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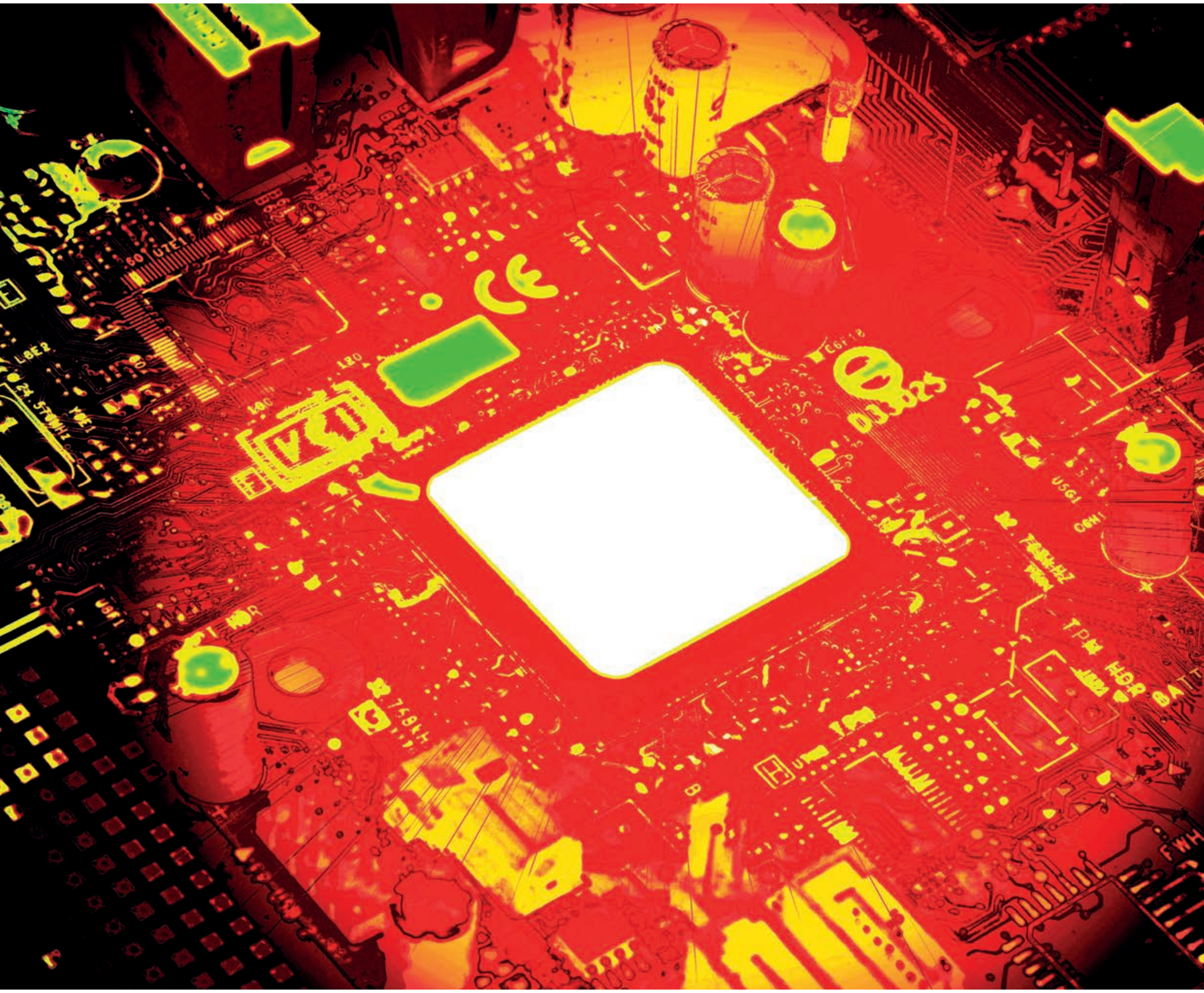
# THERMAL MANAGEMENT

