POWER ELECTRONICS NEWS

MAY 2025

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AI Drives Demand for Power MOSFETs in Data Centers

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EDITOR'S LETTER

Powering Progress: Innovations in AI Infrastructure, Automotive, and Energy Storage

Artificial intelligence is reshaping data center design, with skyrocketing power demands pushing the industry toward more efficient architectures. This issue highlights how the shift from 12-V to 48-V power delivery, driven by AI workloads and GPU-intensive processing, has made high-performance MOSFETs indispensable at every design. Infineon's article analyzes this transformation with a broad portfolio of high-performance silicon and SiC MOSFETs, as well as advanced packaging technologies to achieve higher power density, better thermal performance, and greater overall efficiency. The automotive industry is experiencing a rapid evolution, driven by the megatrends of Connected, Autonomous, Shared & Services, and Electric (CASE) and Mobility as a Service (MaaS). As automobiles become more complex, with new sensors, communication technologies, and power management systems, the impact of noise interference is more significant than ever. In this issue, we analyze how Nisshinbo Micro Devices' solutions for op-amps and low-dropout regulators play a critical role in ensuring the stability and reliability of automotive electronics. Moreover, the automotive industry seeks to optimize energy efficiency and the use of raw materials. Semiconductor power switches allow fusion-based traction inverters to achieve efficient and affordable e-mobility. With fusion technology, silicon and SiC chips operate in parallel within the same traction inverter, achieving a balance between drive-cycle efficiency and cost.

Filippo Di Giovanni explores the topic of batteries in this issue. The large-scale deployment of lithium-ion (Li-ion) batteries across various applications raises significant concerns regarding their recycling and reuse after reaching the end of their lifecycle. Therefore, it is essential to implement techniques and procedures that minimize environmental impact and create new business opportunities. This approach aligns with the principles of circular and green economies. In a dedicated market report, IDTechEx estimates that by 2035, the global second-life EV battery market will be worth $4.2 billion. The availability of retired EV batteries will drive second-life storage adoption, but feasibility and competitiveness depend, to a large extent, on battery chemistry and their repurposing. It is thus important to assess the efficiency and operating costs of second-life batteries with respect to incumbent first-life Li-ion battery energy storage systems.

Other topics include the electrical grid and GaN and SiC solutions Mayra Alejandra Fuentes explores the evolving landscape of electricity infrastructure in the Netherlands, highlighting key projects, technological advancements, and strategies to ensure a stable, efficient, and future-ready grid. Sonu Daryanani highlights some of the light- and no-load improvements achieved by Cambridge GaN Devices in its H2 series of ICeGaN integrated GaN products. Moreover, we analyze the evolution of IGBT technology, tracing its development from its first demonstration by GE in 1982 to its widespread adoption across power electronics. The discussion then shifts to SiC IGBTs, exploring their advantages in high-power, high-voltage applications such as solid-state transformers and smart grids. With insights from key research efforts and industry trends, we examine how SiC is shaping the future of IGBTs for next-generation power conversion and motor drive systems. Finally, Stefano Lovati updates us on advancements in perovskite solar cell stability.

Yours Sincerely,

Maurizio Di Paolo Emilio, Ph.D.

Editor-in-Chief, Power Electronics News and embedded.com

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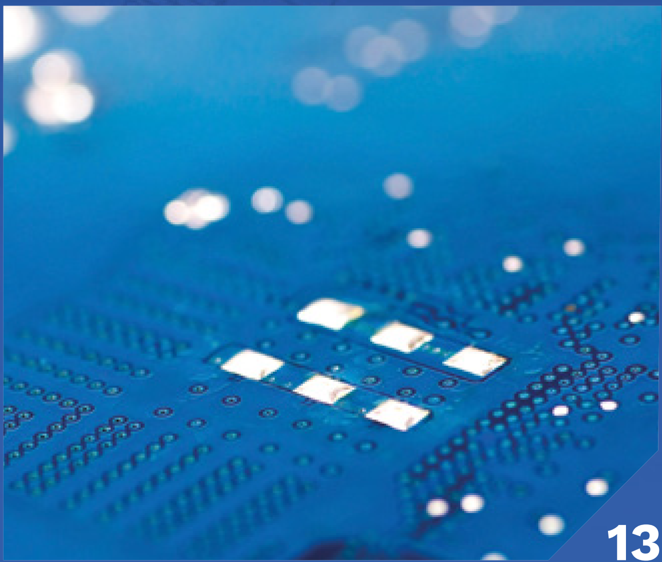

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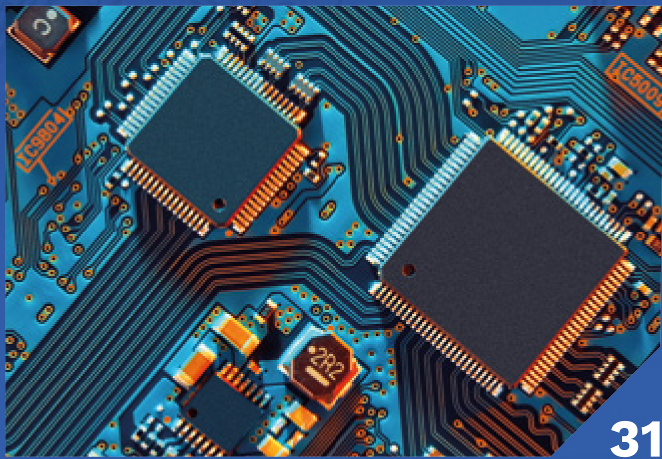

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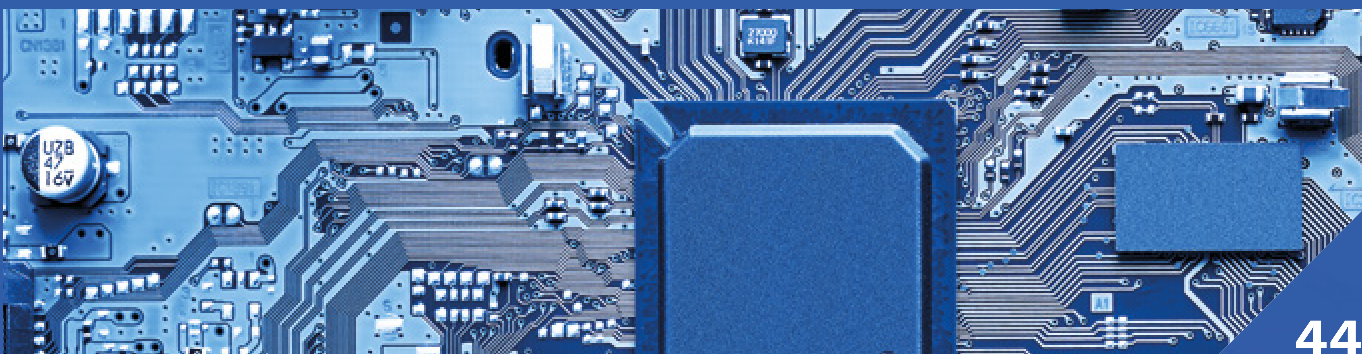

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The Rise of AI Makes Power MOSFETs Critical in Data Center Architecture

By Infineon Technologies

Energy usage has always been a concern for data center operators, but the challenge has grown acute with the rise of artificial intelligence. The amount of power necessary to sustain the explosive growth rate of AI workloads escalates with each passing year, making it essential to achieve the greatest possible energy efficiency.

Infineon has a strategy to improve the performance of entire energy systems from grid to core, but here, we will focus on how AI has affected data center architecture and what those changes mean for server and rack technologies. Specifically, we'll discuss how data center energy efficiency has been improved by shifting to a 48-V architecture and how high-performance silicon MOSFETs are being used in servers, racks, and associated equipment to support this architectural evolution.

DATA CENTERS AND POWER

Data centers account for roughly 2% of the world's total electricity use today, but that could rise to 7% by 2030. To put that into perspective, the world's data centers in aggregate would consume roughly the same share of global power consumption as the entire country of India today.

Rapidly increasing demand for AI is fueling these projections. Most AI workloads run much better on GPUs, and GPUs running AI workloads consume much more power. Together, they also dissipate far more waste heat, necessitating more extensive cooling systems that necessitate the consumption of yet more power.

Meeting the data center industry's projected demand for electricity will require enormous global investment to build many new power plants. This explains the heightened imperative to also make data centers as energy-efficient as possible.

DATA CENTER POWER EVOLUTION

One of the most important measures the industry has adopted to make data centers more energy-efficient is transitioning from an intermediate bus voltage of 12 V to a 48-V power delivery architecture.

A rack typically holds four or more servers. Any given rack that consists of servers running CPUs might use 3 kW to 5 kW today, but a rack filled with servers running high-performance GPUs and accelerators processing AI workloads uses 10 kW to 100 kW or even more.

The consequences are easily predicted. Assuming a consistent voltage, resistance goes up as the current increases ($P = I^2R$), translating into mounting transmission losses. Not coincidentally, currents in data centers are expected to keep increasing at a steep rate.

Given all that, moving to a higher voltage was necessary to minimize transmission losses and enable a more efficient way to transfer power. The move to a 48-V architecture in data centers was initiated several years ago.

As the AC power from the data center enters the rack, it is converted to DC and stepped down in voltage several times, increasingly to 48 V, then to 12 V or 6 V, and finally to the precise voltages that meet the various needs of the range of processors (CPUs, GPUs, TPUs) used in different servers installed throughout each data center. Processor requirements are commonly about 1 V_{DC}.

Optimizing each stage of this process is vital to minimizing energy loss and maximizing efficiency. This is where high-performance MOSFETs are crucial.

THE ROLE OF MOSFETs

MOSFETs are integral to efficient power conversion, starting with bringing in 208- to 277-V_{AC} input and in each step down through 48 V, 12 V, 6 V, and 1 V or less, moving through the power delivery network from racks to boards to ICs. MOSFETs are also required for conversions of AC to DC along those paths.

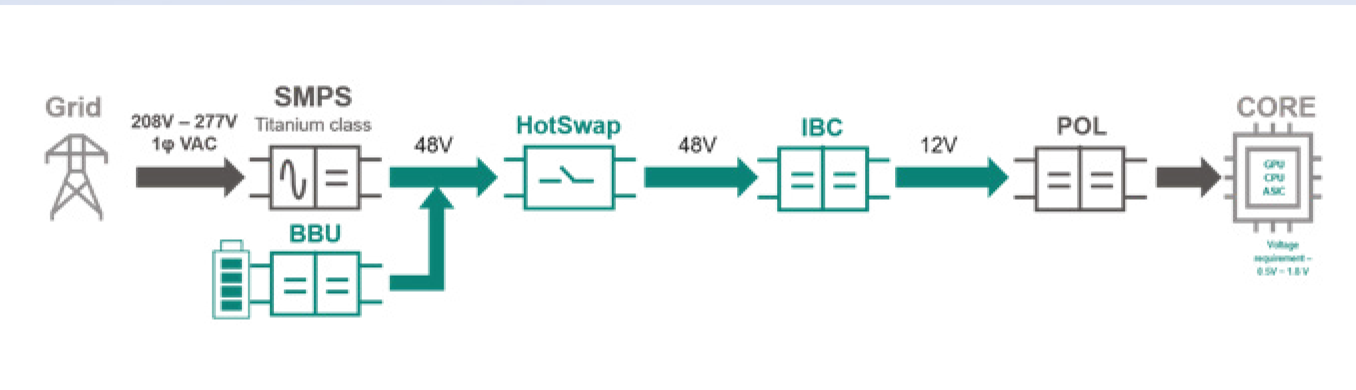
MOSFETs are integral to power delivery systems and in several rack and server subsystems. These include switched-mode power supplies (SMPSes), power supply units (PSUs), intermediate bus converters (IBCs), points of load (POLs), and battery backup units (BBUs).

A given in power design is to use MOSFETs that exceed the stated voltage, so the adoption of a 48-V interim bus dictates the use of 25-V to 650-V MOSFETs.

Power from the grid entering a data center passes through an SMPS, typically a Titanium-class SMPS (by definition, having efficiencies greater than 97%). Data centers commonly specify Titanium-class power technology, which is to say, the most energy-efficient versions available.

PSUs

The average power supply shelf in a rack incorporates a half-dozen PSUs. MOSFETs are used in PSUs for power-factor correction (PFC), in the isolated DC/DC power converter on both the primary and secondary sides, and MOSFETs can be used instead of diodes in ORing circuits at the DC output.



MOSFETs are critical elements in multiple subsystems in data center power delivery networks, helping to step down voltage and condition the power. These subsystems include SMPSes, PSUs, IBCs, POLs, and BBUs.

650-V MOSFETs are being used for the PFC and the primary of the isolated DC/DC converter stage; these can be silicon MOSFETs like Infineon's CoolMOS™ superjunction MOSFETs or silicon carbide MOSFETs like CoolSiC™. LLC is the most commonly used topology for the isolated DC/DC converter stage. The secondary-side synchronous-rectifier FETs of the LLC converter (with full-bridge rectifier) and the ORing MOSFETs at the output commonly use 80-V MOSFETs. Infineon's 80-V OptiMOS™ 6 power MOSFET technology enables significant performance improvements by offering low-$R_{DS(on)}$ MOSFETs for higher system efficiency.

The secondary-side synchronous-rectifier FETs of the LLC converter (full-bridge rectifier) and the ORing MOSFETs at the output commonly use 80-V MOSFETs.

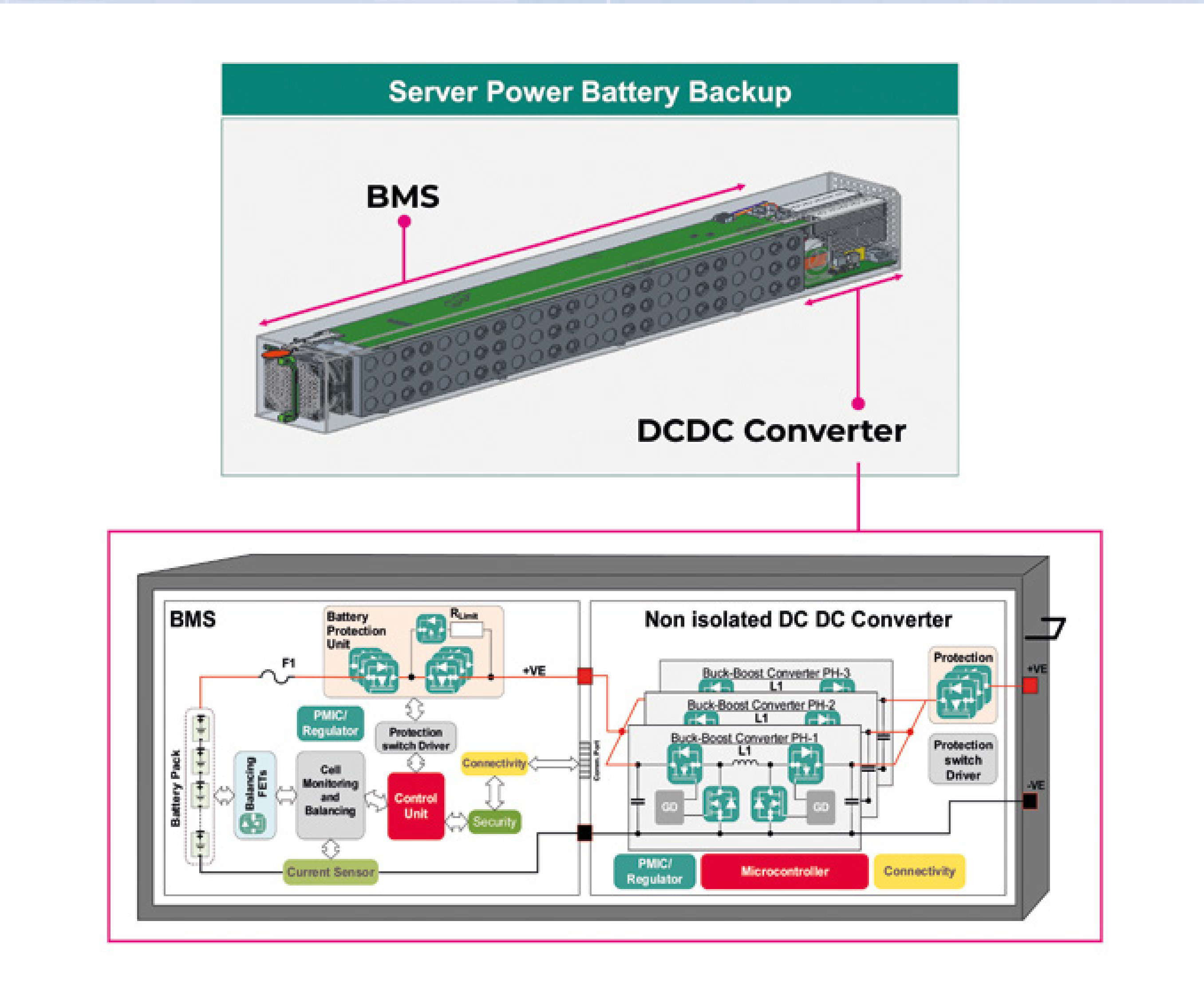
In addition to maximum power efficiency, PSU designers are looking for devices that are as compact as possible for higher power density and that support thermal management.

IBCs

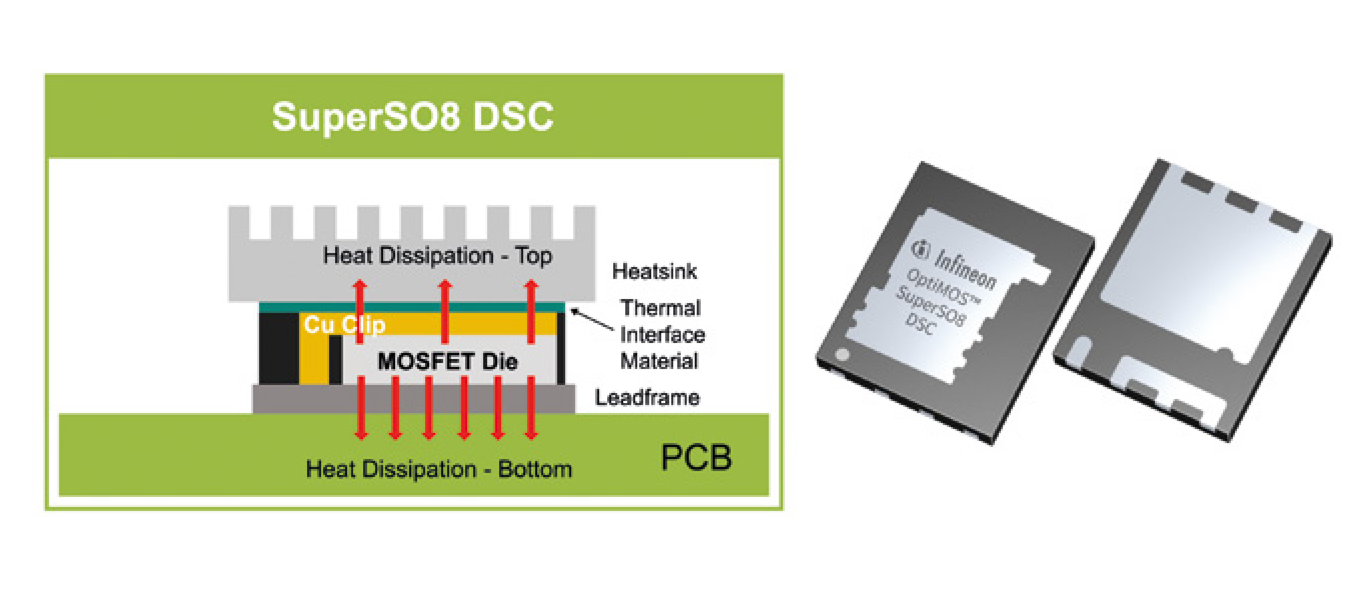
There are numerous computer trays and switch trays for every server in every rack. IBCs need to convert 48-V power to the several voltage levels required by various subsystems within the rack.

To that end, multiple MOSFETs are integrated into the 48-V first stage converters on the power delivery boards, where power must be efficiently stepped down to intermediate voltages, commonly 12 V, 9.6 V, 8 V, 6 V, and 4.8 V.

