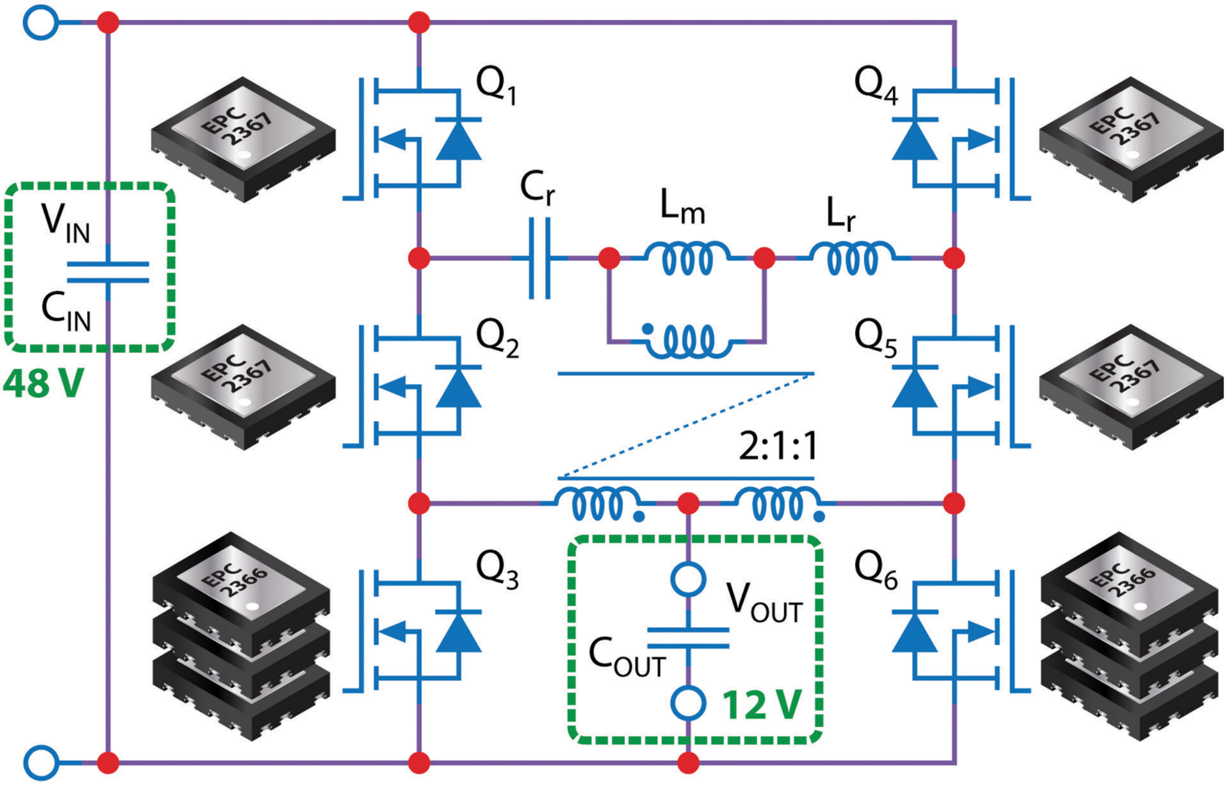

Q_1
Q_2
Q_3
Q_4
Q_5
Q_6
EPC 2367
EPC 2366
V_{IN}
C_{IN}
48 V
C_r
L_m
L_r
2:1:1
V_{OUT}
C_{OUT}
12 V

EPC 2367

EPC 2366