## Thermal Management Help Hardworking Chips



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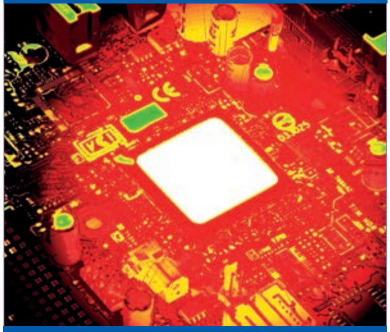
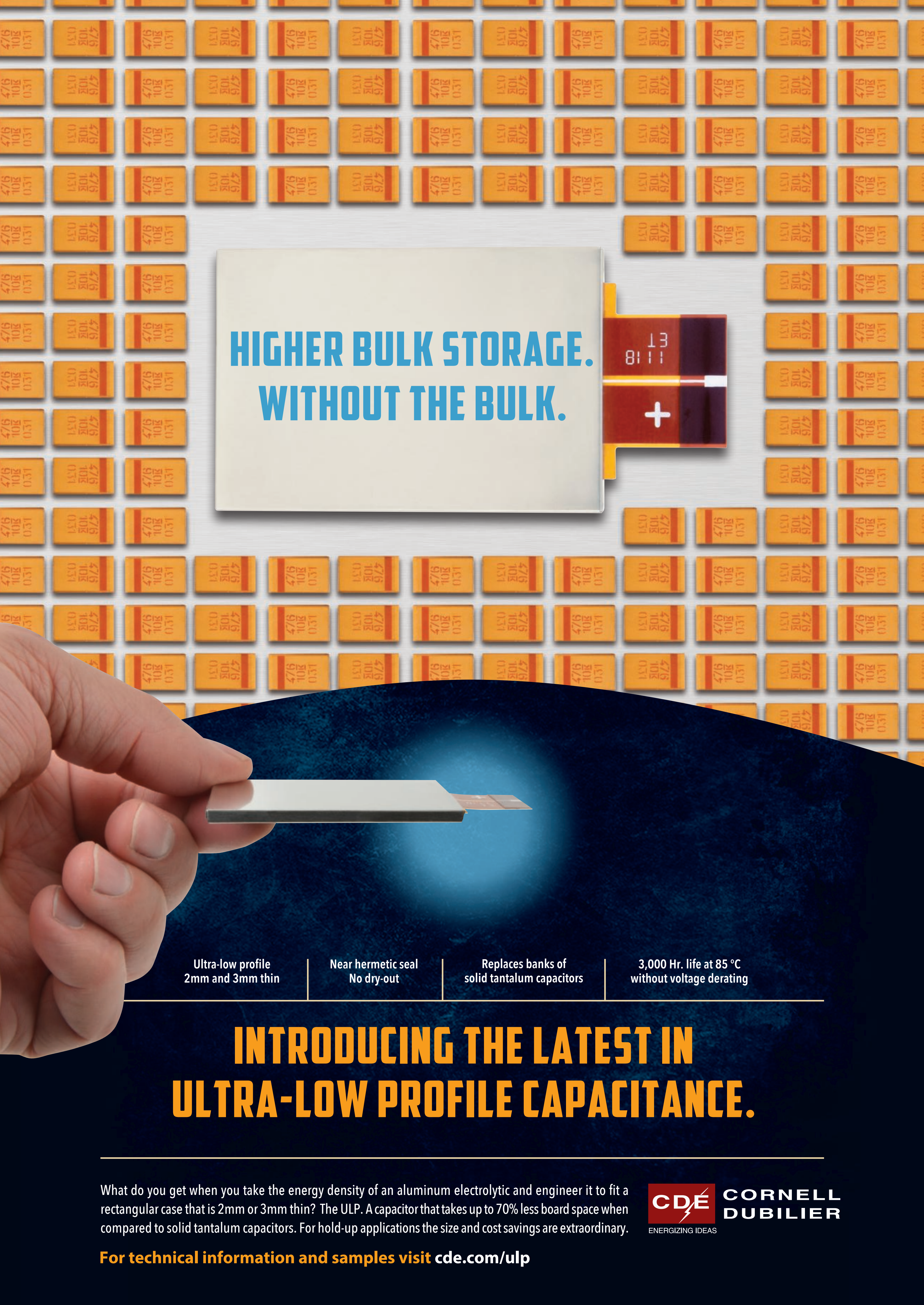
## COVER STORY



## Thermal Management Help Hardworking Chips

Today's electronics designers face unrelenting pressure to increase system power density, or to add new and more impressive functionality within smaller product dimensions. Either way the result is that components may be working harder, or crammed within a smaller space, or both – placing upward pressure on operating temperatures. Design for thermal management can, and should, begin at an early of the project. It is possible to minimize thermal challenges later by selecting components carefully at the beginning: in power applications this could include choosing the latest and most efficient MOSFETs or IGBTs. More generally, system-level power management, taking advantage of chip idle modes and opportunities to power-down unused components or subsystems minimizes the quantity of heat that must be dealt with through dedicated thermal management. Hardworking components can be expected to require a heatsink, and a wide variety of thermal interface materials and off-the-shelf metal heatsinks are available to help extract heat as effectively as possible.
More on page 28.

Cover image supplied by Mouser Electronics Europe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# Automotive Inspires Innovation

The power electronics semiconductor market is in a growth period, which started in 2017 and continued in 2018. According to market researcher Yole it is now saturated for some segments, specifically MOSFETs in 2019, but high demand is expected to continue. Market researcher Yole expects a 4.5 % Compound Annual Growth Rate (CAGR) from 2018-2024 for IGBT modules, while discrete IGBT parts' CAGR will be 2.7 %. The IGBT and MOSFET markets will continue to increase but part of the market will go to SiC, especially when talking about modules for EV/HEV.

The adoption of SiC-based power solutions is rapidly growing across the automotive market as the industry seeks to accelerate its move from internal combustion engines to EVs. Market researcher IHS estimates that, by 2030, 30 million high voltage electrified light vehicles will be sold representing 27 % of all vehicles sold annually. Inverters are one of the highest-value electrification components and their efficiency has an industry-changing impact on many aspects of vehicle performance. Automotive supplier Delphi and Cree/Wolfspeed announced a partnership to utilize SiC semiconductor device technology to enable faster, smaller, lighter and more powerful electronic systems for future electric vehicles. The Cree SiC MOSFETs will initially be used in Delphi's 800 V inverters for a premium global automaker. Production will ramp in 2022. Also STMicroelectronics has been chosen to supply SiC power electronics by Renault-Nissan-Mitsubishi (Alliance) for advanced on-board chargers (OBCs) in its upcoming electric vehicles. The OBCs with ST's SiC are scheduled to enter volume production in 2021.