More MOSFETs, generally 25-V MOSFETs, are needed for the second-stage POL converters on the GPU boards to efficiently step the power down to levels at or near 1 V, depending on the requirements of the specific processors used. The power levels of AI accelerator modules are already exceeding



This cutaway representation of a BBU shows how MOSFETs are used in multiple places in multiple subsystems in data centers.



The new SuperSO8 package for OptiMOS™ 5 power MOSFETs enables higher power density as well as improved robustness, achieving excellent efficiency and system reliability. Roughly 30% of the heat generated on the silicon is transferred to the top-side heatsink; the exposed clip leads to more effective top-side cooling.

750 W, with currents as high as 1,000 A (at 0.75-V core voltage). With as many as eight of those modules on one mainboard, the power ratings and thermal management efforts become challenging.

There are multiple possible configurations for server racks that will dictate how IBCs themselves will be configured. Designers will need to take thermal management options (e.g., air-cooled versus water-cooled) into account; balance quality and reliability requirements to achieve targeted rates for mean time between failure; anticipate power density requirements as GPU power increases; and consider efficiency with total cost of ownership (TCO) in mind.

Again, everything will depend on specific configurations, but in general, 80-V MOSFETs tend to be preferred for the primary/input side, and 15-V to 60-V MOSFETs are often found suitable for the secondary/output side. Infineon's OptiMOS™ power MOSFETs provide excellent best-in-class performance with features that include ultra-low $R_{DS(on)}$ and improved figures of merit ideal for high-switching-frequency applications.

BBUs AND HOTSWAP

MOSFETs are also necessary in the BBU in every server rack. Both the battery management system and internal DC/DC converter typically incorporate 80-V and 100-V MOSFETs.

There is another subsystem where MOSFETs play a critical role. Data centers are engineered to hotswap boards, either to replace malfunctioning boards or to upgrade them, typically in favor of similar boards that are either more powerful or have new processing capabilities. MOSFETs provide protection for the hotswap; these are usually 100-V MOSFETs. Infineon's OptiMOS™ 5 Linear FET 2 is an ideal device for these types of protection functions.

PACKAGING

As application requirements become more exacting, the performance of any power device can no longer be considered without also taking into account device packaging. This is just as true of AI servers as it is with any other demanding application.

The on-state resistance ($R_{DS(on)}$) of a MOSFET is the sum of the silicon resistance (R_{si}) and package resistance (R_{pack}). Over time, with refinements in silicon technology, R_{si} has been consistently diminishing.

A consequence of continuously reducing R_{si} is that R_{pack} is becoming a larger portion of the $R_{DS(on)}$. Moving forward, achieving the best performance requires reducing R_{pack} to improve the overall efficiency and thermal performance of a power device as a whole.

Infineon leads in packaging as well. Many of our MOSFETs are available in the power quad flat no-lead (PQFN) package, with options for both top-side and dual-side cooling. MOSFETs in either package will be characterized by minimal $R_{DS(on)}$.

Advanced packaging will also lead to lower parasitic inductance, which will help improve the switching performance. This is crucial for applications such as AI servers, where power density requirements are increasing and switching frequencies are increasing.

Improved packaging concepts also enable higher ID rating for the devices, which helps to address the ever increasing power ratings of the systems.

NEXT STEPS FOR INFINEON'S POWER MOSFETs

Answering the increasing power requirements of AI will require ongoing innovation in silicon power MOSFET technology.

MOSFET manufacturers are accustomed to churning out generic, one-size-fits-all devices. Infineon is optimizing MOSFET designs to balance power capacity, efficiency, and power density to suit specific applications, of course for AI but also for a range of other end uses.

Dedicated products for both hard- and soft-switching use cases will enable another level of system optimization, leading to an increase of system power and efficiency.

An example is the upcoming ***OptiMOS™*** 7 25 V line, which features fully switching-optimized technology configurations. The parameters in these MOSFETs have been tailored to the requirements of certain IBC (48-V conversion) topologies.

Another is the new ***IQEH46NE2LM7ZCGSC***, a 25-V class MOSFET with a typical $R_{DS(on)}$ of 0.38 mΩ in a small, PQFN 3.3 × 3.3 package in source-down with dual-side cooling as an option.

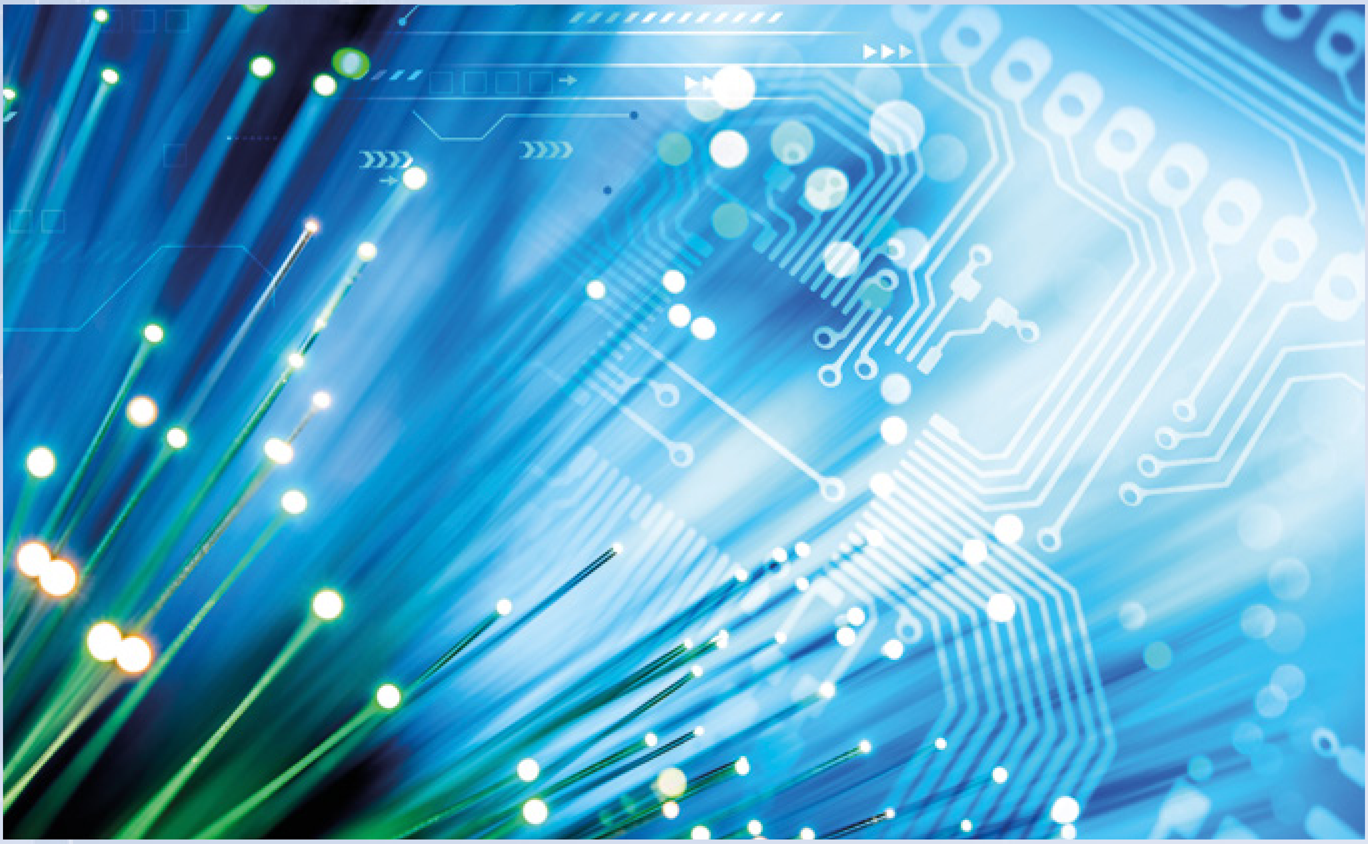
Infineon plans to extend this approach to other voltage nodes, empowering customers to further optimize their system solutions using fully application-optimized power MOSFETs.

SUMMARY

Energy usage patterns in data centers make energy efficiency an imperative. Managing power within data centers is almost as much of an engineering challenge as the data processing itself.

Energy efficiency must start with discrete components and be pursued all the way to the system level. Data centers are vast, and any reduction in energy, even at the microwatt level, becomes substantial by virtue of being replicated over and over again throughout a facility. Even MOSFETs matter.

Using the highest-performing MOSFETs, such as Infineon's OptiMOS™, CoolMOS™, and CoolSiC™ MOSFETs, in the most compact, thermally efficient packaging reduces the TCO for data centers, increases the application robustness, and ensures that the systems can handle the increasingly complex computations required by advanced AI algorithms without compromise.



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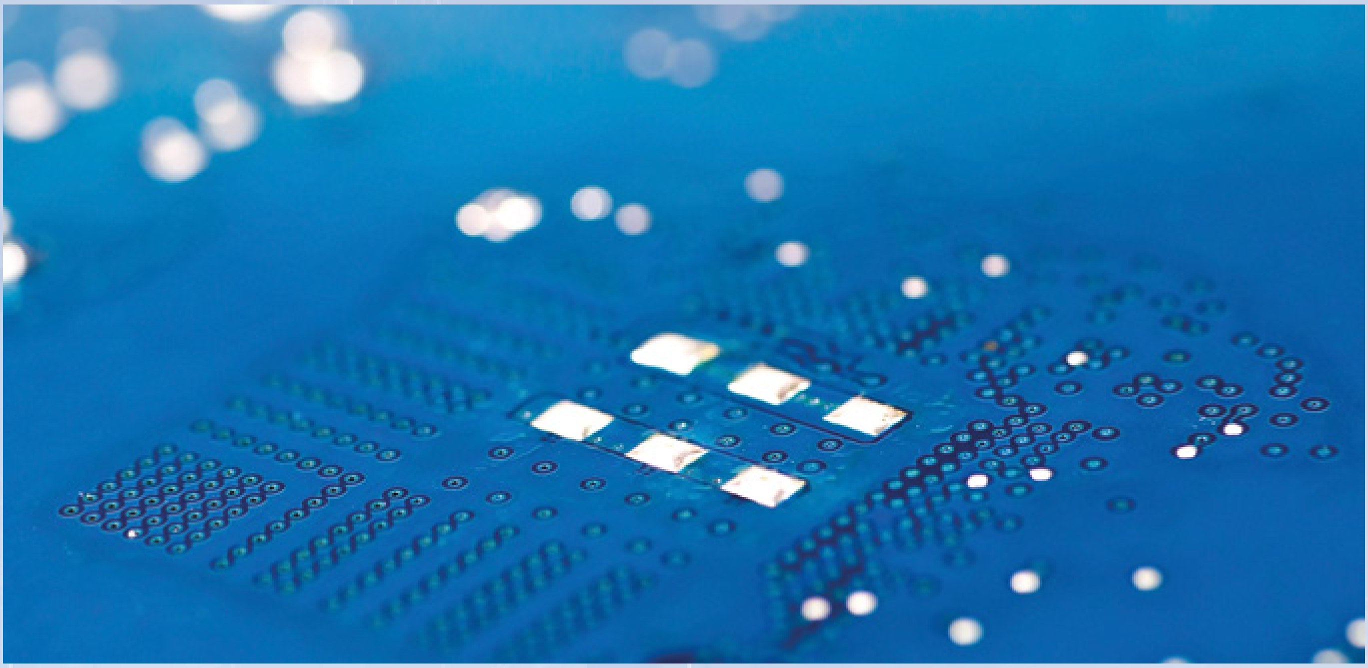


Combating Electronic Noise in Automotive Systems: Advanced Solutions for Op-Amps and LDOs

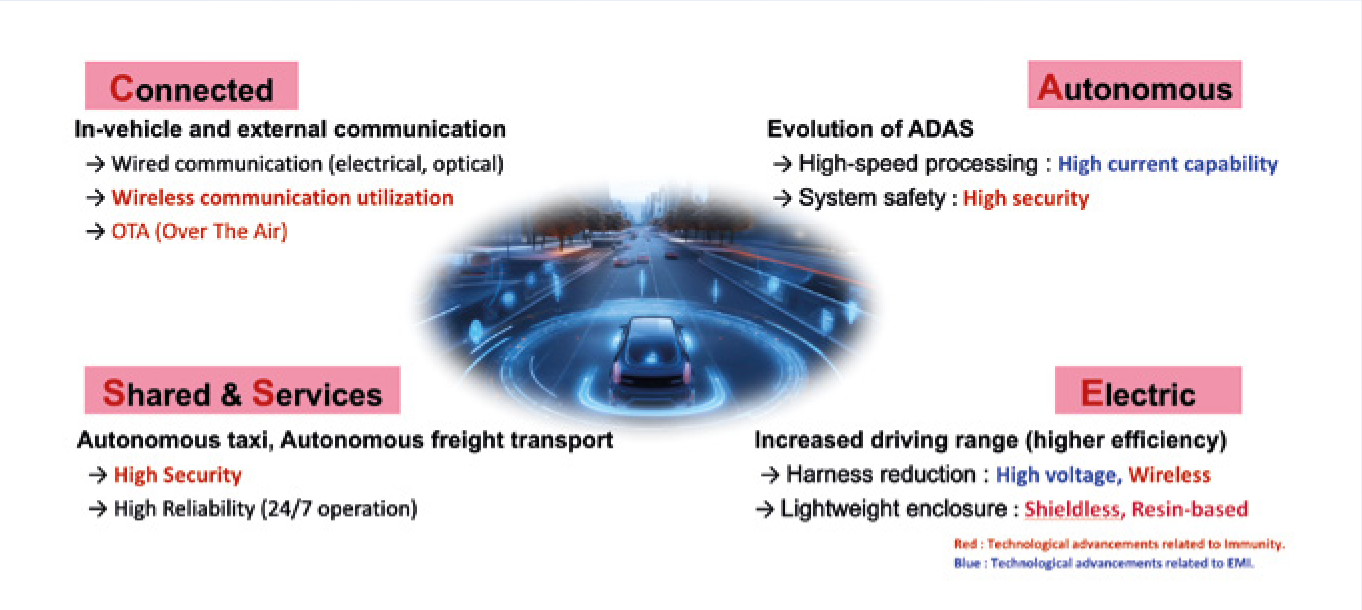
By Nisshinbo Micro Devices Inc.

The automotive industry is experiencing a rapid evolution, driven by the megatrends of Connected, Autonomous, Shared & Services, and Electric (CASE) and Mobility as a Service (MaaS). With vehicles becoming increasingly connected and automated, the demand for advanced electronic systems has surged. From autonomous-driving features like advanced driver-assistance systems (ADAS) to electric vehicles with complex power management platforms, the number of electronic control units (ECUs) and components in modern automobiles is growing exponentially. However, with these advancements comes an increasing challenge: electronic noise.

As automobiles become more complex, with new sensors, communication technologies, and power management systems, the impact of noise interference is more significant than ever. Unintended malfunctions caused by electronic noise can lead to performance issues and drastically affect vehicle safety and delay development cycles. This is where ***Nisshinbo Micro Devices'*** solutions for operational amplifiers (op-amps) and low-dropout regulators (LDOs) play a critical role in ensuring the stability and reliability of automotive electronics.

THE GROWING COMPLEXITY OF AUTOMOTIVE ELECTRONICS

The integration of sensors and communication systems in vehicles is a direct response to the shift toward autonomous driving and electric mobility. Autonomous vehicles, for example, rely on various sensors, such as radar, LiDAR, and cameras, to monitor the environment and make real-time



The CASE megatrend is driving rapid changes in the automotive industry.

decisions. These sensors must function without interruption, which means their signals must remain free from interference—no small feat in a modern vehicle environment. Furthermore, the rise of EVs has introduced a host of new challenges, including advanced battery management systems, motor control systems, and charging technologies, all of which are highly sensitive to noise.

As vehicles become more connected, they are equipped with technologies that allow them to communicate wirelessly with the internet, other vehicles, and passengers' smartphones. Other systems, such as keyless entry and tire pressure monitoring, are also becoming more prevalent, increasing the number of electronic components in the vehicle. All of these systems improve functionality and increase the potential for electromagnetic interference (EMI) and radio frequency (RF) noise.

With noise becoming an ever-present issue, it is critical that automotive systems operate under harsh electromagnetic conditions. Without proper countermeasures, electronic systems can suffer malfunctions, which compromise vehicle performance and can also lead to significant delays in development. Engineers must ensure that each system operates as expected in an environment full of potential noise sources, requiring stringent testing and effective noise-immunity solutions.

THE IMPORTANCE OF EMC STANDARDS AND NOISE IMMUNITY

To combat the growing issue of noise in automotive electronics, international electromagnetic-compatibility (EMC) standards have been developed. These standards, which address both EMI and electromagnetic susceptibility, are essential to ensuring that automotive systems do not interfere with one another and that they can withstand external noise. Automotive electronics must pass these rigorous EMC tests to meet safety regulations and prevent malfunction in noisy environments.

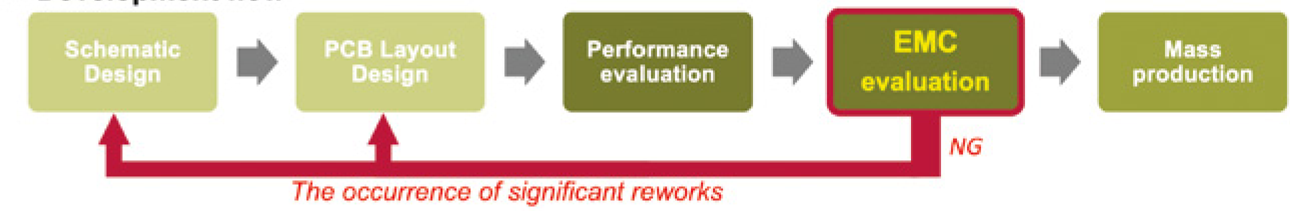
For example, the ***ZVEI*** Guideline Generic IC EMC Test Specification Version 2.1, along with the ***JEITA*** ED-5008 standard, provides guidelines for testing semiconductors for their EMC performance. However, one of the challenges that automotive engineers face is the lack of standard products, such as op-amps and LDOs, that can consistently meet the evolving EMC performance demands. As the automotive sector moves toward greater automation and electrification, meeting these standards with existing components becomes increasingly difficult, making the need for high-performance, noise-immune solutions more critical.

THE COST IMPACT OF EMC REWORK IN AUTOMOTIVE DEVELOPMENT

The development flow for automotive electronic systems generally follows a defined sequence: schematic design, PCB layout design, performance evaluation, EMC evaluation, and mass production. However, issues discovered during the EMC evaluation phase can trigger costly and time-consuming reworks at earlier stages of the design process.

When noise-immunity problems are identified at the EMC evaluation stage, engineers often need to revisit the schematic and PCB layout design. This process can involve modifying circuit designs, rerouting traces, and

■ Development flow



■ Development man-hours / Development cost (reference values)

Process	Man-hour [Day]	Number of engineer	Rate USD/Day	Test Cost USD/Day	PCB modification cost	Total
Re-Schematic Design/Velification	30	2	USD 500	-	-	USD 30,000
Re-PCB Layout Design	3	2		-	USD 5,000	USD 8,000
Re-Performance Evaluation	15	2		-	-	USD 15,000
EMC evaluation	10	2		USD 2,000	-	USD 30,000

*This is an example based on a small-scale ECU, and in reality, much more effort and cost would be incurred.

Reworks in the development process can lead to significant expenses.

replacing components to improve EMC. These rework activities delay the project and can also significantly increase costs, particularly if issues arise late in the development cycle.

These reworks can have substantial financial impacts, even at the small-scale ECU level. In addition to the direct costs of labor and materials required for redesigns, there are indirect costs, such as delays in the overall project timeline, testing and validation setbacks, and the potential for delays in mass production. In the automotive industry, where time to market is critical, any delay caused by EMC-related rework can have a cascading effect on production schedules and cost overruns.

By utilizing high-performance components with built-in noise immunity, such as Nisshinbo's op-amps and LDOs, automotive engineers can mitigate the risk of EMC issues emerging during the evaluation phase. This proactive approach to noise immunity can significantly reduce the need for costly design revisions, streamline the development process, and keep projects on track, ultimately saving time and money.