But what's about GaN we reported now over ten years? Most questions ranked about d-mode (cascode) versus e-mode with GaN-on-Silicon substrate. The major problems with GaN-on-Si are wafer bow due to different thermal expansion coefficient of Si and GaN and dislocation mismatch due to different crystal orientation between these materials. But now other substrates comes into play opening new opportunities. In July Power Integrations announced new members of its InnoSwitch3 families of offline CV/CC flyback switcher ICs. The new ICs feature up to 95 % efficiency across the full load range and up to 100 W in enclosed adapter implementations without requiring a heatsink. This increase in performance is achieved using an internally developed high-voltage (750 V) GaN-on-Sapphire die that has been firstly integrated in a commercially available device. Now the second product family has been released, the new LYTSwitch6 safety-isolated LED-driver ICs for smart-lighting applications with so-called PowiGaN technology enable designs that deliver up to 110 W with 94 % conversion efficiency also using a simple, flexible flyback topology. The high efficiency eliminates the need for heatsinks – reducing ballast size, weight and cooling airflow requirements. The 650 - 750 V GaN primary switches provide very low on-resistance and reduced switching losses. This improvement, combined with existing LYTSwitch-6 features, increases power conversion efficiency by up to 3 %. The company's strategy is to enclose and protect the GaN device within the ICs. Engineers see significant performance benefits, but won't otherwise notice a change. Certainly other product families will be equipped with GaN-on-Sapphire power transistors in the future, for example the last year introduced BridgeSwitch. So far Power Integrations is resilient to disclose technological details of their GaN technology, but we will check in upcoming issues.

In research many attempts try to overcome the problems of different substrates and conducting GaN layer. At PCIM Europe in May 2019 Panasonic demonstrated lateral GaN power transistors on freestanding 2-inch GaN substrates with reduced on-resistance and output capacitance compared to Silicon. In addition, lower dislocation density yields high electron mobility, resulting in lower on-resistance. This enables boost converters to operate at MHz-region with ZVS technique. The lateral conducting GaN-on GaN transistor is fabricated on thick insulating buffer layers with high crystal quality to achieve not only the small output capacitance between the drain and the substrate but also a high breakdown voltage. It is difficult to grow thick GaN layers on Silicon substrates due to the mismatch of the lattice constants and the thermal expansion coefficients between GaN and Si. On the other hand, thick GaN layers can be grown on GaN substrates because there are inherently no mismatches of those kinds, and the GaN layers exhibit much lower dislocation density.

The US Arpa-E SWITCHES projects have investigated unique vertical GaN device designs, expecting to provide even better performance for future devices. Hopefully the transfer from research to products will take lesser time than the transfer from first GaN-on-Si research to practice. We will keep you up-to-date.

**Achim Scharf**
**PEE Editor**

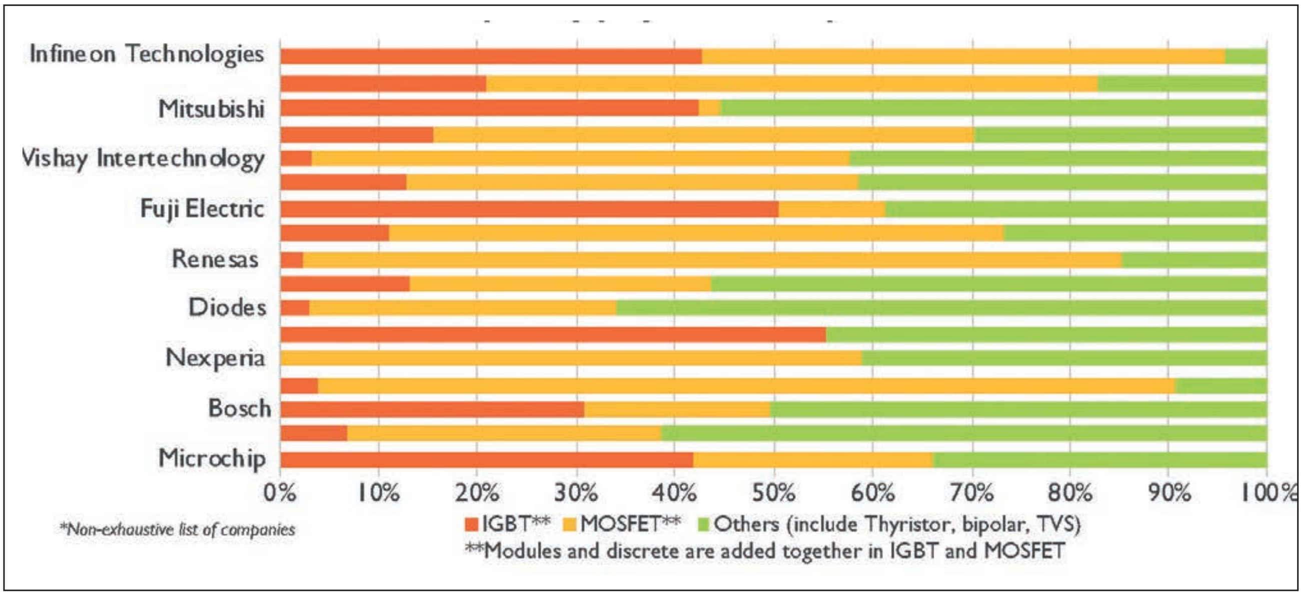
# Power Electronics Market Dynamics Drives 300 Millimeter Wafer-Based Production

The power electronics industry is experiencing a shift in its dynamics, coming from the increase of demand predicted for coming years, which translates into a move for 300 mm wafer-based production.

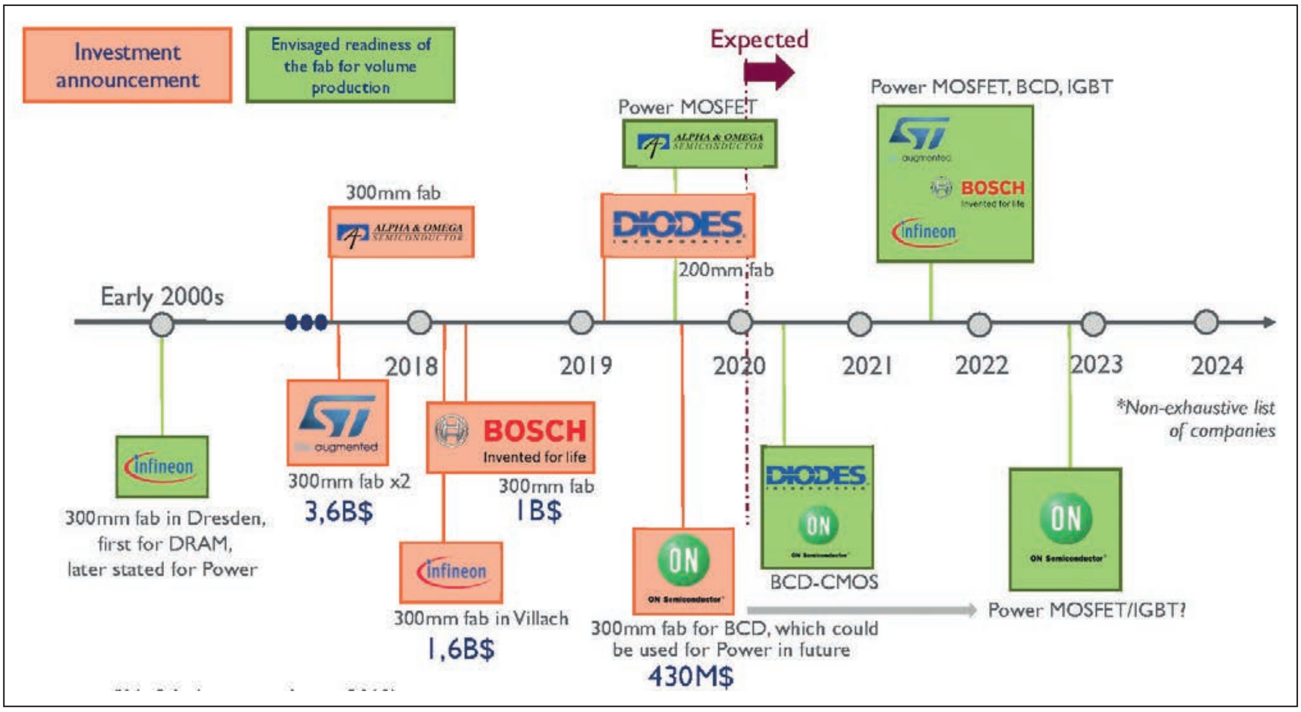
The power electronics market comprised $53.4 billion for power inverters in 2018, and $17.5 billion for power semiconductor devices. Key driving factors include electrical power conversion optimization and expansion, driven by electrification trends in transportation, $CO_2$ emission reduction goals, the development of clean electricity sources, and industrialization.

"We can say that the main driving application with a huge market potential and technological

innovation is electric and hybrid electric vehicles (EV/HEVs). But let's not forget that there are other applications that are boosted by electrification needs and by EV/HEVs. This is the case in renewable energy, which is boosted by clean driving trends and growing electricity consumption. More grid lines also need to be deployed to sustain greater amounts of required energy. Similarly, more energy storage systems need to be deployed for better distribution of the energy to the grid. The grid must also reach newly installed EV charging stations outside cities, enabling many cars to be plugged in at the




**Power electronics landscape: key players* and repartition of their activities Source: Yole Développement August 2019**




**Development timeline of power electronics fabs: investments of the main players* in 300 mm/200 mm wafer size Source: Yole Développement August 2019**

same time with an acceptable charging time. Moreover, if we take into account automated driving and long term vehicle-to-everything (V2X) communication, more data centers could be required, more LiDAR systems, along with other supporting technology. Hence, we are living an era where established applications are boosted by electrification and also by the EV/HEV transition, making the power electronics market very interesting to follow" said analyst Ana Villamor from Yole Développement.