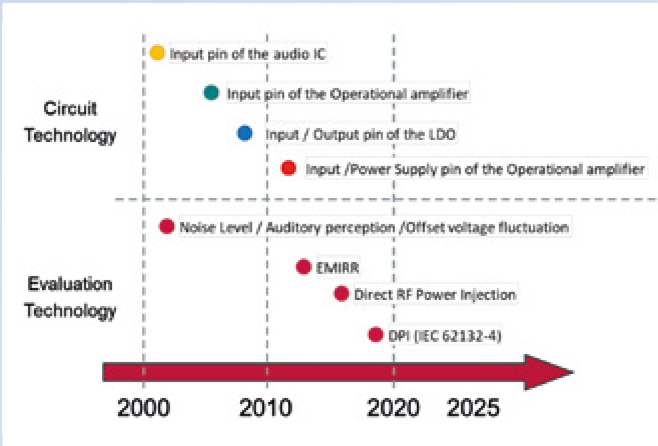
NISSHINBO'S APPROACH TO NOISE IMMUNITY IN AUTOMOTIVE ELECTRONICS

Nisshinbo has been at the forefront of addressing noise challenges in automotive applications. With over 40 years of experience supplying analog semiconductors to the automotive industry, the company has developed a range of products expertly designed to combat electronic noise and ensure reliable operation in noisy environments. Its innovative op-amps and LDOs offer high noise immunity and comply with the latest EMC standards, reducing the risk of malfunctions and speeding up development time.

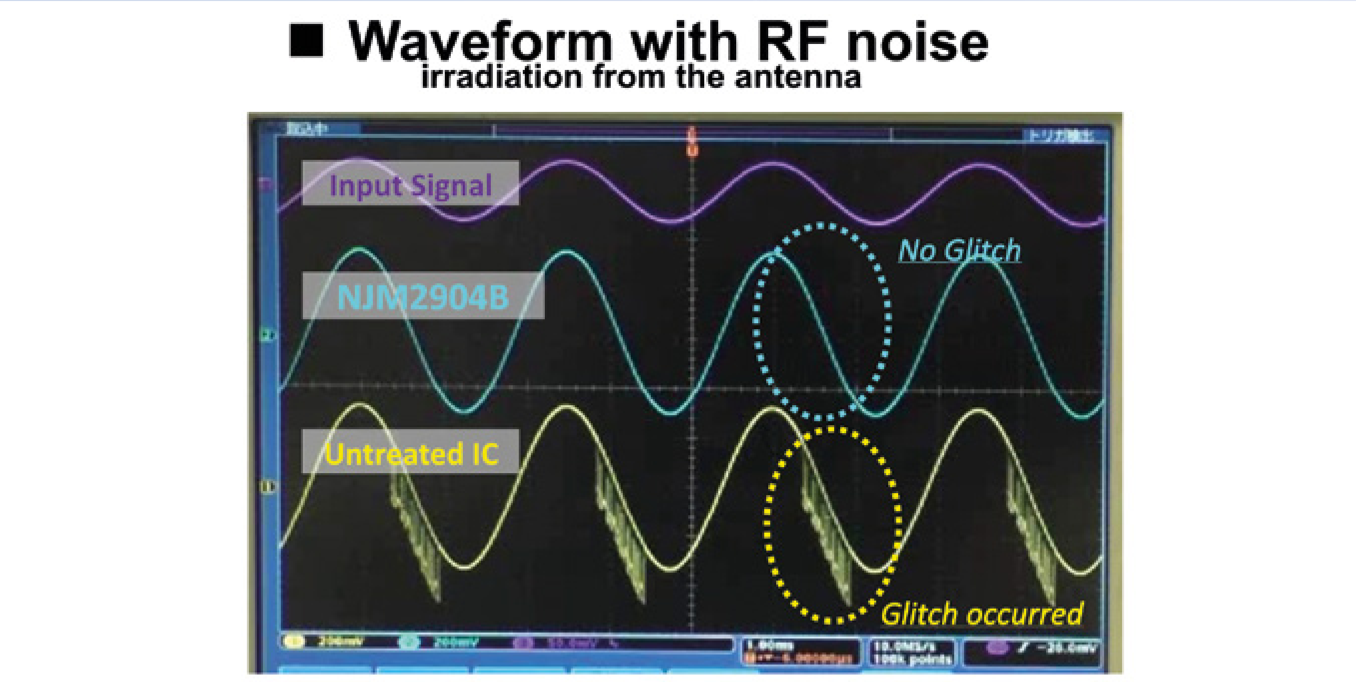
Op-amps for enhanced noise immunity

Op-amps are a fundamental component in automotive electronics, used for signal amplification in systems such as ADAS, engine control units, and sensor processing. However, in noisy automotive environments, op-amps must be capable of operating without interference from external electromagnetic noise.

Nisshinbo's NJM2904B and NJM2902B op-amps have been designed to provide industry-leading noise immunity. Unlike conventional op-amps, which typically address noise only at the signal input stage,



Nisshinbo's techniques for noise immunity over time



Comparison of the waveform for Nisshinbo's NJM2904B versus an untreated IC

these products incorporate countermeasures at the power input, amplification, and output stages. This holistic approach to noise suppression ensures that the op-amps maintain stability and performance in the presence of internal and external noise sources.

By implementing advanced EMC countermeasures across the entire op-amp, Nisshinbo has enhanced the noise immunity of its products to industry-leading levels. The NJM2904B and NJM2902B have been evaluated based on IEC 62132-4 and ED-5008 standards, confirming their ability to withstand RF and EMI across a wide frequency range, from several hundred kilohertz to tens of gigahertz. This makes them ideal for use in modern vehicles, where noisy environments are becoming more challenging due to the increasing number of electronic components and communication systems.

Visit Nisshinbo's ***noise-immunity op-amp page*** to learn more. You can also view the datasheets for the ***NJM2904B*** and the ***NJM2902B***.

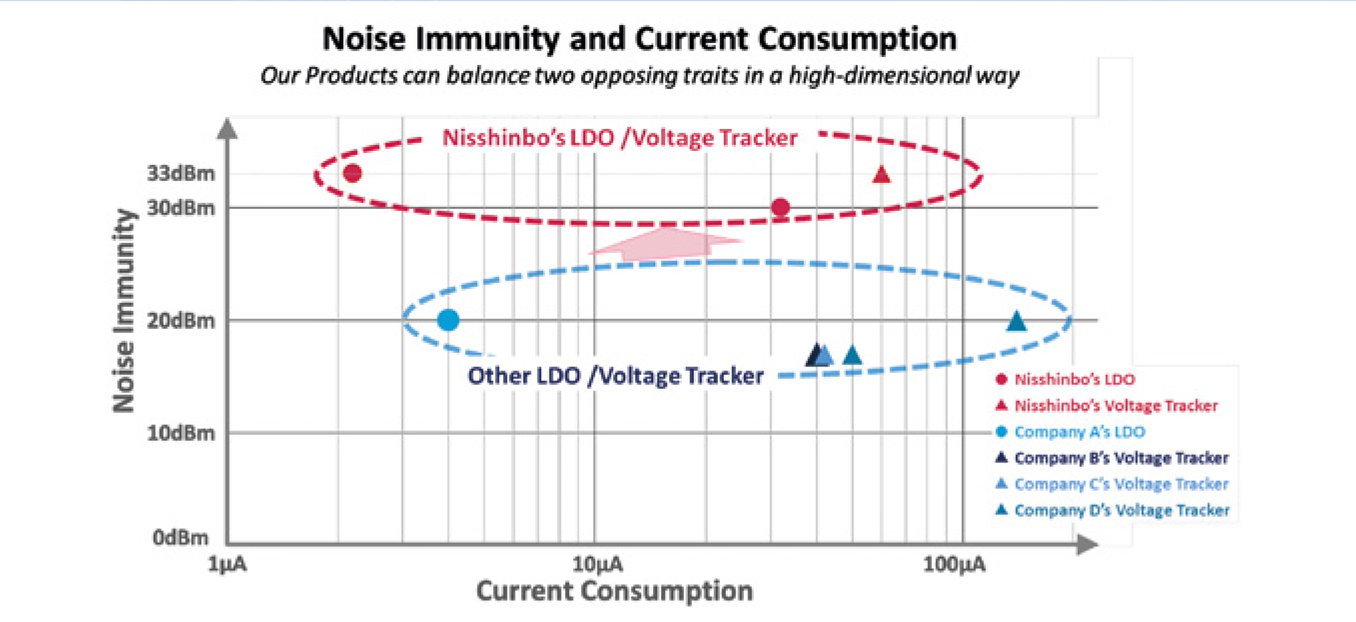
Feature	NJM2904B	NJM2902B
AEC-Q100 grade	Grade 1	Grade 1 (in progress)
Internal EMI filter	Yes	Yes
Voltage range	3 to 36 V	3 to 36 V
Current consumption	0.7 mA (typ.)	1.2 mA (typ.)
Slew rate	0.4 V/μs (typ.)	0.4 V/μs (typ.)
Input offset voltage	0.5 mV (typ.)	0.5 mV (typ.)
Package	MSOP8 (VSP8)	SSOP14-B4
Stability	Unity-gain stability	Unity-gain stability

LDOs for stable power regulation

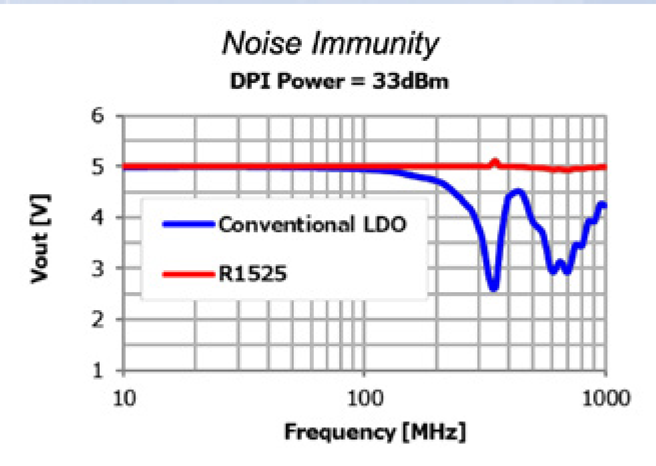
LDOs are essential for providing stable voltage to sensitive electronic components, especially in EVs and AVs, where precise power management is crucial. Traditional LDOs often rely on filtering noise components through output capacitance, but these methods are limited by the need to specify the noise frequency and consider other factors such as substrate impedance.

Nisshinbo's R1525, R1526, and R1540 LDOs are engineered to offer high-EMC characteristics, ensuring that they operate stably in the presence of noise across a broad frequency range. By applying proprietary circuit technology, these LDOs provide noise immunity from 150 kHz to 1 GHz, eliminating the need for additional components to suppress noise. This reduces the mounting area and simplifies the board design for automotive engineers.

Visit Nisshinbo's ***high-noise-immunity power management IC page*** to learn more. You can also view the datasheets for the ***R1525***, the ***R1526***, and the ***R1540***.



Noise-immunity performance of Nisshinbo's LDO and voltage tracker versus competitor offerings



While conventional LDOs experience degrading noise immunity as the frequency increases, the R1525 maintains performance even at high frequencies.

ENSURING RELIABLE PERFORMANCE IN A NOISY WORLD

As the automotive industry continues to innovate, the need for advanced noise-immune components becomes even more critical. Nisshinbo's op-amps and LDOs provide engineers with the solutions they need to ensure stable operation in the face of increasing electronic complexity and environmental noise. By adhering to the highest EMC standards and offering advanced noise-suppression technologies, Nisshinbo's products help reduce development time, enhance system reliability, and meet the stringent demands of modern automotive applications.

With its industry-leading noise immunity, Nisshinbo's op-amps and LDOs are an excellent choice for engineers looking to future-proof their automotive designs and ensure safety and performance.

Feature	R1525 Low Supply Current Regulator	R1526 Fast Transient Response Regulator	R1540 Voltage Tracker
Input voltage range	3.5 to 42 V (50 V max.)	3.5 to 42 V (50 V max.)	3.5 to 42 V (50 V max.)
Output voltage range	1.8 to 12 V	1.8 to 9 V	2.2 to 14 V
Output current	200 mA	300 mA	70 mA
Supply current	2.2 µA (typ.)	32 µA (typ.)	60 µA (typ.)
Operating temperature	–50°C to 125°C	–40°C to 125°C	–40°C to 125°C
Standby current	0.1 µA (typ.)	0.1 µA (typ.)	0.1 µA (typ.)
Package	DFN(PL)1820-6, SOT-23-5, SOT 89-5, HSOP-6J	HSOP-8E	SOT-23-5, HSOP-8E

The AspenCore Guide to

Gallium Nitride

This 150+ page book on **Gallium Nitride (GaN)** power devices provides a comprehensive look at the technology, applications, market, and future of this emerging wide-bandgap material for power electronics.

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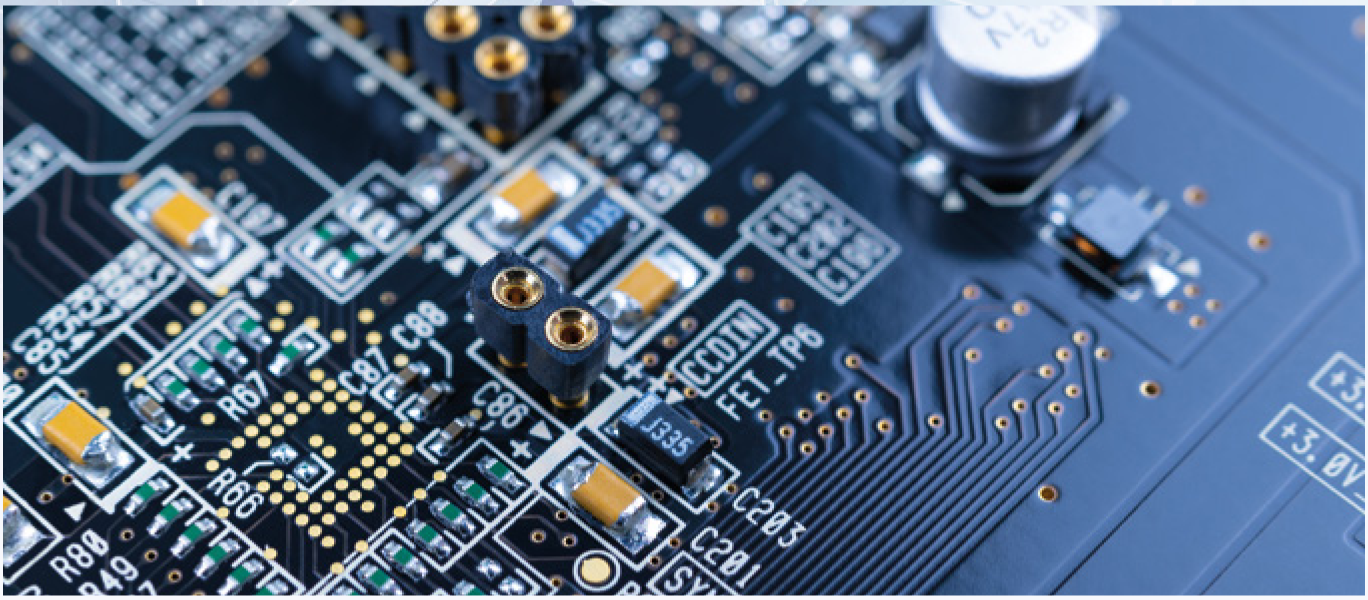


High-Voltage Electrical Substations and Challenges in the Netherlands

By Mayra Alejandra Fuentes, contributing writer for Power Electronics News

The electric grid uses electrical substations to transfer energy from the generation side to the consumer side. Electrical substations interconnect different power grids, and they have diverse functions, such as increasing the voltage for high-voltage transmissions, reducing the voltage for lower-voltage distribution, and converting the alternating current (AC) to direct current (DC).

Electricity generation in 2023 in the Netherlands was mainly sourced from natural gas, wind, solar photovoltaic, and other fossil sources such as coal, biofuels, and oil. On the transmission side, the highest voltage level increased over the years, from the 50-kV level toward a grid with connections at 110, 150, 220, and 380 kV.

The Netherlands is working on new high-voltage direct-current (HVDC) projects, including high-voltage electrical substations. Transmission system operator ***TenneT*** is also developing new management techniques to overcome grid congestion.

WHAT IS A HIGH-VOLTAGE ELECTRICAL SUBSTATION?

A substation is a part of an electrical generation, transmission, and distribution system. Substations transform voltage from high to low (or vice versa) or perform other functions. Between the generating station and the consumer, electric power may flow through several substations at different voltage levels. A substation may include transformers to change voltage levels between high transmission voltages and lower distribution voltages, or at the interconnection of two transmission voltages. Transformers are a common electric component of the infrastructure.

Substations may be owned and operated by an electric utility or a large industrial or commercial customer. They use the supervisory control and data acquisition (SCADA) system for remote supervision and control.

SCADA is a control system architecture comprising computers, networked data communications, and graphical user interfaces for high-level supervision of machines and processes. It enables operators to remotely monitor and control protection relays, circuit breakers, voltage regulators, and other substation equipment.

An electrical substation has multiple uses and is suitable for:

- Increasing the voltage produced by electric power generation for efficient transmission over long distances using step-up transformers
- Interconnection of different power grids
- Reducing the voltage from transmission to lower-voltage distribution lines that supply individual homes or businesses
- Converting from AC to DC
- Electrical substations and energy sources in the Netherlands

ENERGY SOURCES AND ELECTRICAL SUBSTATIONS IN THE NETHERLANDS

According to the ***International Energy Agency*** and as shown in Figure 1, electricity generation in 2023 in the Netherlands was mainly sourced by natural gas, which produced 37.9% of the total electricity, followed by wind (24%) and solar photovoltaic (16.5%). Other sources, such as coal (8.8%), biofuels (4.6%), and oil (1.3%), were less representative.

Figure 2 illustrates the changes in sources of electricity generation in the Netherlands from 2000 to 2023. In 2023, natural gas generated the most electricity, at 45,987 GWh, followed by wind (29,164 GWh), solar photovoltaic (19,992 GWh), coal (10,706 GWh), biofuels (5,625 GWh), nuclear energy (3,985 GWh), oil (1,531 GWh), hydro (68 GWh), and other sources (48 GWh).

Total electricity production in the Netherlands in 2020 amounted to 89,631 GWh, while in 2023 it reached 121,331 GWh, a 35% increase. Total electricity consumption per capita in 2023 was 6,197 MWh/capita, down 5% from 2000.

TenneT and six distribution system operators oversee the Dutch electric grid. TenneT holds responsibility for the high-voltage electricity grid, specifically operating within the range of 110 to 380 kV. This includes the integration of offshore wind parks into the onshore transmission grid, as well as the management of cross-border interconnectors to neighboring countries. Additionally, TenneT administers the national high-voltage grid, which facilitates electricity transmission at voltage levels of 110, 150, 220, and 380 kV.

The standard voltage in the Netherlands is 230 V at a frequency of 50 Hz. The voltage classification in Amsterdam goes from 400 V to 525 kV, covering distributed voltage, high voltage, and extra-high voltage, as indicated in Table 1. The 220-kV and 380-kV high-voltage transmission grid is part of the Dutch power grid and is responsible for transporting power.

Table 2 shows some recent transmission project substations in the Netherlands for HVDC lines.