The power electronics semiconductor market is in a growth period, which started in 2017 and continued in 2018. According to market researcher Yole it is now saturated for some segments, specifically MOSFETs in 2019, but high demand is expected to continue. Yole expects a 4.5 % Compound Annual Growth Rate (CAGR) from 2018-2024 for IGBT modules, while discrete IGBT parts' CAGR will be 2.7 %. These forecasts are directly linked with investments in manufacturing lines from different players. The IGBT module market will be directly affected by the penetration of SiC during coming years, with a big push in the EV segment. "Power modules are being developed with new substrates, die attach materials or new semiconductor materials. Different players are focusing on innovation for modules and pushing production to enter this market. On the other hand, established players are fighting for their position in the market through innovation and delivering good product offerings",Villamor expects.

In 2018 there was saturation of 200 mm wafer demand, leading to wafer price rise instead of wafer supply. "As of today, more than seven power electronics players have announced investments in new fabrication capabilities, to be in production from 2021", Villamor said. "The power device market expanded by 14 % in 2018 compared to 2017, leading to a second consecutive high growth year in the power electronics market after a couple of flat years. And the power electronics semiconductor market reached $17.5 billion in 2018, not including power ICs. The IGBT and MOSFET markets will continue to increase but part of the market will go to SiC, especially when talking about modules for EV/HEV. However, SiC remains small compared to the Silicon market, still accounting for less than a 10 % share by 2024", Villamor explained.

Regarding the semiconductor players, Infineon has invested $1.9 billion in Villach to build a second fab for power devices on 300 mm wafers. STMicroelectronics has also started the expansion of its Agrate site for 300 mm production, for Bipolar CMOS-DMOS, power MOSFETs and IGBTs. Another example is Bosch, which has also started building its 300 mm fab in Dresden, preparing for the imminent increase in volumes for both automotive and Internet of Things (IoT) applications. Chinese players have also started the expansion to 300 mm, like Silan Microelectronics or GTA Semiconductors, the latter having confirmed that it is working on its automotive-grade IGBT production line. A concern with these moves might be the equipment delivery time. This is one of the reasons why players such as ON Semiconductor and Diodes Inc have acquired an existing fab. Such acquisitions also require lower investments. The ramp up for production for ON Semiconductor will therefore be in 2020 with advanced CMOS technology. Once that transfer is complete in 2022, the equipment can be used for a possible ramp up in power devices, depending on demand, as the equipment will already be established.

**www.yole.fr**

# Future 3Ccar On Europe's Roads

By 2030, 50% of newly registered vehicles will be electrically powered, connected or automated, according to 3Ccar's hypothesis on market development potential for electromobility and automated driving, based on 100,000 new vehicles per year. This dramatic upsurge in functionality requires a new system approach in vehicle architecture to support electromobility and highly automated driving.

Conventional cars were already equipped in 2014 with between 70 and 100 connected electronic control units (ECUs), and this figure would continue



to rise driven by growing demands for environmental compatibility, efficiency, safety and convenience. The European project "Integrated Components for Complexity Control in affordable electrified cars", 3Ccar for short, was set up to tackle this challenge. 48 partners from 14 different countries have worked on and presented innovative highly integrated semiconductor-based solutions. "What we need in order to reach our ambitious objectives are a strong European ecosystem, innovation and long-term collaboration within major strategic research projects," says Dr. Sabine Herlitschka, CEO of Infineon Technologies Austria AG and Chair of the Joint Undertaking.

Infineon Technologies AG was responsible for managing and coordinating the project. The project was financed by the European Union, the German Federal Ministry of Education and Research (BMBF), other participating countries and partners from industry. The research budget amounted to €54 million. The 3Ccar project kicked off in 2015 and ran for 41 months. The eleven German partners have now presented their research results in a final report. The partners' overriding goal was to reduce complexity, while at the same time enhancing the reliability of electric and automated vehicles. To this end, 3Ccar developed a new system approach that reorganizes vehicle architecture into what are known as vehicle domains. These domains enable functional and task-oriented coordination. The reduces complexity despite growing requirements, significantly simplifying the development of autonomous electric vehicles.

The individual Engine Control Units (ECUs) are integrated into the respective domains, from where functionalities such as steering, brakes and drive are controlled. This involves the use of a small number of powerful domain controllers. These are based on multi-core automotive processors, such as the AURIX™ microcontrollers. The conventional powertrain, for example, has a domain of its own. As well as controlling complexity, the smaller number of ECUs and the higher level of integration also increase robustness.

Up to now, the considerable amount of cabling in car batteries has meant high costs and a low level of reliability. Working together with the Fraunhofer Institutes IISB and IPA, 3Ccar developed a new, modular and flexible concept for future batteries to be used in electric and hybrid vehicles. The sensors and electronic components are integrated with the battery cell network instead of at battery pack level. This is a completely new approach that simplifies battery management and, further down the line, will also offer the option of producing "Smart Batteries Made in Europe" at a competitive price. The system has fewer individual parts, making it less prone to errors and hence boosting the robustness of the vehicle architecture.

3Ccar developed a new safety shut-off for discharging fuel cells. Compared to products available today, this shut-off is more compact and can be reused. While existing concepts can only be used once, since they are destroyed by the activation process, the new development can short-circuit the fuel cells in a targeted manner and release them again several times over.

Together with Siemens, 3Ccar has developed an electric drive featuring a higher power density than comparable products. Its compact structure means high vehicle performance is possible even with challenging space constraints. In addition, the new drive motor is also more efficient and reliable.

The Amberg-Weiden University of Applied Sciences developed special vehicle-to-network communication (V2N) for electric vehicles. The goal was to develop a basic service that can take over the entire route planning process. A server-based system for route planning in road networks was deployed and combined with information on charging stations. This server-controlled routing system made it possible to determine optimized routes specifically suited to electric vehicles.

**https://3ccar.eu/**

3CAR

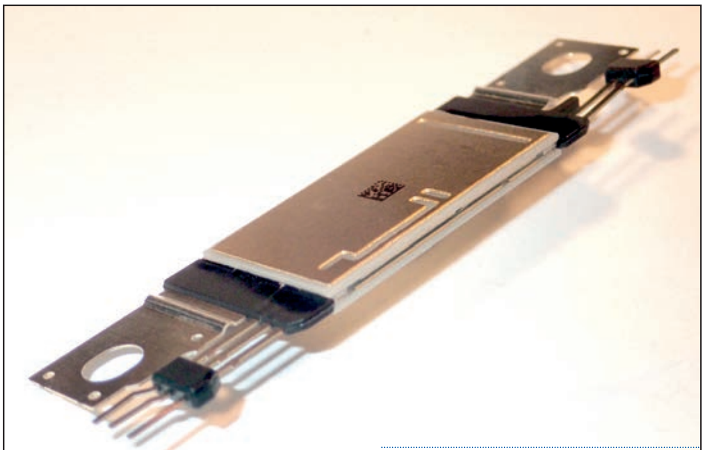
# Delphi to Partner with Cree for Automotive Silicon Carbide Devices

Automotive supplier Delphi and Cree/Wolfspedd announced a partnership to utilize silicon carbide semiconductor device technology to enable faster, smaller, lighter and more powerful electronic systems for future electric vehicles.

The adoption of SiC-based power solutions is rapidly growing across the automotive market as the industry seeks to accelerate its move from internal combustion engines to EVs. IHS estimates that, by 2030, 30 million high voltage electrified light vehicles will be sold representing 27 % of all vehicles sold annually. Inverters are one of the highest-value electrification components and their efficiency has an industry-changing impact on many aspects of vehicle performance. Cree's SiC MOSFET technology coupled with Delphi Technologies' traction drive inverters, DC/DC converters and chargers will extend driving range and deliver faster charging times of EVs, while also lowering weight, conserving space and reducing cost. The Cree SiC MOSFETs will initially be used in Delphi's 800 V inverters for a premium global automaker. Production will ramp in 2022.

"Our collaboration with Cree will create a significant benefit to automakers as they work to balance meeting stricter global emissions regulations with consumer appetite for electric vehicles. Overcoming driver anxiety related to electric vehicle range, charging times and cost will be a boon for the industry", commented Richard F. Dauch, CEO of Delphi Technologies. "Cree's technology is at the heart of the change underway in EVs, and we are committed to supporting the automotive industry as it transitions from Silicon-based designs to more efficient, higher performing Silicon Carbide solutions," said Gregg Lowe, CEO of Cree. "This partnership with Delphi Technologies will help drive the adoption of Silicon Carbide in the automotive sector. As the leader in Silicon Carbide, we will continue to expand capacity to meet market demands to help achieve a new, more efficient future."

**www.delphi.com, www.cree.com**

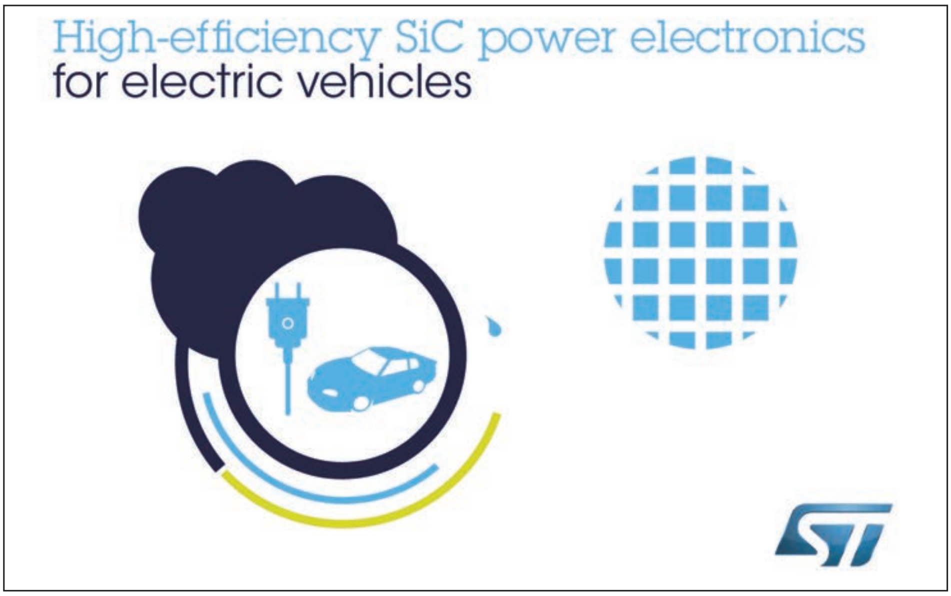


**Delphi's Viper 4 inverter power switch**

# STMicroelectronics Supplies Silicon-Carbide Power Electronics to Renault

STMicroelectronics has been chosen to supply SiC power electronics by Renault-Nissan-Mitsubishi (Alliance) for advanced on-board chargers (OBCs) in its upcoming electric vehicles.