OVERVIEW OF ZEEWOLDE ONSHORE WIND FARM WITH HIGH-VOLTAGE SUBSTATION

In the Dutch province of Flevoland (Netherlands), the 320-MW Zeewolde onshore wind farm has 91 wind turbines, each with a capacity of 3.5 MW. The wind farm is connected to a high-voltage substation, which includes two 240-MVA transformers. The electricity supplied by the wind turbines at a 33-kV level is transformed up to 150 kV to feed into the national high-voltage network. In addition to the 33-kV and 150-kV switching equipment, ***ABB*** supplied the protection equipment, the SCADA system, and all the

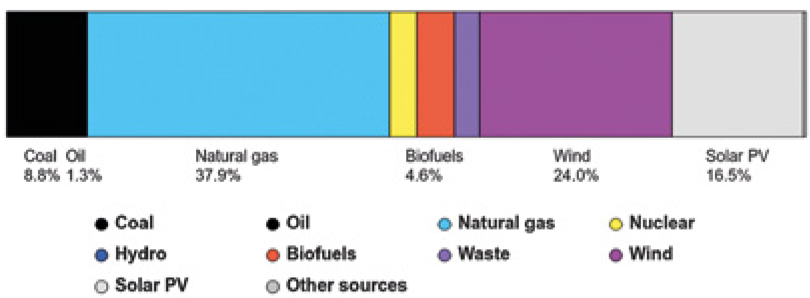


Figure 1: Electricity generation sources in the Netherlands by 2023 (Source: International Energy Agency)

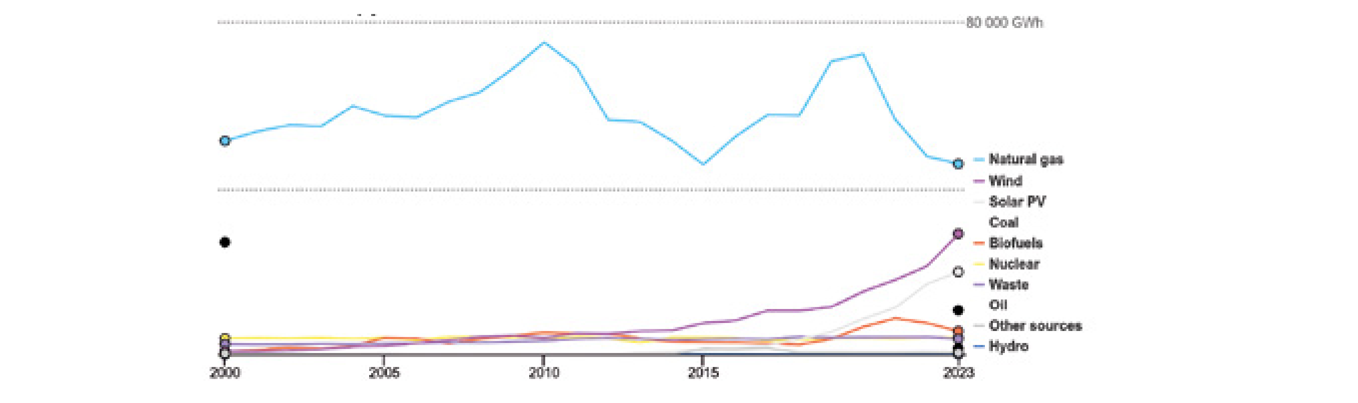


Figure 2: Evolution of electricity sources in the Netherlands since 2000 (Source: International Energy Agency)

	Extra-High Voltage (kV)	High Voltage (kV)	Distributed Voltage (kV)
Voltage level	525 kV 380 kV 220 kV	110 kV	20 kV 10 kV 400 V

Table 1: Dutch voltage levels

structural facilities for the substation. The 6.5-km cable connects the wind farm to the 150-kV station of TenneT.

So far, ***Battery Park Zeewolde*** (Batterij Park Zeewolde B.V.) has obtained all permits to build a 65-MW energy storage system. Rolls-Royce Power Systems is working on the project and supplying the large-scale battery storage system, involving 16 battery containers. This project also includes inverters and transformers.

The Zeewolde site also has a project involving the construction of a 15-MW hydrogen plant. This project is H2 Park Zeewolde B.V. and is supported by ***Windpark Zeewolde***. The hydrogen technology exists, and H2 Park Zeewolde has applied for the permit for Phase 1 of a 15-MW hydrogen plant.

OVERCOMING ELECTRIC GRID CONGESTION

As of September 2024, some grids in the Netherlands are congested, meaning the electricity transmission demand exceeds the available transmission capacity of the existing grid. The waiting list for new or increased connections includes about 10,000 large users (consumers or batteries) and 7,500 large generation projects (bigger than household scale).

TenneT is investing in the ***construction of new power lines*** as well as the further development of the existing allocation procedure to improve the situation. It is also developing methods to handle congestion management.

Project Name	Nederwiek I–Borssele HVDC line	Nederwiek II–Maasvlakte HVDC line	Nederwiek III–Geertruidenberg HVDC line	Eemshaven–Diemen line	Krimpen–Oostzaan line
Voltage level	525 kV/380 kV	525 kV/380 kV	525 kV/380 kV	380 kV	380 kV
Description	525-kV part oh/ug Nederwiek I offshore converter station to Borssele converter station	525-kV part oh/ug Nederwiek II offshore converter station to Maasvlakte	525-kV part oh/ug Nederwiek III offshore converter station to Geertruidenberg	380-kV overhead line with a length of 200 Ckm running from Eemshaven to Diemen	380-kV overhead Krimpen to Oostzaan
Place in the Netherlands	Borssele, Zeeland	Maasvlakte, South Holland	Nederwiek III–Geertruidenberg HVDC Line	Eemshaven–Diemen Line	Krimpen–Oostzaan Line
Year	2030	2030	N/A	N/A	N/A

Table 2: Electrical projects in the Netherlands (Sources: Power Technology and Wikipedia)

Automotive Power Module Market Innovations Advance E-Mobility

Fusion technology traction inverters combine silicon and SiC power switches to balance efficiency, cost, and sustainability.

By Diego de Azcuénaga, contributing writer for Power Electronics News

The automotive industry seeks to optimize energy efficiency and the use of raw materials. Semiconductor power switches allow fusion-based traction inverters to achieve efficient and affordable electric mobility. With fusion technology, silicon and silicon carbide chips operate in parallel within the same traction inverter, achieving a balance between drive-cycle efficiency and cost.

Some silicon can be added to SiC to increase the maximum performance of a vehicle. For example, a silicon part capable of supplying an additional 160 kW to an 80-kW motor would result in a very sporty car.

Dual-eAxle (Figure 1) is a car configuration in which silicon and SiC technologies are implemented in different axles. A SiC inverter achieves higher efficiency,

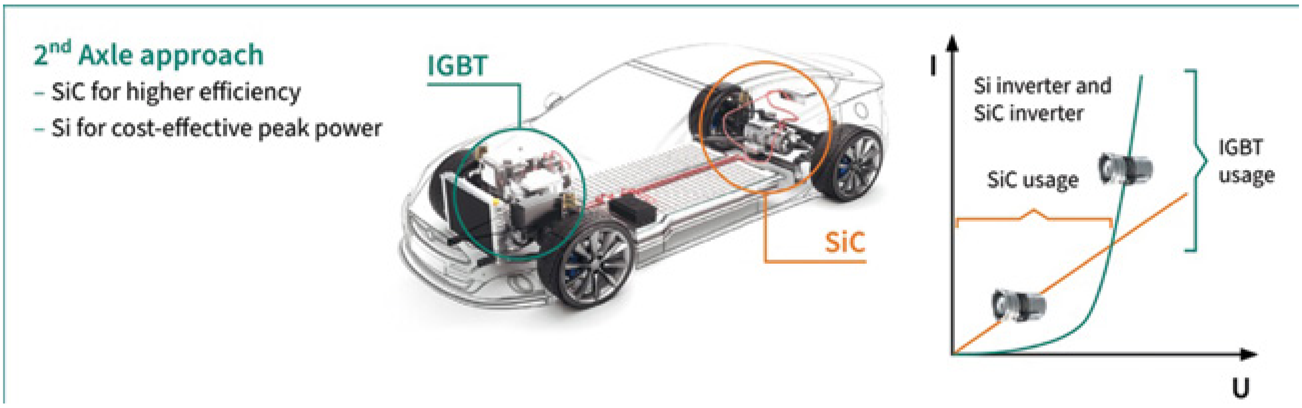


Figure 1: Dual-eAxle car configuration (Source: Infineon Technologies)

while a silicon inverter achieves cost-effective maximum power. Additional torque provides four-wheel-drive capability and maximum performance.

INVERTER OPERATING MODES

The inverter's operating modes are as follows:

- Exclusive operating mode, in which only one semiconductor technology (silicon or SiC) is used
- Simultaneous switching mode, in which silicon and SiC are always used in parallel
- Individual operating mode, in which the inverter can seamlessly switch between exclusive and simultaneous modes

Traction inverters with fusion technology can be implemented for different market segments, depending on product availability and appropriate engineering capabilities.

Exclusive mode (Ex2G)

- SiC is used below a certain current threshold. If a higher current is demanded, the SiC switches are turned off and just the IGBTs are in operation. Once the current falls below the threshold again, the SiC switches are reactivated.
- Higher peak currents are achieved than possible with IGBT-only designs due to the thermal capacity utilized.
- Efficiency is dictated by SiC behavior.
- Single technology commutation
- Adaptable during operation
- Limp-home functionality/fail-operational

In a vehicle, power demands below 80 kW are covered by SiC. If a higher output power is required from the traction inverter, silicon is used.

The design of state-of-the-art inverters requires the availability of appropriate gate drivers, microcontrollers, and power supply ICs.

Because both technologies operate independently, Ex2G mode offers ease of control, requiring independent PWM signals and, by extension, two gate drivers to control the IGBT and SiC.

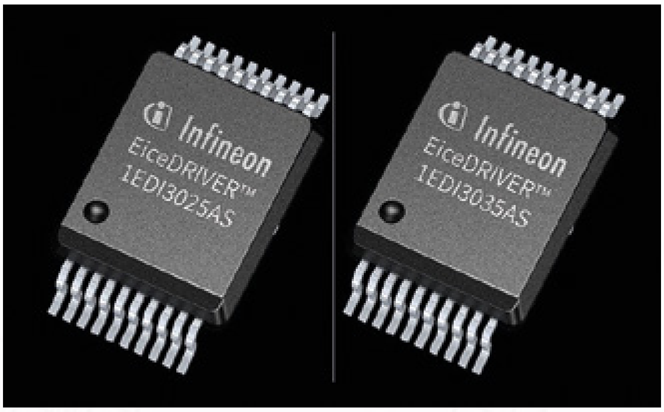


Figure 2: EiceDRIVER gate drivers 1EDI3025AS and 1EDI3035AS (Source: Infineon Technologies)

The EiceDRIVER 1EDI3025AS and 1EDI3035AS (Figure 2) gate drivers come in compact, 20-pin dual small out-lint (DSO) packages and have been optimized for IGBTs and SiC, respectively. This combination enables power switches to detect and respond to short-circuits independently. Their coreless transformer technology enables fast, precise and well-matched signal transmission, achieving optimized synchronization between silicon and SiC. Furthermore, the independent gate drivers support emergency mode if a power semiconductor device fails.

Because only one power device is turned on or off at a time in exclusive Ex2G mode, the gate driver's turn-on/turn-off behavior is similar to the switching of a typical IGBT or SiC inverter.

Disabling the inactive power semiconductor gate driver is accomplished by using the appropriate PWM inputs or by bringing it into a "PWM-disabled" state. This results in minimal interference to the gate driver that is actively switching the power device.

In the event of a SiC gate-source failure, it is switched to the safe state via its gate driver, while the IGBT remains operational in case the system safety concept requires emergency capabilities.

With Ex2G, two gate drivers are used: one for SiC and one for IGBTs. SiC or IGBTs are selected in the gate drivers by the MCU.

Simultaneous mode (S1G & S2G)

In this mode, the SiC MOSFET and IGBT are controlled by one common PWM signal. Unlike Ex2G mode, silicon and SiC are always used simultaneously. A gate signal allows switching between both technologies, with a unique design where all individual switches share the current.

There are two implementation options with simultaneous mode: one-gate (S1G) or two-gate (S2G). With S2G, the MCU generates a PWM signal, which is channeled through two gate drivers to reach the individual gates, while in S1G, there is one driver and one gate pin and the signal is matched in the power module.

The power configuration always handles the same load current because the silicon and SiC are turned on or off simultaneously.

Up to the gate driver output, the IGBTs and SiC can be controlled with the same signal and subsequently matched appropriately in the gate resistor circuit (S2G) or within the power module (S1G).

The EiceDRIVER 1EDI3051AS gate driver (Figure 3) comes in a 36-pin DSO package with integrated SPI,

Figure 3: EiceDRIVER gate driver 1EDI3051AS (Source: Infineon Technologies)

offering the highest degree of compatibility with IGBTs and SiC power technologies.

Its outstanding capabilities include independent gate monitoring and overcurrent protection for IGBTs and SiC. It also has an integrated flyback controller that offers high-precision control of the gate voltage, allowing conduction losses to be minimized, especially in SiC.

Features include:

- High-power internal amplifier stage that allows peak currents of up to 20 A to drive modules with high gate charges
- Accurate dual-channel 12-bit delta-sigma ADC able to monitor two signals, such as the IGBT and SiC temperatures, using temperature diodes or NTCs placed close to the chips
- Independent internal active Miller clamp for gate monitoring and fault detection in IGBT and SiC power semiconductors
- Common VCC2 and VEE2 power supply for both IGBT and SiC, minimizing the need for additional power supplies

Simultaneous switching of silicon and SiC is achieved by the S1G, S2G, and S2G_dir methods. In the S1G variant, only one gate is present, which is selected by an adaptation circuit located in the power module. In S2G, there are two gates: one for SiC and one for silicon, with an adaptation circuit on the PCB. The novelty introduced in S2G_dir is the ability of silicon and SiC to work together by short-circuiting both gates on the PCB without requiring additional adaptation.

Individual mode (In2G)

- Current conduction on silicon and SiC is controlled individually.
- For lower power, only the SiC conducts; for medium power, only the silicon does; for higher power, both semiconductors conduct.
- At the turn-on/turn-off, there is total flexibility in the transitions.
- Highest optimization potential
- Limp-home functionality/fail-operational

This mode requires two PWM signals per switch and can be tuned by adapting the PWM pattern online within the control strategy.

To minimize the overload caused by the technology by optimizing the transient current sharing, the turn-on and turn-off edges can be shifted, as SiC can switch faster than silicon. In limp-home mode, one technology is switched off in the event of a failure, and the system relies on the remaining technology to return to normal.

While In2G mode requires two gates and therefore presents a more complex control strategy, it focuses on individual switching dynamics taking full advantage of the benefits of traction inverters with fusion technology. In failure recovery, it offers the advantage of redundancy between the two technologies.

In2G requires separate PWM signals to control the IGBT and SiC, and each channel has its own gate driver. This optimizes the switching behavior of the devices and provides independent diagnostic capabilities.

The combination of the EiceDRIVER 1EDI3025AS and 1EDI3035AS gate drivers provides a powerful internal amplifier stage capable of generating peak currents up to 20 A per driver, intended for modules with high gate loads. It features independent 12-bit delta-sigma analog/digital converters to monitor IGBT and SiC temperatures, using temperature diodes or NTCs placed near the chips.

Features include:

- Separate VCC2 and VEE2 power supplies, minimizing conduction losses, especially in SiC
- Independent internal active Miller clamp for gate monitoring and fault detection in IGBT and SiC power semiconductors
- Limp-home capability if one power semiconductor device fails
- Ex2G mode can be adapted to switch only one of the devices

Power devices can be turned on and off independently due to the presence of two gate drivers, adjusting the timings with a delay to optimize switching and conduction losses.

In2G_Red mode is the same as In2G but includes a certain level of redundancy, which is reflected in the silicon and SiC devices such as power semiconductors and gate drivers for each switch down to redundant calculation of the PWM pattern on different cores of an MCU.

The concept of redundancy points to future application cases of fusion inverters, based on redundant (two switches in parallel) and diverse (silicon and SiC) power switches.

Redundancy is created within an MCU using multicore architecture. In2G_Red mode can be applied in robotaxis (autonomous vehicles that do not have a driver), where a high level of availability and reliability is required.

Simultaneous switching's advantage lies in the simplicity of the circuit, where there is only one gate driver channel and the adaption circuit can be designed with only a few resistors. Its optimal variant is S2G_dir, where there are no additional components and the two gates can simply be connected to each other.

In normal operation with individual switching, silicon and SiC operate simultaneously, as in S2G mode. In the event of a fault, the In2G_Red variant allows the inverter to continue operating with only one technology. To increase system availability and redundancy, this fusion method uses two technologies, taking advantage of the BOM with a low impact on efficiency.

Innovative designs of fusion-based traction inverters combine the advantages of silicon and SiC to increase performance, optimize material use, and overcome supply constraints. They thus broaden the outlook for the next generation of efficient, cost-effective, and sustainable e-mobility solutions.

Quantifying the Benefits of Second-Life Lithium-Ion Batteries

By Filippo Di Giovanni, contributing writer for Power Electronics News

The large-scale deployment of lithium-ion (Li-ion) batteries across various applications raises significant concerns regarding their recycling and reuse after reaching the end of their life cycle. Therefore, it is essential to implement techniques and procedures that minimize environmental impact and create new business opportunities. This approach aligns with the principles of circular and green economies.

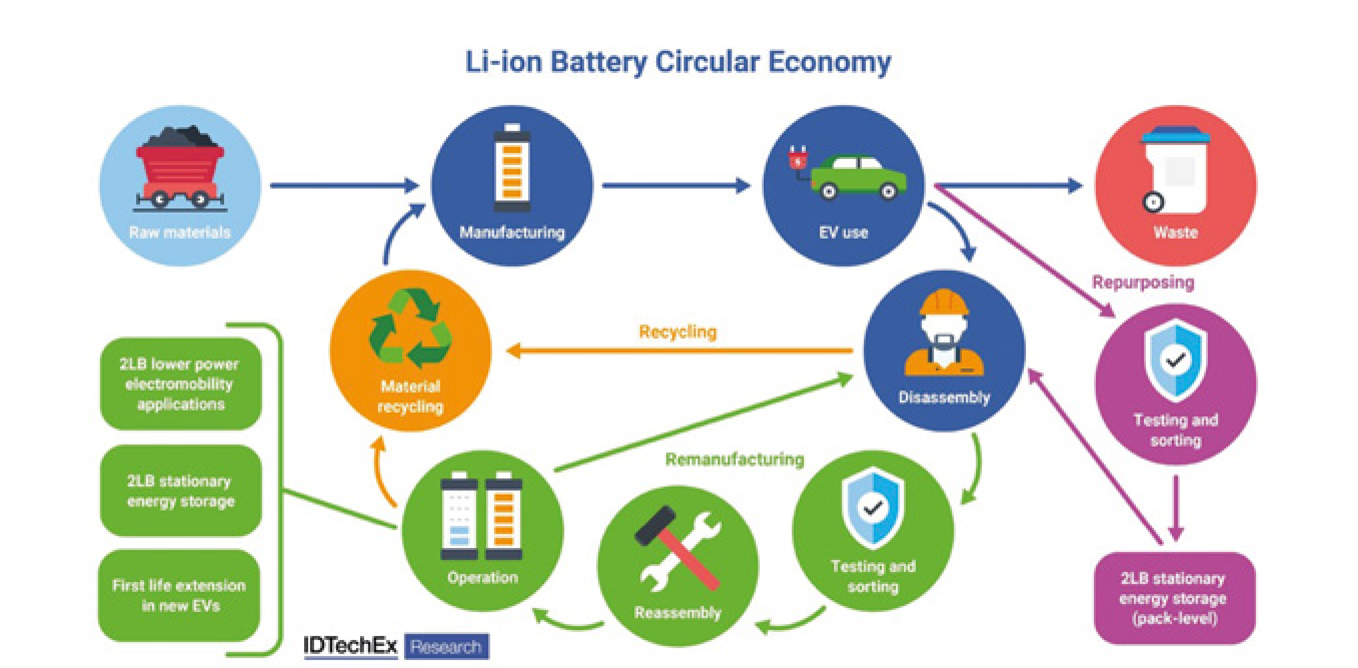
In a ***dedicated market report***, IDTechEx estimates that by 2035, the global second-life electric-vehicle battery market will be worth $4.2 billion. The availability of retired EV batteries will drive second-life storage adoption, but feasibility and competitiveness depend, to a large extent, on battery chemistry and their repurposing. It is thus important to assess the efficiency and operating costs of second-life batteries with respect to incumbent first-life Li-ion battery energy storage systems (BESSes).

HOW Li-ION BATTERIES ARE BUILT

Li-ion batteries consist of several key materials, categorized into four components: cathode, anode, electrolyte, and separator.