Renault-Nissan-Mitsubishi has already created a 22 kW OBC for the Renault Zoe model, which can fully recharge the battery in about one hour. Now, by upgrading the OBC to leverage the superior efficiency and small size of SiC MOSFETs and rectifier diodes, the Alliance can further reduce the size, weight, and cost while increasing energy efficiency.




Renault-Nissan-Mitsubishi plans to use the new SiC power technology to build more efficient and compact high-power OBCs that will further increase attractiveness of electric vehicles by cutting battery-charging time and enhancing driving range. ST is also to supply Renault-Nissan-Mitsubishi with associated components, including standard Silicon devices. The OBCs with ST's SiC are scheduled to enter volume production in 2021. "As a pioneer and global leader in zero-emission electric vehicles, our objective remains to be the number one provider of mainstream mass-market and affordable EVs around the world," said Philippe Schulz, Alliance VP Design Electric & Hybrid Powertrain. "The small size, light weight, and high energy efficiency we can achieve using ST's SiC technology in our OBC, combined with the increased battery efficiency, will enable us to accelerate the adoption of electric vehicles by reducing charging times and extend the range of our Evs." Marco Cassis, ST's President, Sales, commented: "SiC technology can help the world by reducing dependence on fossil fuels and increasing energy efficiency. ST has successfully developed manufacturing processes and established a portfolio of qualified, commercialized SiC products also in automotive-grade version. Building on our long cooperation, we are now working with Renault-Nissan-Mitsubishi to realize the many advantages SiC can bring to EVs. Moreover, this commitment helps ensure success by increasing the economies of scale to deliver SiC-based circuits and systems that are also cost-effective and affordable".

**www.st.com**

# EPC Partners with Solace Wireless Power

EPC announces collaboration with Solace Power, a wireless power, sense and data company, to enable 250 W wireless power solutions designed for 5G, aerospace, automotive, medical, and industrial applications.

Solace Power's wireless platform use EPC's 200 V eGaN power transistors. This modular platform shares the same Equus™ architecture and enables up to 250 W of transmitted power with six degrees of spatial freedom. "Solace focuses on delivering complete, modular systems which are pre-tested for CISPR/FCC compliance and optimized in-house for rapid development in real world applications. These new solutions solve the most important challenges for applications requiring 200 watts or more. For wireless power applications with higher power demands than traditional consumer devices, Silicon-based transistors become inefficient. To address this limitation, we selected a 200 V gallium nitride-based power transistor for the 250 W solution", said Solace Power CEO, Michael Gotlieb. "Wireless power is ready to be incorporated into our daily lives and the modular platform that Solace Power has developed will improve design cycle times and help new industries implement wireless power quickly and inexpensively," commented Alex Lidow, CEO and co-founder of EPC.


**www.epc-co.com, www.solace.ca**

# Energy Storage Attached to 50% of Solar Installs by 2030

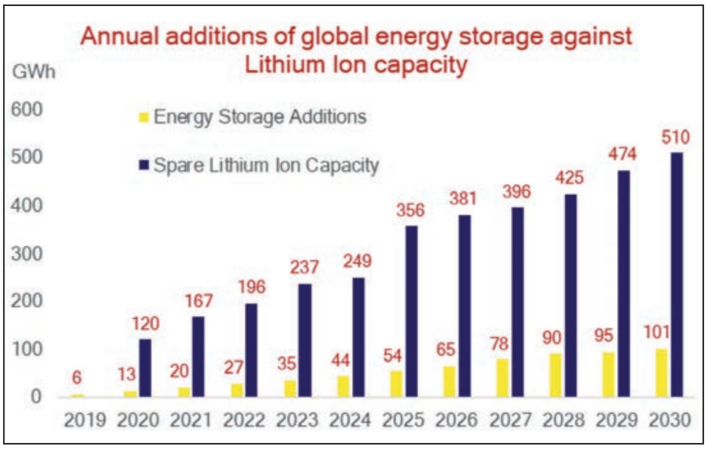
The rise of the idea that energy can be stored for any time in a 24 hour cycle and used either on the electricity grid or directly at a business or home, has really been resurrected by the rise and rise of Electric Vehicles and the corresponding fall in the cost of Lithium Ion batteries. Energy Storage will grow from 6 GWh installed today to over 635 GWh cumulatively by 2030. Annual additions will go from 6 GWh in 2019 to 101 GWh buy 2030, according to a report from UK-based Rethink Technology.