The cathode (positive electrode) stores lithium ions and determines the battery's voltage and capacity. Lithium does not exist in pure metallic form in nature due to its high reactivity, which depends on its relatively low first ionization energy (520 kJ/mol). This means it easily gives up its outermost electron to form a Li^+ ion. Lithium is obtained from different compounds:

- Lithium cobalt oxide
- Lithium nickel manganese cobalt oxide (NMC), commonly used in EVs
- Lithium iron phosphate (LFP), suitable for both energy storage systems and EVs
- Lithium nickel cobalt aluminum oxide, used in Tesla's EV models



Birth and regeneration of Li-ion batteries (Source: IDTechEx)

The anode (negative contact), typically made of natural or synthetic graphite, serves as the storage site for lithium ions when the battery is charged. The electrolyte enables lithium ions to move between the two electrodes. It consists of lithium salts dissolved in a solvent made of organic carbonates, such as lithium hexafluorophosphate. The separator physically separates the anode from the cathode while allowing lithium ions to pass freely between them. It is usually made from microporous polymer films such as polyethylene or polypropylene.

Once lithium is extracted from source compounds, cathode and anode materials are mixed with binders and coated onto aluminum (cathode) and copper (anode) foils with uniform thickness. The next step involves stacking the anode, separator, and cathode to form cells, which are then sealed to prevent leakage.

Before the cells are assembled into a module, they undergo a controlled charge and discharge cycle under preset conditions to form a stable solid electrolyte interface (SEI) layer. Finally, individual cells are connected into modules and assembled into larger packs equipped with a battery management system for monitoring and safety.

AVERAGE LIFESPAN OF EV Li-ION BATTERIES

The life expectancy of Li-ion batteries in EVs typically ranges between eight and 15 years under normal driving conditions. This corresponds to approximately 240,000 to 480,000 km (150,000 to 300,000 miles), depending on factors such as usage, climate conditions, and battery chemistry. Most EV manufacturers provide a battery warranty of eight years, or 100,000 miles—whichever comes first. Some third-party providers, such as XCare by Xcelerate Auto, offer extended warranty schemes, which can provide extra coverage beyond the manufacturer's warranty. However, these figures can vary significantly. For instance, some Tesla Model S and Model 3 owners have reported driving more than 300,000 miles while retaining about 80% of their battery capacity.

WHY Li-ION BATTERY PERFORMANCE DEGRADES OVER TIME

Chemical and physical processes accelerated by charge-discharge cycles occur within a battery, leading to gradual degradation over time. After 1,000 to 2,000 cycles, most EV batteries retain only 70% to 80% of their original capacity. Heat is a major factor that accelerates chemical reactions, deteriorating the cathode, anode, and electrolyte. Frequent exposure to extreme temperatures—above 35°C to 40°C (95°F to 104°F)—further speeds up degradation. DC fast charging generates additional heat, increasing stress on the battery. Frequent sudden acceleration or heavy loads drain power quickly, contributing to faster wear. Repeatedly discharging the battery below 10% or charging it to full capacity also accelerates degradation.

A protective SEI layer forms on the anode during initial charging cycles, but it thickens over time, increasing internal resistance and reducing efficiency. At temperatures below 0°C, fast charging can cause lithium plating, where metallic lithium deposits on the anode, leading to capacity loss and potential safety hazards.

CAN EV BATTERIES BE USED ELSEWHERE BEFORE RECYCLING?

Due to the factors mentioned above, EV batteries are removed from electric powertrains once their performance declines. While exhausted batteries can be recycled to recover raw materials for manufacturing new ones, a more sustainable approach is repurposing them for second-life applications to maximize their value and extend their lifespan.

In some cases, replacing individual cells or modules within a battery pack can prolong its first life in an EV. However, when batteries are no longer suitable for vehicle use, they can be repurposed for stationary energy storage systems or other applications with lower efficiency demands.

Second-life Li-ion batteries can store excess electricity generated from renewable sources such as solar and wind. This helps stabilize the grid by ensuring a reliable power supply even when energy generation fluctuates during cloudy days or low-wind conditions.

WHY EUROPE AND THE U.S. PREFER NMC BATTERIES

Europe and the U.S. have opted for NMC battery chemistries due to their superior energy density, longer driving range, strong power output, fast-charging capability, and balanced performance—offering a better lifespan relative to power and cost.

Unlike LFP batteries, the presence of nickel and cobalt in NMC batteries enhances their recycling profitability, making the recovery process economically viable and supporting a more sustainable supply chain for the EV industry. Cobalt and nickel are expensive and relatively scarce, making their recovery economically sound.

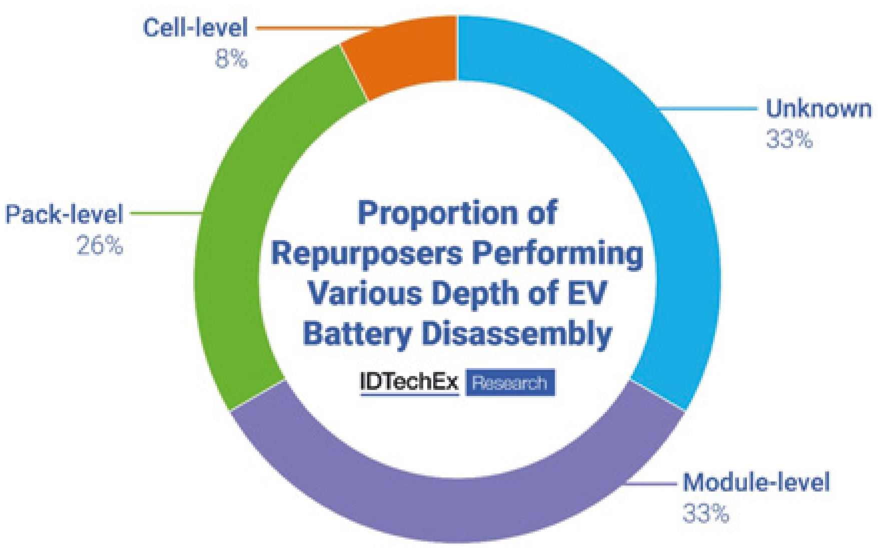
Additionally, because NMC batteries have a higher energy density, they contain more valuable materials per unit of weight. Recycled nickel and cobalt can be reused in new NMC batteries, reducing reliance on mining and minimizing environmental impact.

ECONOMIC CONSIDERATIONS

Several companies in the U.S. and Europe are actively repurposing Li-ion batteries, giving EV batteries a second life in various applications.

In a ***recent announcement***, BMW of North America partnered with Redwood Materials, a company founded by Tesla co-founder and former CTO J.B. Straubel, to recycle Li-ion batteries from all of its electrified platforms. Under this deal, BMW dealers will send used batteries from all BMW, Mini, and Rolls-Royce electrified models—including battery-electric and hybrid vehicles—to Redwood for recycling. Redwood will process these end-of-life batteries at its facility in Reno, Nevada, and its upcoming facility in Charleston, South Carolina, which is strategically located near BMW's Spartanburg and Woodruff plants.

Other players include B2U Storage Solutions, whose technology allows these batteries to be repurposed without modification, reducing costs and supporting



Disassembly can occur at different levels. (Source: IDTechEx) grid stability; BeePlanet Factory, which is focused on large renewable energy installations, commercial and industrial self-consumption, and charging infrastructures; Connected Energy in the U.K., which provides scalable and sustainable energy storage solutions; and Zenobē.

However, the decreasing cost of first-life Li-ion BESSes in Europe and the U.S. has created challenges for second-life battery repurposers, making it difficult to remain competitive. To succeed, second-life BESSes must be priced lower than first-life Li-ion BESSes, reflecting the degraded value of used EV batteries. Several factors influence second-life battery costs, including logistics complexity, component/material costs, and the repurposing process itself—which involves battery grading, disassembly, and reassembly. Battery grading time, which is required to assess and classify batteries based on performance, capacity, and quality, can take several weeks, so reducing its length is key to lowering costs.

INNOVATIONS IN REPURPOSING PROCESSES

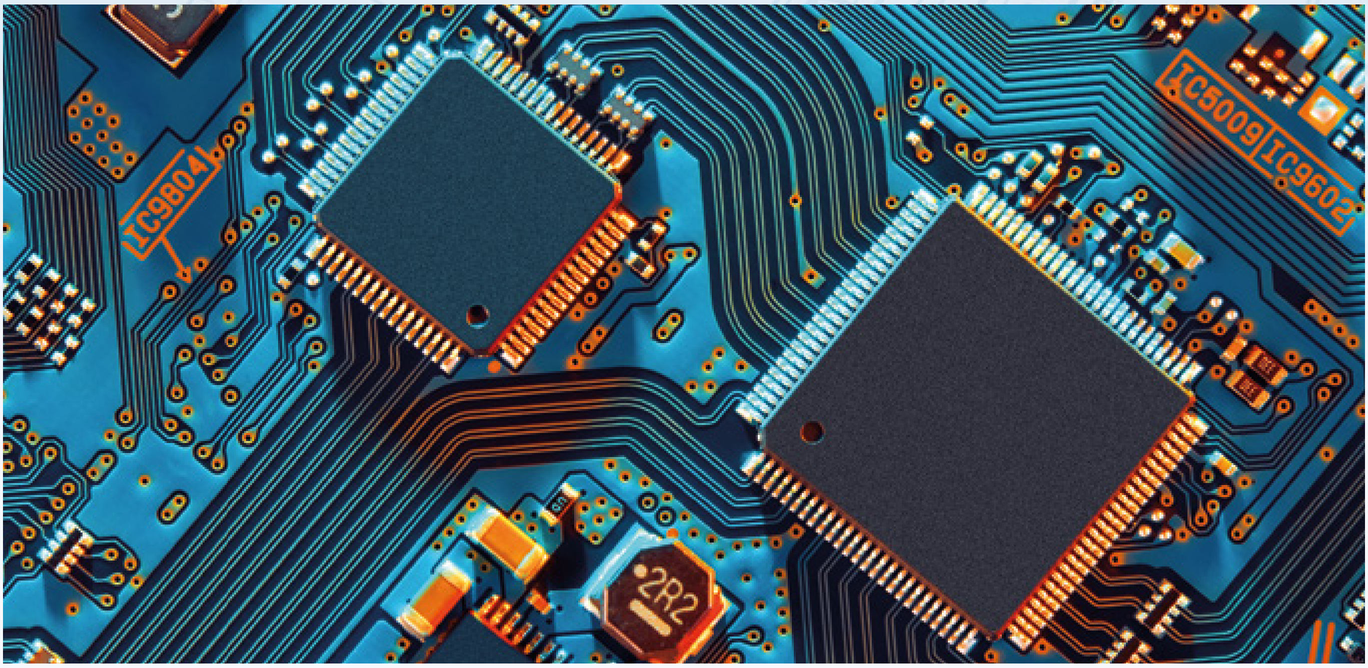
To optimize costs, some projects have turned to semi-automated disassembly, reducing labor requirements. IDTechEx reports that advanced in-vehicle battery grading technologies can now determine a battery's state of health within minutes, significantly cutting testing time and costs. Currently, retired EV batteries are available at $25/kWh to $75/kWh in low volumes, and economies of scale are expected to drive these costs down further.

For reference, in 2023, the average Li-ion battery cost was close to $140/kWh according to Bloomberg, marking a decrease from the previous year. In 2024, prices dropped another 20%, reaching a record low of $115/kWh. Some analysts predict that by 2026, costs could fall to $80/kWh, a 50% decline from 2023, making it increasingly difficult for second-life BESS providers to compete.

FUTURE BUSINESS MODELS AND MARKET OUTLOOK

Given these cost pressures, second-life battery businesses must focus on cost reduction in repurposing and logistics while exploring innovative business models. Possible solutions include Battery Storage as a Service and leasing second-life batteries to customers. These models, explored in-depth by IDTechEx, could create new revenue streams and enhance commercial viability.

Despite these challenges, the growing volume of retired LFP EV batteries in Europe and the U.S. should help to lower retired EV battery costs, allowing repurposers to offer their second-life batteries at lower costs to potential users. However, the long-term feasibility of second-life battery storage will still depend on the cost trajectory of first-life Li-ion BESSes, which continues to trend downward.



Improvements in Integrated GaN Power Devices Under Light-Load Conditions

By Sonu Daryanani, contributing writer for Power Electronics News

Lateral gallium nitride ***HEMTs*** are increasingly popular in various power conversion application. Significant improvements in efficiency and power density are key advantages driving this growth. In this article, we will highlight some of the light- and no-load improvements achieved by ***Cambridge GaN Devices*** (CGD) in its H2 series of ICeGaN integrated GaN products.

INTEGRATED GaN POWER DEVICES

The lateral HEMT power device, typically manufactured in a GaN-on-silicon production line, has several pros and cons compared with the more common vertical device architecture used in silicon and silicon carbide. Higher voltage and power scaling is more easily accomplished with the vertical architecture. Here, scaling of the vertical drift region is the primary knob for voltage rating. The lack of commercially viable large-diameter GaN substrates is seen as a primary bottleneck for the creation of ***vertical GaN devices***.

Conversely, the lateral HEMT topology offers many advantages. The two-dimensional electron gas that forms the conduction channel has a high carrier mobility and drift velocity. Although the specific resistance (on-state resistance [$R_{DS(on)}$] × device area) can be worse than SiC devices, especially at the higher-voltage (>600 V) range, improvements in switching losses over silicon and SiC can translate to net advantages for GaN. GaN's higher switching frequencies also enable passive component size reductions, improving power density. Manufacturing on silicon substrates creates a means of manufacturing on large-diameter silicon wafers in fabs that share many commonalities with standard CMOS process flows. This can create cost advantages and a lower environmental impact in the GaN-on-silicon process flow than the more complex SiC manufacturing process. A big advantage of a lateral device is also the possibility of monolithically integrating other devices with the power device.

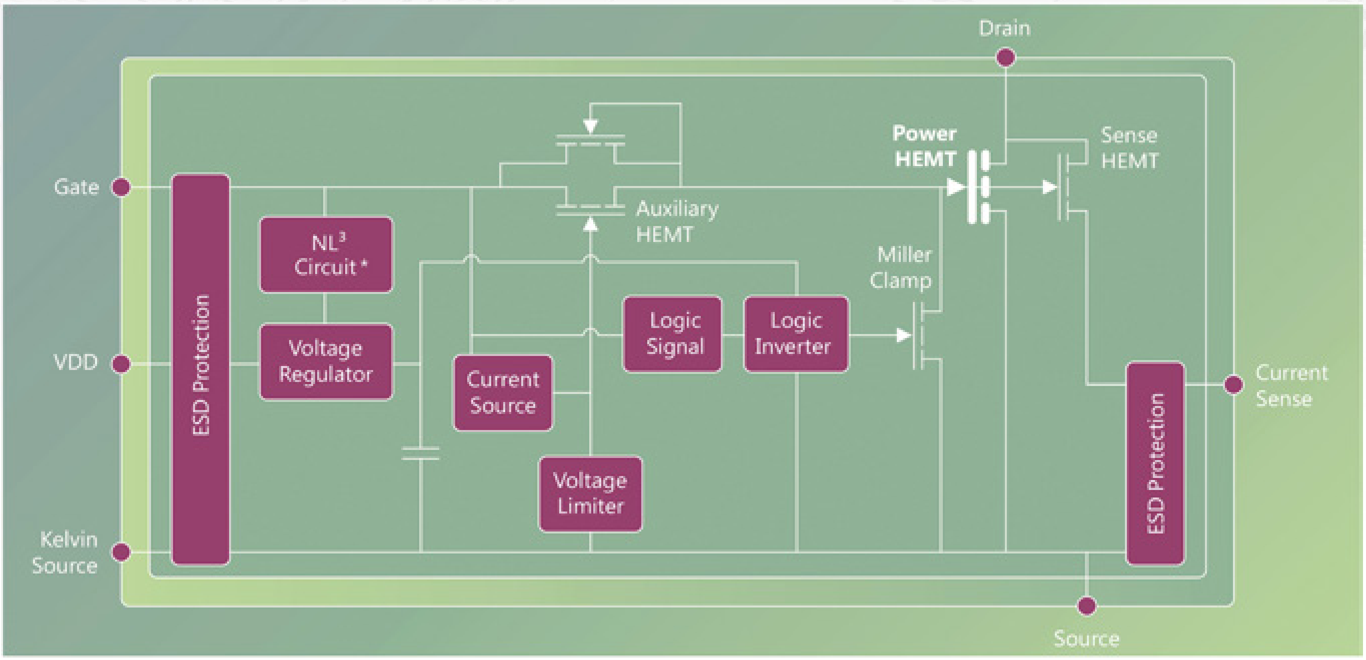


Figure 1: A simplified block diagram of the H2 ICeGaN products (Source: Cambridge GaN Devices)

These can include the gate drive, sense and protection devices, and GaN-based logic circuits.

The difficulty of forming viable p-type devices hampers the ability to create CMOS-like low-power devices with GaN. ***Silicon PMOS devices*** have been integrated with GaN switches. ***Direct-coupled FET logic and resistor transistor logic*** have also been demonstrated using a combination of enhancement-mode (e-mode) and depletion-mode devices, with penalties of higher power consumption.

CGD's ICeGaN products are examples of monolithic GaN integration that improves the performance, robustness, and reliability of the p-GaN Schottky gate e-mode power HEMT. A block diagram of the ICeGaN products is depicted in Figure 1.

Some of the key features of ICeGaN products are:

- The low-voltage auxiliary HEMT, along with the current source and voltage limiter, serves as the interface between the external gate voltage (V_{gsext}) and internal gate voltage (V_{gsint}) seen by the e-mode Schottky p-gate power HEMT. Over the full specified range of V_{gsext} (typically –1 V to 20 V), the V_{gsint} is controlled to remain within the power HEMT gate safe operating area, typically 0 to 5.5 V. This enables standard silicon or SiC power device gate drivers to be used. ***V_{gsext} overshoots of over 65 V*** can be tolerated, compared with about 25 V for the standard discrete Schottky gate e-mode HEMTs.
- The integrated Miller clamp ensures that the internal gate is clamped to 0 V when the external gate is off, even under fast drain voltage transients. Parasitic turn-on events that can occur from current flow in the external gate resistor and the associated inductive path are therefore eliminated. Undesirable gate oscillations and shoot-through losses are avoided. A 0-V V_{gsext} can be used for turn-off, simplifying gate drive designs. The improved noise immunity can also make device paralleling more robust.
- Reliability improvements include a positive temperature coefficient on the V_{gsint} voltage limit, hence reducing this at low temperatures. This reduces the likelihood of low-temperature time-dependent Schottky breakdown, which is a dominant failure mode in standard p-gate GaN HEMTs.
- An integrated current sense eliminates the need for a separate sense resistor, allowing the device to be soldered directly to the large copper ground plane, potentially improving thermal performance.

NO-LOAD, LIGHT-LOAD PERFORMANCE IMPROVEMENTS

A new feature of the H2 series of ICeGaN products is the lower power consumption from the associated integrated logic circuitry under no-load and light-load conditions. The V_{dd} pin shown in Figure 1 draws this

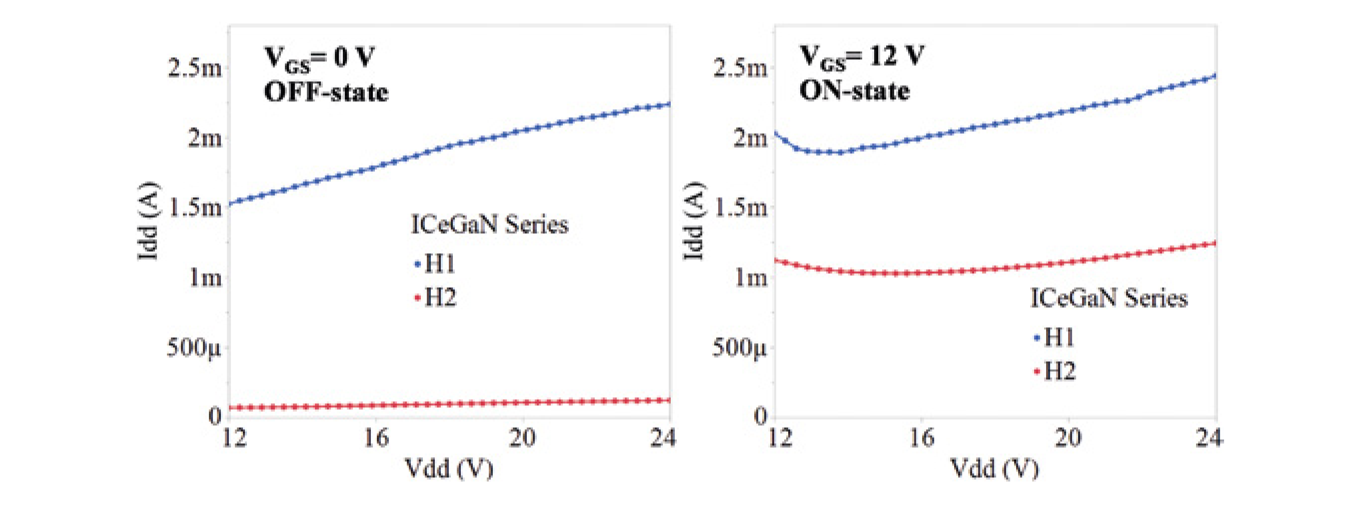


Figure 2: I_{dd} current draw comparisons at 25°C between the H1 and H2 series of ICeGaN products (Source: Cambridge GaN Devices)

current I_{dd}. Applications such as USB PD chargers have strict requirements on power consumed under no-load conditions. The ***NL³ (No Load and Low Load) circuit block*** shown in Figure 1 switches the voltage regulator block from its normal high-bandwidth, high-power mode to a low-bandwidth, low-power mode. This makes the current source and voltage limiter blocks inactive, essentially creating a standby mode whereby the I_{dd} consumption is brought close to zero. As shown in Figure 2, at a V_{gsext} of 0 V, the I_{dd} at a V_{dd} of 12 V is reduced from 1.5 mA to 70 µA.

A 40% reduction in I_{dd} is obtained under on-state conditions at 25°C. The Miller clamp is unaffected by this NL³ block and continues to provide gate protection.

RMS Input Voltage	No Load Power (mW)		No-load power reduction with H2
	H1	H2	
115 V_{AC}	58	34	41 %
230 V_{AC}	101	77	23 %

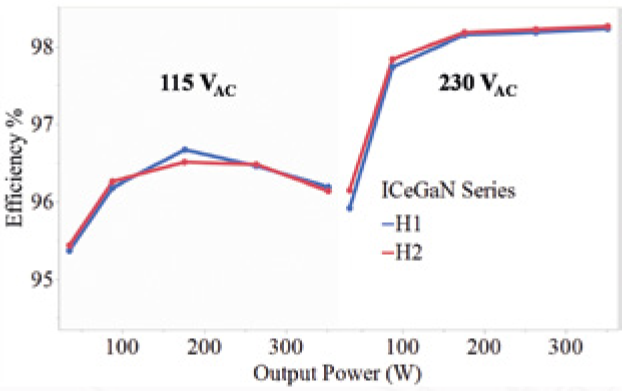
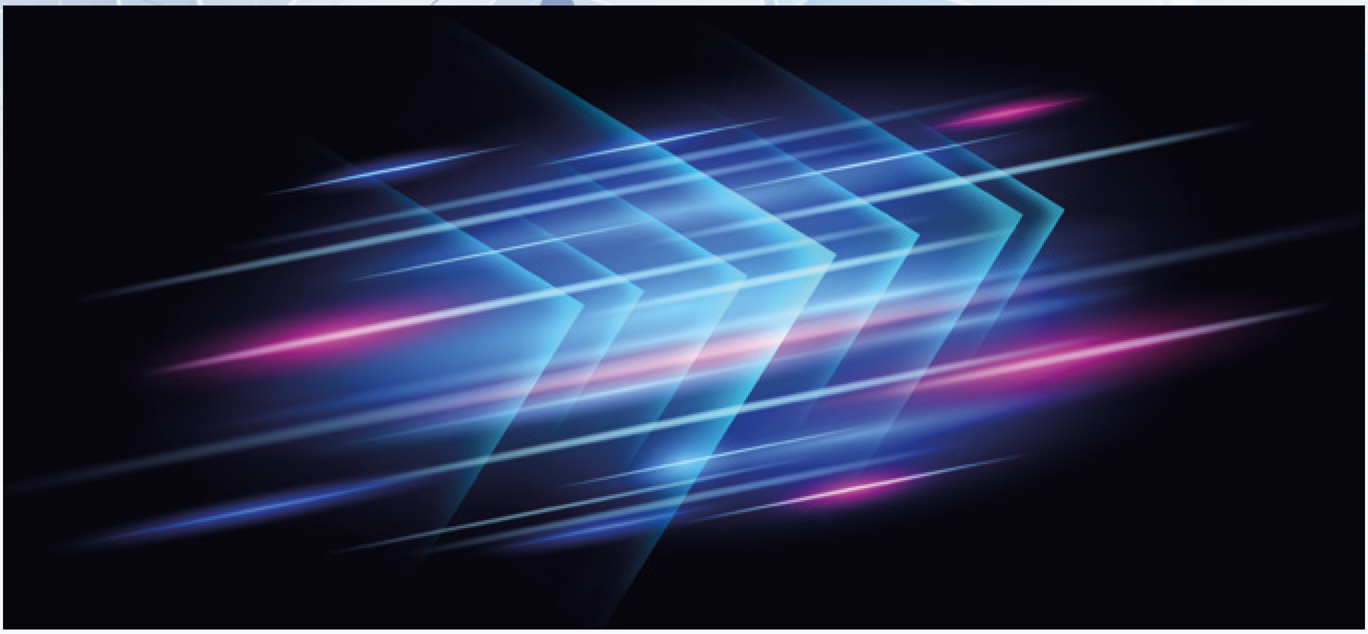


Figure 3: No-load power consumption comparisons between the H1 and H2 series of ICeGaN products in a TP-PFC stage (Source: Cambridge GaN Devices)

The no-load consumption benefits in a converter application have been demonstrated using a totem-pole power-factor-correction (TP-PFC) circuit. A 350-W (396 V at 0.89 A) PFC stage was characterized using 55-mΩ H1 and H2 ICeGaN devices. The TP-PFC operates in burst mode under no load, with conduction, switching, and static losses all contributing to the total loss. Figure 3 shows that the no-load power consumption of the H2 devices is reduced by about 24 mW at both 115 V_{ac} and 230 V_{ac}, with no loss in efficiency. Comparatively, a lower-power 65-W quasi-resonant flyback AC/DC converter using the 240-mΩ H1 and H2 devices showed about a 30-mW lower no-load power consumption with the H2. This corresponds to an improvement of approximately 35%.

OTHER H2 SERIES ICeGaN IMPROVEMENTS

Significant improvements in device capacitances were achieved in the H2 series through design advances that include the use of a fully pad-over-active layout for both the logic and high-voltage HEMT. The output capacitance (C_{oss}) shows a 29% improvement over H1 devices, resulting in a significant, 25% improvement in one of the key switching figures of merit (FOMs), $R_{DS(on)} \times C_{oss}$. Similarly, the gate charge (Q_g) is reduced on the H2, enabling a 33% reduction in another FOM, $R_{DS(on)} \times Q_g$. An approximate 15% improvement in turn-off delay and rise time has been demonstrated under double-pulse testing at 400 V, 10 A on the 55-mΩ devices.



SiC Gives IGBTs a New Lease on Life

By Ashok Bindra, contributing writer for Power Electronics News

Since its first demonstration in 1982 by General Electric (GE), the silicon-derived IGBT has evolved substantially in the last 40+ years. While GE initially commercialized the IGBT, Toshiba solved the latch-up problem to broaden the commercial scope of the power device. As a result, many other players joined the fray later to expand the adoption of the device in many power conversion and motor drive applications. Consequently, there are approximately 20 suppliers worldwide today, and the market for these devices has grown from a few million to several billions of dollars. Some key players include Infineon Technologies, Mitsubishi Electric, Fuji Electric, Toshiba, ON Semiconductor, ABB, STMicroelectronics, Renesas Electronics, Semikron International, and Texas Instruments.

Concurrently, for the last few decades, the IGBT has continued to advance in design, packaging, and thermal management, resulting in improvements in current and voltage ratings, along with high reliability. Consequently, the breakdown voltage has been scaled from 600 V to 6,500 V, and the current-handling capability has improved from 10 A to over 2,000 A. Today, the IGBT is an essential power transistor in electric vehicles and hybrid-electric cars, as well as in most other electric motors used in consumer and industrial applications. It is all around us, reducing energy consumption and making electricity use reliable in medical diagnostic equipment such as X-ray machines, CAT scanners, and MRI units deployed in hospitals; microwave ovens and induction stoves in our kitchens; air conditioning and refrigeration for homes and buildings; and portable defibrillators, which were made possible by IGBTs and are now saving countless lives around the world every year. The performance capabilities of modern IGBTs have expanded to the point that today's IGBT-based power converters and inverters dominate nearly every major application, with a power rating from 1 kW to about 10 MW.

ADOPTING SiC TECHNOLOGY

However, the silicon IGBT is not the answer for all applications. As silicon carbide matures, so does the device it is based on. There are high-voltage and medium-voltage applications such as solid-state transformers (SSTs), high-voltage DC converters, and other high- and medium-voltage military and industrial applications that demand efficient devices that can handle voltages above 10 kV with high-current capability while switching at high frequencies to deliver efficient and high-density power converters.

For more than a decade, SiC has been pushing the performance of power MOSFETs and diodes to new heights, setting new benchmarks for power conversion systems and motor drives while enabling a range of critical applications that were not practically feasible with silicon power devices. Thus, the market for SiC power semiconductors has risen to several billions of dollars and will continue to grow, as predicted by analysts. Recently, leading market research company Yole Group predicted a market value of $10 billion for SiC power devices by 2029, growing at a CAGR of 24% from 2023 to 2029.

Hence, like MOSFETs, IGBTs must exploit the benefits of wide-bandgap semiconductors to advance its performance and expand its application horizon. So it is not surprising to see that researchers and some IGBT manufacturers have begun the transition from silicon to SiC for IGBTs. While several researchers began this journey more than a decade ago, one has been actively investigating the applications that can benefit from IGBTs. Subhashish Bhattacharya is a Duke Energy Distinguished Professor with the Department of Electrical and Computer Engineering at North Carolina State University and a founding faculty member of FREEDM Systems Engineering Research Center and PowerAmerica Institute. For more than 10 years, Bhattacharya and his students have been studying the performance and applications of high-voltage SiC IGBTs with samples provided by Cree (now Wolfspeed).

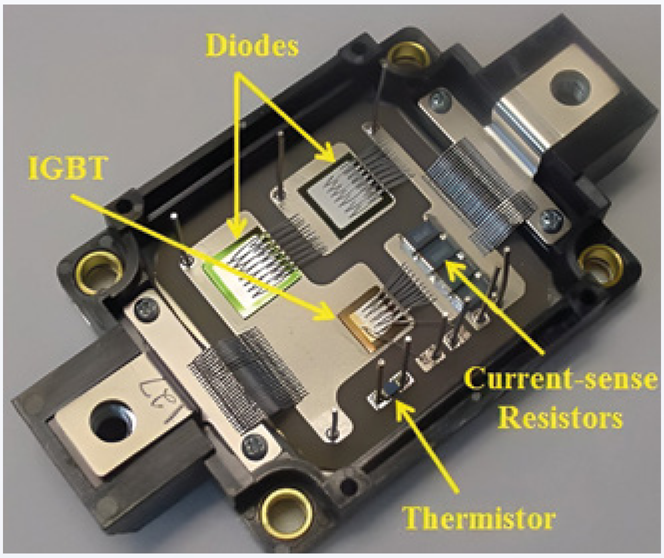


Figure 1: 15-kV SiC IGBT fabricated by Cree (now Wolfspeed) (Source: Kadavelugu et al., 2013)

Since 2010, under the Advanced Research Projects Agency-Energy (ARPA-E) contract, Bhattacharya's group has been studying the characteristics of a 15-kV SiC IGBT fabricated by Cree (Figure 1). Besides measuring the performance of the SiC IGBT and comparing it with a 10-kV SiC MOSFET, the team has demonstrated a complete medium-voltage SST and some other medium-voltage power conversion systems. But prior to developing applications for the SiC bipolar transistor, they investigated the characteristics of the SiC IGBT, which was published in a paper titled "***Characterization of 15 kV SiC n-IGBT and its application considerations for high power converters***" and presented at the 2013 IEEE Energy Conversion Congress & Exposition in Denver.

In this paper, the researchers reported the characteristics of the 15-kV, 20-A n-IGBT for the first time, which includes the turn-on and turn-off transitions of the IGBT, which were experimentally evaluated up to 11 kV. At the time, according to the paper, it was the highest switching characterization voltage ever reported on a single power semiconductor device. Aside from providing the dependency of the power loss with respect to voltage, current, and temperature, the paper compares the switching characteristics of the SiC IGBT and SiC MOSFET, as depicted in Table 1. For this characterization, the power devices were provided by Cree, according to the paper.

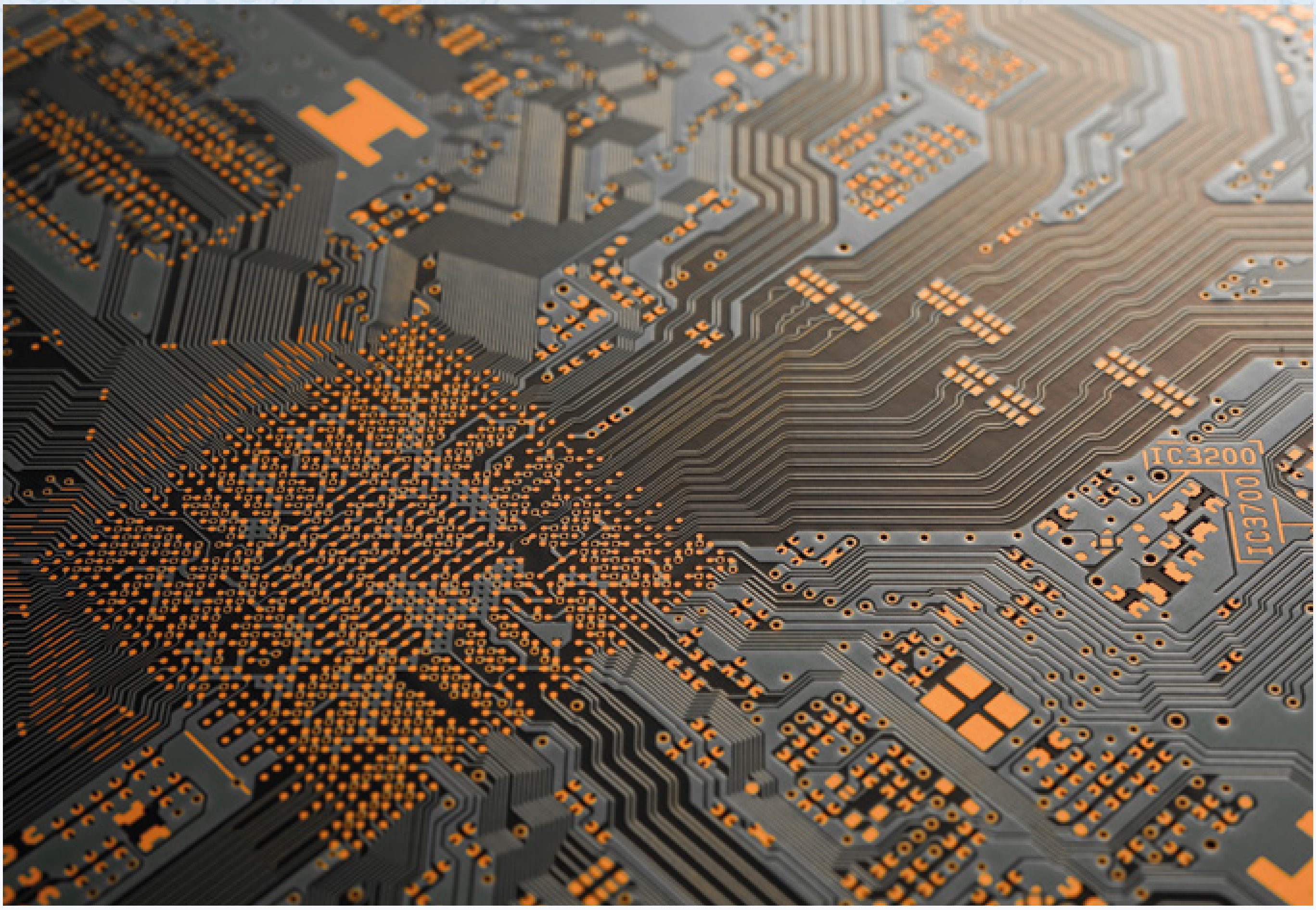
The paper also argues that the ultra-high voltage-blocking capability of the 15-kV SiC IGBT makes it a unique choice for medium-voltage smart grid and drive applications. In such applications, the complex multilevel topologies can be replaced with two-level converters, which drastically reduces the component count and increases the reliability.

Bhattacharya's team is now looking at applications for the U.S. Navy and Department of Defense that will need SiC IGBTs at 20 kV and higher.

Parameter	10-kV, 10-A MOSFET	12-kV, 10-A, 2-µm IGBT	12-kV, 10-A, 5-µm IGBT
Turn-on loss at 6 kV, 4 A	15.1 mJ	10.7 mJ	10.7 mJ
Turn-off loss at 6 kV, 8 A	1.9 mJ	11.1 mJ	4.4 mJ
Turn-on current spike magnitude	7.5 A	24 A	12.5 A
$R_{G(ON)}$	100 Ω	100 Ω	100 Ω
$R_{G(OFF)}$	10 Ω	10 Ω	10 Ω
Forward drop at 10 A	4.1 V	4.4 V	5.3 V

Table 1: Comparing SiC IGBTs with SiC MOSFETs (Source: Kadavelugu et al., 2013)

ENERGY STORAGE



Recent Advancements in Perovskite Solar Cell Stability

By Stefano Lovati, contributing writer for Power Electronics News

Perovskite materials, a class of compounds with a distinct crystal structure, have gained considerable attention in recent years due to their promising potential in solar energy conversion. These materials, named after the mineral perovskite ($CaTiO_3$), are defined by a general formula of ABX_3, where *A* and *B* are cations and *X* is an anion.

In the context of solar cells, perovskites are typically organic-inorganic hybrid materials, with the most widely researched being methylammonium lead halide perovskites, such as $CH_3NH_3PbI_3$. These materials have shown remarkable properties that make them highly attractive for photovoltaic applications.

KEY ADVANTAGES OF PEROVSKITE SOLAR CELLS

One of the most notable advantages of perovskite solar cells is their high absorption efficiency. Perovskites can absorb a broad range of the solar spectrum, enabling them to capture sunlight efficiently, even with relatively thin layers of material.

This high-light-absorption efficiency, combined with their ability to convert light into electricity, has led to rapid advancements in the power conversion efficiency (PCE) of perovskite solar cells. Laboratory devices have already achieved efficiencies exceeding 25%, rivaling the performance of traditional silicon solar cells. This impressive performance places

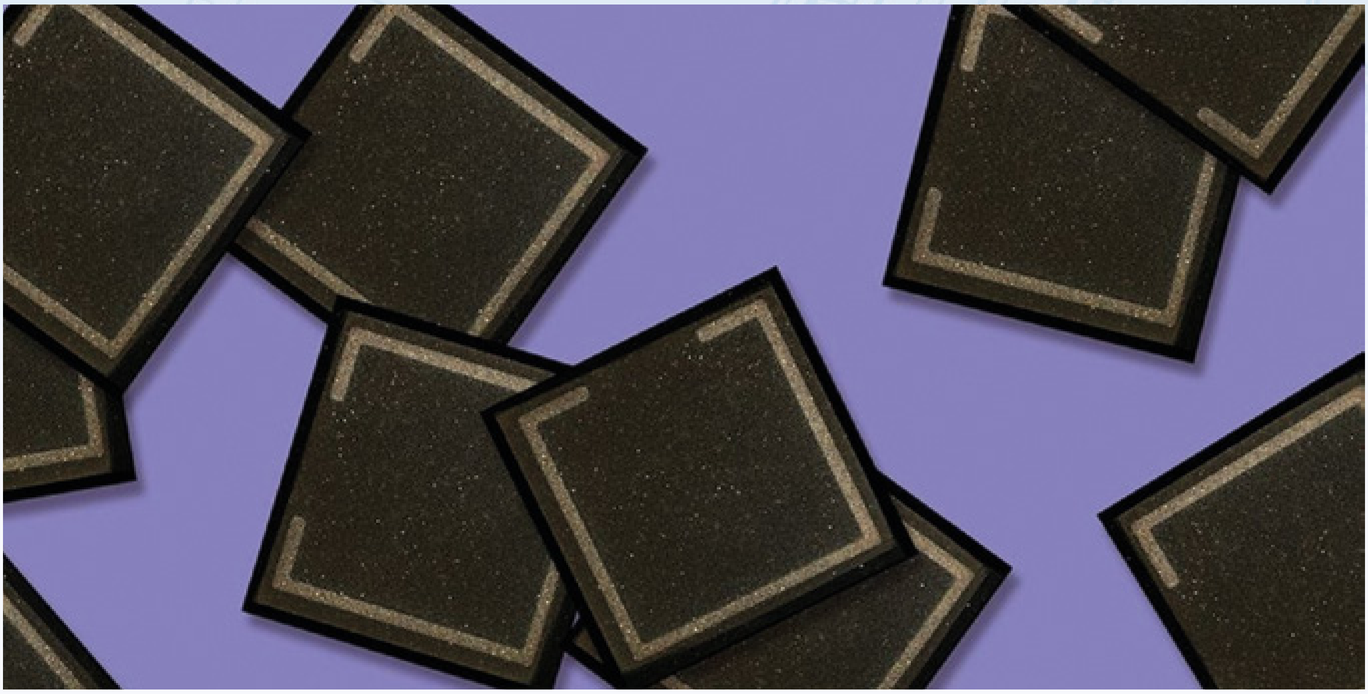


Figure 1: Test sample of a perovskite-silicon tandem solar cell developed at MIT (Source: Felice Frankel/MIT-Stanford University)

perovskite solar cells at a competitive position within the photovoltaic market.

Moreover, perovskite materials exhibit a tunable bandgap, meaning their electronic properties can be adjusted by altering their composition. This flexibility optimizes perovskite solar cells for different solar energy harvesting conditions, such as varying light intensities and angles.

One of the most promising applications of this tunable property is in tandem solar cells, where perovskites are stacked on top of silicon or other materials to create a multijunction device. These tandem cells (Figure 1) can capture a broader spectrum of sunlight, leading to higher overall efficiencies than traditional silicon-based solar cells. With research making significant strides, tandem solar cells that combine perovskite with silicon have already achieved efficiencies exceeding 30%, paving the way for even more efficient solar technologies.

In addition to their impressive efficiency, perovskites also offer the potential for low-cost manufacturing. Unlike silicon-based solar cells, which require high-temperature processes and expensive materials, perovskite solar cells can be produced using solution-based techniques, such as spin coating and inkjet printing. These methods are relatively simple, cost-effective, and scalable, making perovskite solar cells an attractive alternative for large-scale commercial production. This cost advantage, combined with the materials' high efficiency, makes perovskite solar cells a promising option for lowering the overall cost of solar energy generation.

Another notable feature of perovskite solar cells is their flexibility. These cells can be fabricated on flexible substrates, opening up a wide range of potential applications, such as portable solar chargers, wearable electronics, and building-integrated photovoltaics. The ability to manufacture solar cells on flexible materials also enables innovative designs that can be integrated into a variety of surfaces and structures, from clothing to windows, making solar energy harvesting more accessible and versatile than ever before.

CHALLENGES WITH PEROVSKITE SOLAR CELLS

Despite their remarkable advantages, perovskite solar cells face significant challenges that must be addressed before they can achieve widespread commercial adoption. The most pressing issue is their stability and durability. Perovskite materials are highly sensitive to environmental factors such as moisture, oxygen, and UV radiation, all of which can degrade the material over time and reduce its efficiency. As a result, perovskite solar cells have struggled to maintain long-term performance when exposed to real-world conditions.

To address this issue, researchers are focusing on improving the stability of perovskite materials by developing new compositions and encapsulation methods. For example, improving the materials' resistance to moisture and UV radiation can help extend their lifespan, making them more viable for commercial applications.

Another area of focus is the development of new device architectures that enhance the overall stability and durability of perovskite solar cells. These advancements could ultimately lead to perovskite solar cells that perform consistently in a variety of environmental conditions.

The toxicity of lead, which is commonly used in the most efficient perovskite solar cells, is another significant challenge. While lead-based perovskites have demonstrated exceptional efficiency, the use of lead raises concerns about the environmental impact and potential health risks associated with the material. In response, researchers are actively exploring lead-free alternatives, such as tin-based perovskites, which could eliminate the toxicity issue. However, these lead-free alternatives often face tradeoffs, such as lower efficiencies or greater instability, which must be addressed through further research and development.

Scalability is another obstacle to the widespread adoption of perovskite solar cells. While laboratory-scale devices have demonstrated impressive efficiencies, scaling up the production of perovskite solar cells for large-area commercial applications remains a challenge. Issues such as achieving uniformity in the material across large areas, developing cost-effective large-scale manufacturing techniques, and ensuring consistent quality across production batches need to be resolved before perovskite solar cells can be produced on a commercial scale.

RECENT ADVANCEMENTS AND REAL-WORLD PERFORMANCE

Recent advancements in perovskite solar cell research have led to promising breakthroughs, particularly in addressing stability and durability concerns. One of the most significant recent developments comes from ***imec***, a leading research institution in Belgium, in collaboration with the ***University of Cyprus***. Researchers at imec have demonstrated the long-term outdoor stability of perovskite solar modules, marking a major step toward the commercialization of this technology.

In a comprehensive study, mini modules measuring just 4 cm^2, developed at imec/EnergyVille in Belgium (Figure 2), were tested over two years in real-world outdoor conditions in Cyprus. The results were remarkable: The most durable modules retained 78% of their initial PCE after one year outdoors—far superior to the current performance of perovskite solar modules, which typically degrade significantly within weeks or months. This achievement represents one of the first real-world demonstrations of perovskite solar cells' ability to maintain efficiency over extended periods when exposed to natural elements.

The study also uncovered valuable insights into the degradation behavior of perovskite solar cells, revealing a consistent pattern of performance degradation during the day and recovery overnight. This data, coupled with machine-learning models, allowed researchers to predict the modules' future performance with a high degree of accuracy. These findings are crucial for the

*Figure 2: The perovskite mini modules developed at imec/EnergyVille in Belgium (Source: **imec**)*

future of perovskite solar technology, as they offer new insights into how these cells perform under real-world conditions and pave the way for further improvements.

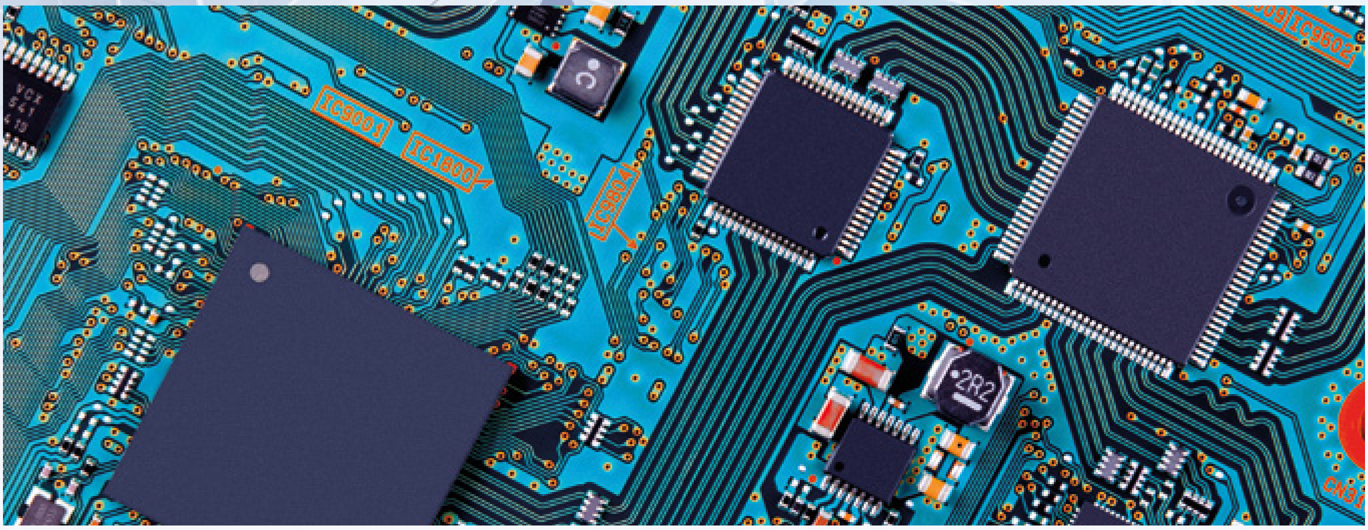
In addition to the tests in Cyprus, the perovskite solar modules will be evaluated in a range of other climates, including the rainy conditions of Brussels, the arid desert of New Mexico, and the moderate climates of Madrid and Freiburg. This multiclimate testing will provide deeper insights into the performance and degradation of perovskite solar cells in diverse environmental conditions, which is essential for ensuring their viability for commercial use around the world.

THE FUTURE OF PEROVSKITE SOLAR CELLS

The potential applications of perovskite solar cells are vast. Beyond standalone devices, perovskites can be used in tandem solar cells, where they are stacked on top of silicon-based solar cells to enhance overall efficiency. Additionally, the flexibility of perovskite materials allows for the development of bifacial solar modules, which capture sunlight from both the front and back, further boosting energy yield. As research continues to advance, perovskites are also being explored for use in flexible and wearable electronics, portable solar chargers, and even integrated building materials, making solar power more accessible and adaptable than ever before.

Perovskite solar cells offer immense potential to revolutionize the solar energy industry. Their high efficiency, tunable properties, and cost-effective manufacturing methods position them as a strong contender to replace traditional, silicon-based solar cells. While challenges such as stability, toxicity, and scalability remain, recent breakthroughs in research—such as the outdoor stability findings from imec—demonstrate that these obstacles are being addressed. With ongoing advancements, perovskites could soon play a pivotal role in the future of solar energy, offering a cleaner, more efficient, and cost-effective way to harness the power of the sun.

DESIGN



Smart Power Fab in Dresden Secures EU Approval

By Filippo Di Giovanni, contributing writer for Power Electronics News

In recent years, the European Union (EU) has implemented a range of strategic policies and financial initiatives aimed at fostering high-tech investments. These efforts are designed to strengthen Europe's technological leadership, enhance industrial resilience, and ensure long-term competitiveness in key sectors such as semiconductors, renewable energy, and artificial intelligence. This push has become increasingly critical as the global landscape is shaped by intensifying competition between the world's two leading superpowers, driving the EU to bolster its position in innovation, supply chain security, and technological sovereignty.

Unlike other supranational institutions, such as the European Parliament, which represents EU citizens and co-legislates; the European Council, where EU leaders (heads of state or government) set overall policies; and the Council of the EU, which represents member states' governments (national ministers) and co-legislates with Parliament, the European Commission serves as the EU's executive arm. It is responsible for proposing and enforcing laws, managing the EU budget, and implementing policies. Additionally, it represents the EU in international negotiations and trade deals, carving out its position on the global stage.

TOOLS LEVERAGED BY THE COMMISSION

The European Commission employs various mechanisms, frameworks, and legislative acts to plan and approve investments in high tech. Below is a list of some of the Commission's instruments.

InvestEU

InvestEU is a key initiative aimed at stimulating investment, innovation, and job creation within the EU. It sets a dedicated budget to support financing and mobilize public and private investments. The recent €2.5 billion budget increase seeks to reduce administrative and regulatory burdens for businesses, particularly small and medium-sized enterprises, by 25% to 35%, fostering a more favorable environment for high-tech investments.

Horizon Europe

Horizon Europe (2021–2027) is the EU's flagship research and innovation program, with a €95.5 billion budget to drive scientific excellence and advance high-tech sectors, including AI.

Digital Europe Program

Complementing Horizon Europe, the Digital Europe Program focuses on building the EU's strategic

Rendering of Infineon's Smart Power Fab in Dresden (Source: Infineon Technologies)

digital capacities and facilitating the adoption of digital technologies, such as quantum computing, AI, cybersecurity, and advanced digital skills.

European Chips Act

Adopted in September 2023, the European Chips Act aims to strengthen Europe's semiconductor ecosystem, enhancing competitiveness and resilience in this strategic sector. The act seeks to mobilize over €43 billion in public and private investments by 2030, with the goal of doubling the EU's global market share in chip production to 20%.

Important Projects of Common European Interest (IPCEI)

The IPCEI program, including IPCEI2, is one of the Commission's most strategic investment tools for enhancing EU technological sovereignty. While other initiatives focus on innovation, industrial development, and technology deployment, IPCEIs target large-scale, high-risk industrial and technological advancements that require significant public-private collaboration.

The IPCEI2 program, an extension of the initial IPCEI wave, focuses on breakthrough technologies, particularly in semiconductors, batteries, hydrogen, cloud computing, and healthcare. A key initiative within IPCEI2 is microelectronics and communication technologies (IPCEI ME/CT), approved in June 2023, with €8.1 billion in state aid from 14 EU countries.

A critical component of IPCEI is "dissemination," the process of sharing and spreading project knowledge and results. The aim is to maximize impact by reaching researchers, industry stakeholders, policymakers, and the general public. This process fosters further R&D efforts, innovation, and additional economic activities.

SMART POWER FAB PROJECT IN DRESDEN

The European Commission has approved funding under the European Chips Act for Infineon Technologies' Smart Power Fab in Dresden, in the state of Saxony, Germany. However, official approval from Germany's Federal Ministry for Economic Affairs and Climate Action—which manages the funding—is still pending and expected in the coming months.

The Smart Power Fab is already receiving support through the IPCEI ME/CT innovation program, with total funding for the Dresden site amounting to approximately €1 billion. The laying of the foundation stone began in March 2023, and the project is progressing on schedule, with the fab set to be inaugurated in 2026.

Infineon CEO Jochen Hanebeck stressed that this investment reinforces Dresden's role—alongside Germany and Europe—as a world-class semiconductor hub. The project is designed to create a hub of advanced manufacturing and pioneering innovation for microelectronic components.

"We are increasing semiconductor capacity in Europe and helping to ensure stable supply chains in the automotive, security, and industrial sectors," Hanebeck said.

SEMICONDUCTOR TECHNOLOGIES TO BE PRODUCED IN DRESDEN

The Smart Power Fab in Dresden will focus on producing power semiconductors and analog/mixed-signal chips on 300-mm wafers. The first group includes not only silicon power MOSFETs and IGBTs but also wide- bandgap (WBG) semiconductors such as silicon carbide and gallium nitride, which are crucial for high-efficiency power conversion in automotive applications (electric vehicles, charging infrastructure), renewable energy, AI-enabled industrial processes, and data centers.

Analog and mixed-signal ICs are essential for producing specialized and general-purpose sensors and power management devices. While specific technology nodes for these ICs have not been publicly disclosed, analog and mixed-signal ICs typically utilize mature process nodes, often ranging from 65 nm to 180 nm. These nodes offer a good balance between performance and cost, making them well-suited for applications in automotive, factory automation, energy management, and wireless communication.

BENEFITS FOR EUROPE

The new fab aligns with EU goals by strengthening semiconductor sovereignty and reducing dependence on Asia and the U.S. It will also boost innovation and competitiveness, reinforcing Europe's leadership in power electronics and AI applications—key drivers of economic growth.

Additionally, the project will have a positive impact on employment, creating up to 1,000 direct jobs and many more across the supply chain, fostering ecosystem growth and technological advancement.

WILL THE FAB BE COMPETITIVE ENOUGH?

Europe is expected to strengthen its competitiveness in semiconductors for several key reasons:

- Advanced 300-mm wafer production: The shift from 200-mm to 300-mm wafer technology increases manufacturing productivity, reduces costs, and improves yield, making the fab more competitive in high-demand markets.

- Leadership in SiC and GaN power semiconductors: SiC and GaN semiconductors are critical for EVs, renewable energy, and high-efficiency power applications. With rising global demand, Infineon's expertise and production capabilities place it in a strong market position.

- Maximize Europe's leadership in WBG power electronics: Alongside STMicroelectronics' initiatives in Italy, Infineon's fab will contribute to Europe's leadership in innovative power semiconductors, enhancing the region's role in sustainable and energy-efficient technologies.

- IPCEI and EU support for R&D: The IPCEI initiative ensures substantial funding for cutting-edge R&D, allowing European fabs to stay ahead in technological advancements and industrial innovation.

CHALLENGES AND GLOBAL COMPETITION

By leveraging advanced manufacturing, strategic partnerships, and EU-backed innovation, Infineon's Dresden fab is well-positioned to enhance Europe's competitiveness in the global semiconductor market.

Despite these advantages, Europe faces strong competition from TSMC, Intel, and Chinese manufacturers, which are aggressively expanding their semiconductor capabilities. Although Intel's revenue has been declining for three consecutive years, its investment in new fabs and advanced process nodes should remain unchanged. This scenario looks realistic even in the event—today only a speculation—that the company could be split into two parts, with TSMC and Broadcom, amongst the most successful semiconductor players, emerging as potential buyers.

To maintain its technological edge, Europe must keep investing in innovation, scale up production, and build a resilient supply chain.

ADDITIONAL IMPACT

The Smart Power Fab will focus on technologies—such as energy-efficient power solutions for AI—that drive decarbonization and digitalization while also serving as economic development multipliers.

Beyond funding Dresden's production expansion, Infineon is leveraging the IPCEI ME/CT innovation program to enhance R&D investments across its other sites. Between 2022 and 2027, Infineon is projected to invest €2.3 billion in innovation projects at its locations in Germany and Austria, with a focus on power electronics, analog/mixed-signal technologies, sensor technologies, and RF applications.

As part of EU funding programs, Infineon is also fostering science-industry collaboration by partnering with European universities, research institutes, and startups. It provides young professionals with a platform for sustainable innovation, bridging scientific research with industrial application and reinforcing Europe's position as a global innovation hub.

High-Efficiency GaN Power eBikes, eScooters, AC/DC Chargers

Renesas gallium nitride technology enables high-efficiency, high-power-density charging systems for light electric vehicles. The broad product portfolio supports multiple charging applications, from 2- to 5-kW charging poles down to 240-W on-board chargers.

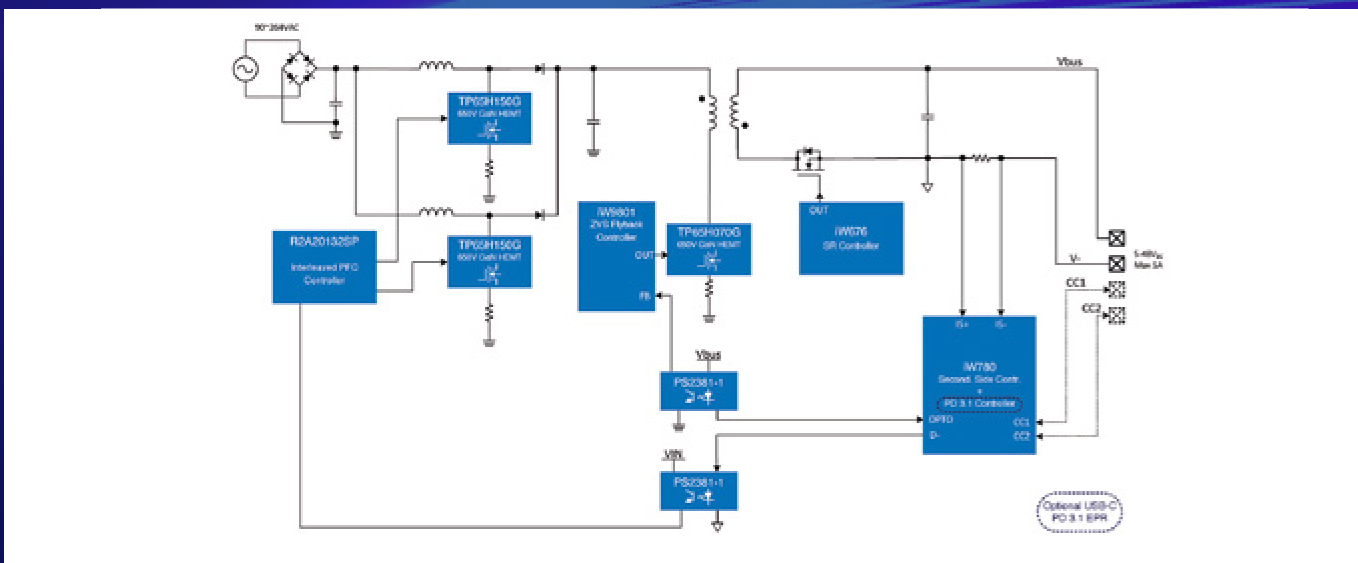
Charging solutions for eBikes/eScooters require efficient AC/DC conversion and involve several key components. A power-factor-correction (PFC) circuit ensures that power drawn from the grid is used efficiently and reduces reactive power, improving the overall power efficiency. A secondary DC/DC regulator efficiently converts the high-voltage output of the PFC (typically in the range of 360 V to 400 V) to a 36-V or 48-V level, suitable for these eMobility battery packs.

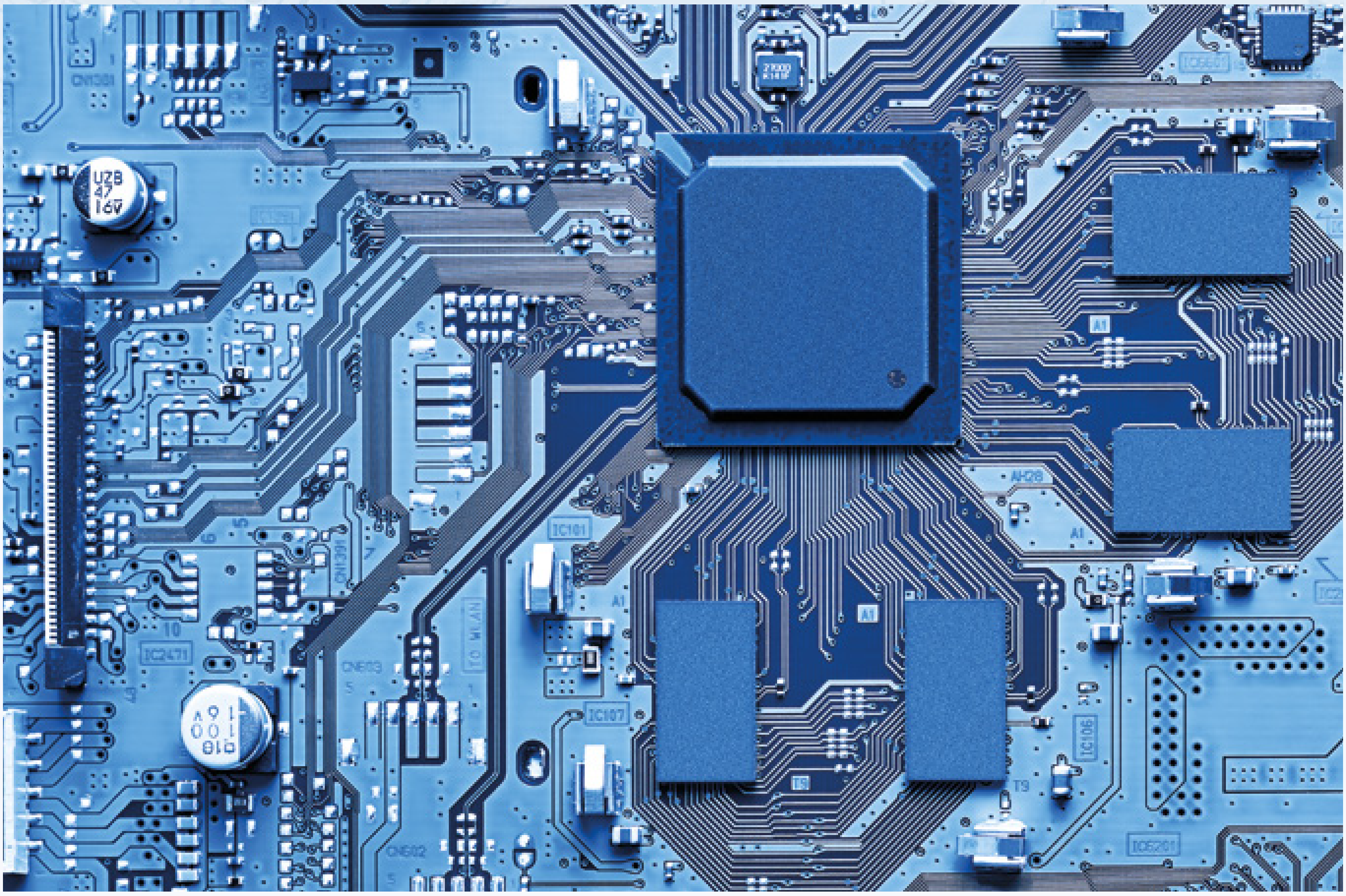
AC/DC solutions from Renesas, shown in the block diagram, enable fast charging time and efficient conversion using digital control in combination with GaN HEMT switches. The iW9801 flyback converter, in addition to the TP65H150G4PS 150-mΩ on-resistance GaN HEMT, enables the power needed to supply the secondary-side controller, iW780, producing up to 48-V/5-A DC output. The USB-C PD 3.1 Extended Power Range (EPR) protocol (up to 240 W) is also supported, increasing design flexibility by reducing product time to market.

Visit ***renesas.com/power*** to learn more about available and upcoming charging solutions!

TP65H150G4PS – iW9801 – iW780

USB-C – Power page





Lithium Battery Cell Developments Create Advantages in E-Mobility Applications

By Sonu Daryanani, contributing writer for Power Electronics News

The world is increasingly dependent on batteries for everyday applications such as mobile electronics, electric vehicles, and renewable energy systems. ***Lithium-ion (Li-ion) batteries*** offer many advantages over other chemistries. Their widespread adoption, however, necessitates further developments for improved performance and cost. In this article, we will highlight some breakthrough improvements made by Integrals Power Ltd. (IPL) on its lithium batteries.

BATTERIES IN EVs

Compared with other battery chemistries, such as lead acid or nickel metal hydride (NiMH), Li-ion batteries have several advantages:

- Greater energy density per weight and volume, as well as specific power
- Longer cycle life
- Extended shelf life
- Improved high-load capability
- Low rate of self-discharge

The Li-ion battery cell is typically composed of the following components:

- Cathode material: This is the material used for the positive electrode and plays a key factor in the voltage and capacity of the battery. One of the two basic groupings of cathode materials consists of the use of Ni, cobalt (Co) and manganese (Mn), termed the NMC cells, and Ni, Co, and aluminum (Al), called NCA cells. Another group consists of cathodes based on iron (Fe) and phosphorus (P), termed LFP. NMC/NCA cells, especially those with high Ni content, have increased cell energy densities, with state-of-the-art cells reaching over 270 Wh/kg. Hence, this makes them lighter and more compact. They are used in higher-performance EVs such as the Tesla Model S. LFP batteries, while having a lower energy density typically in the 100- to 150-Wh/kg range, offer advantages in thermal safety, longer cycle life, lower cost, and low toxicity. LFP cells, whose market share has been increasing, have been adopted in many of the cost-sensitive EVs manufactured in China, as well as the lower-end models from other manufacturers.

- Anode material: This is the negative electrode when the battery is being charged and is where lithium ions are stored. Graphite, silicon, or graphite-doped silicon are typical anode materials.

- Electrolyte: This consists of solvents and salts, forming the conduit between the anode and cathode in the transfer of ions.

- Separator: This is typically a permeable membrane that keeps the two electrodes apart.

The cost of a battery in a current EV can be 30% to 40% of the total cost of the vehicle. The weight of the battery can also be a significant proportion; for example, in a Tesla Model S, the battery weighs over 500 kg. Improvements in battery technology are a key factor in the wider adoption of EVs. Some of the main considerations here are:

- Improvement in the EV range: So-called "range anxiety" is cited by many in their hesitation to adopt EVs. The battery capacity (in kilowatt-hours), the driving efficiency (an inverse efficiency can be expressed as kilowatt-hours per kilometer), the power conversion efficiency of the traction inverter, and the size of the motor all play major roles. Improvements in the battery cell weight and volume energy density are critical, as they directly translate to improved range. A metric cited by many for sustainable efficiency is 10 kWh/100 km.

- Energy density: Higher-energy-density batteries can translate to the use of a smaller, cheaper battery for the same range. This can be a factor in city-driven cars, where average daily commuter miles can be <50 miles.

- Cost: While battery costs have reduced dramatically over the last few years, driving battery costs down further is integral to wider EV adoption. Here, the important metric is the relative battery capacity cost in dollars per kilowatt-hour. LFP batteries are currently priced at about $60/kWh, with their NMC counterparts about 20% to 30% higher.

- Sustainability: A key disadvantage of NMC cells is the toxicity of the core materials, as well as the mining of materials such as cobalt in regions where regulations may not be strictly enforced. The recycling of batteries is another important aspect of the sustainability equation.

- Battery management system (BMS): The BMS is essential for safety and battery performance monitoring. Advanced BMSes with AI algorithms are expected to improve these key metrics in the future.

ADVANCES IN LFP-BASED BATTERIES

Let's now discuss advances made by ***IPL*** on its LFP-based batteries. IPL is a U.K.-based company dedicated to the research, development and commercialization of battery technology. Here, we highlight two important breakthroughs from IPL as related to LFP batteries:

- The cathode material forms a key component that determines battery performance. The Li-ion extraction during discharge mode is determined by the LFP particle size and shape. This innovative, bottom-up approach relies on creating nanoparticles based on atoms, molecules, and aggregate groups of the elements that form the cathode. This is in contrast to bulk precursors being used for

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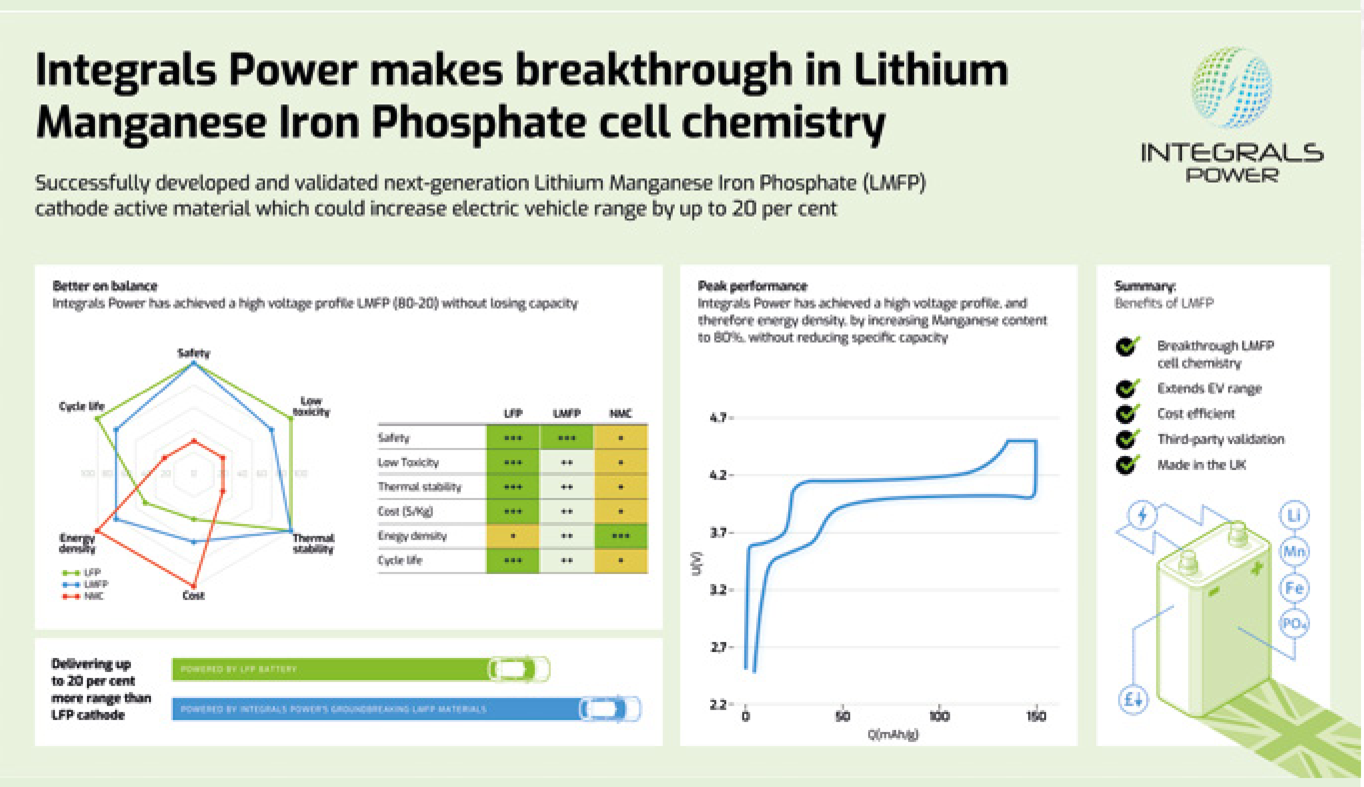

Figure 1: Some characteristics of IPL's LMFP battery cell (Source: Integrals Power Ltd.)

the same in conventional manufacturing. The optimized size and shape created through this proprietary technology thus enhances lithium extraction and creates a lower impedance. Compared with conventional LFP cells, this method improves power density, retains capacity up to 300% (including at extreme temperatures), and allows for high discharge rates of up to 40°C. This result is a more compact battery, simplified cooling system requirements, and no preheating requirements in cold temperatures.

- High-Mn-content LMFP cells: The addition of Mn to LFP increases the energy density and operating voltage, but typical data from the past has shown a disadvantage in decreased specific capacity (in milliampere-hours per gram). In October 2024, IPL announced a ***breakthrough in the development of LMFP cells***. A Mn content of 80% was used, compared with the 50% to 70% typically found. As a result, energy density was improved by 20% compared with LFP cells, which potentially allows an increased

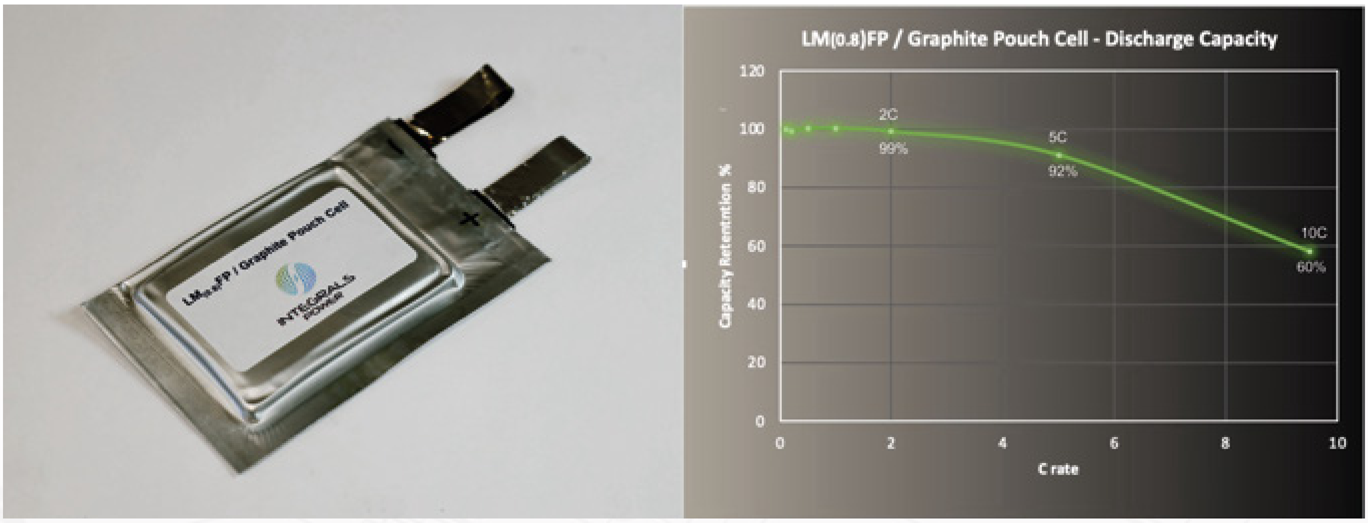

Figure 2: High retention at high discharge rates on IPL's LMFP battery cell (Source: Integrals Power Ltd.)

EV range of 20% for the same battery size and weight. Alternatively, a reduced battery pack size and weight could be used while maintaining the same range, hence creating cost savings. Figure 1 depicts some characteristics of the LMFP cell.

Their innovative manufacturing flow and unique particle properties allowed a specific capacity of 150 mA-h/g to be achieved. The cell voltage of 4.1 V compares favorably with the 3.45 V typically seen in LFP cells. These LMFP cells hence come closer to meeting the energy density available in the more expensive NMC cells while keeping the advantages of LFP cells such as high cycle life, safety, and low toxicity.

In February 2025, ***IPL announced*** that the firm QinetiQ had independently validated high energy discharge rates with excellent retention on its LMFP cells. As shown in Figure 2, tests demonstrated a 92% retention at the 5°C discharge rate. At 2°C, the retention was at 99%. Even at the 10°C discharge rate, which is beyond typical limits, a 60% retention was achieved. The pouch cells tested here were made using IPL's LMFP material and standard commercial-grade graphite and were tested at an electrode loading of 2 $mA\text{-}h/cm^2$.

In an exclusive interview with Power Electronics News, IPL CEO Behnan Hormozi said that the company's battery research, development, and manufacturing were being done at its U.K. Pilot line facility, which is capable of producing 20 tons a year of high-purity raw material. The supply chain is entirely based in Europe and North America. Samples of the cathode materials developed have been shipped to key players in energy storage and the EV sectors across Europe and the U.S. for evaluation and benchmarking. Positive feedback from four customers has validated the improved performance from this cathode material. This LMFP cathode material is also compatible with the development of ***solid-state batteries***, which are considered key to future improvements in battery performance, safety, and reliability.

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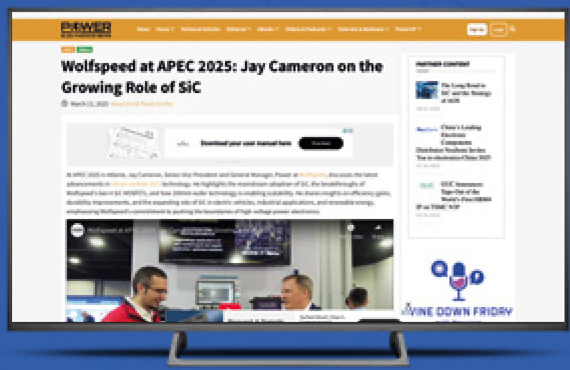

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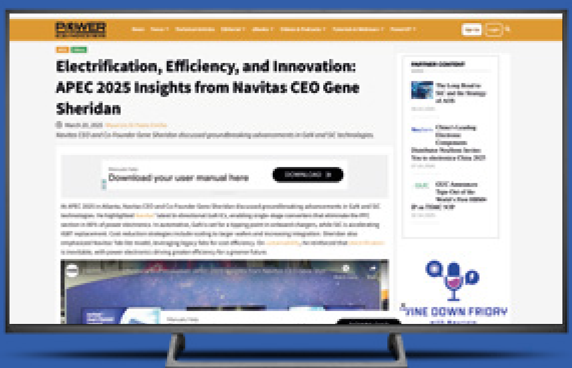

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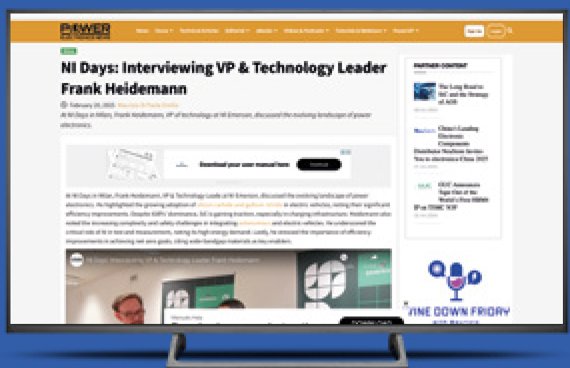

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