The "big" financial moves are in Lithium, where global industrial giants are prepping for the shift from internal combustion engine vehicles to EVs, which are expected to be a force by 2024 when they will pass 10 million additional new vehicles on the road and 40 million cumulatively, before moving on to 2030 when close to 150 million EVs will be on the road, a significantly percentage of what was once a 1 billion vehicle market. Most cars post 2035 will be made with a Lithium Ion or other, yet to be invented, battery.

Throughout this period of dramatic growth the Asia Pacific region, led by China will dominate installations with 273 GWh out of 635 GWh, or some 43 % of all energy storage capacity while the rest of Asia adds around 155 MWh or 24.5 %. Europe will install some 20 % of total cumulative capacity, and the US just 67.7 or some 10.7 % of total global capacity. MEA and Latin America will effectively be left behind with a few percentage points each. The key technology will be Lithium Ion batteries which have massive momentum, brought about by the arrival of Electronic Vehicles. The top 10 manufacturers alone have planned some 510 GWh of annual global factory capacity by 2030, with 45 % of global Lithium Ion manufacturing capacity located China and Europe and South Korea also acting as strongholds, mostly through partnerships with Chinese players.

There will be plenty of room for alternative energy storage technologies such as Vanadium Flow and large storage GWh-class devices including ETES, Liquid air and Energy Vault cranes based systems, but without the huge investment in Lithium Ion batteries, this segment would not take off quite so rapidly. Rethink estimates that 90 % off the global energy storage market will remain Lithium based until a new technology emerges to lead, possibly by 2040.

**www.rethinkresearch.biz**



# The Future of GaN

The projects in US ARPA-E's SWITCHES program, which is short for "Strategies for Wide-Bandgap, Inexpensive Transistors for Controlling High-Efficiency Systems," are focused on developing next-generation power switching devices that could dramatically improve energy efficiency in a wide range of applications, including new lighting technologies, computer power supplies, industrial motor drives, and automobiles. The finding of these projects are underlined by industrial research, for example Panasonic.

SWITCHES projects aim to find innovative new wide-bandgap semiconductor materials, device architectures, and device fabrication processes that will enable increased switching frequency, enhanced temperature control, and reduced power losses, at substantially lower cost relative to today's solutions. More specifically, SWITCHES projects are advancing bulk gallium nitride (GaN) power semiconductor devices, the manufacture of SiC devices using a foundry model, and the design of synthetic diamond-based transistors.

SWITCHES was aimed at transformational advances that address key materials, device fabrication, and device architecture issues that drive costs for SiC and GaN devices, as well as to evaluate ultra-wide-band-gap (UWBG) materials such as a diamond. The goal was to enable the development of high voltage (>1,200 V), high current (100A) single die power semiconductor devices that, upon ultimately reaching scale, would have the potential to reach functional cost parity with Si power transistors. Additionally, they would offer breakthrough relative circuit performance through low losses, high switching frequencies, and high temperature operation.

## Aggressive targets

The projects in the SWITCHES program have made tremendous advances in materials development, vertical device architecture, and low cost device fabrication. The program set out to achieve three key aggressive targets: 1200 V breakdown, 100 A single-die current, and cost of packaged discrete device of no more than ¢0/A.

These transformational technologies would have promise to reduce the barriers to ubiquitous deployment of low-loss WBG power semiconductor devices in stationary and transportation energy applications. From a cost basis perspective, the barrier to market entry needs to be competitive. Low current Silicon switching devices (<50 A) can be purchased as low as ¢5/A. However, this is not the case for high current applications. The SWITCHES cost target for WBG packaged devices was ¢10/A for a 100 A device, which would make them competitive with the best Silicon IGBT devices in the same class.

Before the SWITCHES program, the majority of GaN power device development had been directed toward lateral architectures, such as high-electron mobility transistors (HEMTs). There were no vertical GaN devices commercially available. The lateral devices suffered from well-known issues such as current-collapse, dynamic on-resistance, inability to support avalanche breakdown, and usable breakdown voltages of no greater than 650 V. Vertical devices on the other hand offer the possibility to realize the potential of GaN including true avalanche-limited breakdown.

Two projects in the SWITCHES program (Avogy, Inc. and Cornell University) were able to demonstrate near theoretical, high-power vertical GaN diodes exhibiting very high breakdown voltages (1700 - 4000 V) and figures-of-merit ($V_B^2$ /$R_{ON}$) greater than 3 GW/cm$^2$. The researchers demonstrated that vertical GaN devices are avalanche capable indicating the ruggedness of such devices in breakdown, a critical requirement for power switching and rectifying applications. The pathway towards achieving ¢10/A for GaN devices was shown to be promising. Projects funded by SWITCHES have demonstrated 80 % process yield for 100 A, 1200 V p-n junctions. With the current cost of 4" GaN wafers and a die size of 12-16 mm$^2$ for a 100 A, 1200 V device, vertical GaN devices should be capable of reaching the price range of ¢5/A to ¢7/A.

## From lateral to vertical GaN transistors

Normally-off vertical transistor devices have been more challenging to fabricate compared to diodes, especially at high current levels, due to the requirement of selective area doping in many vertical device architectures.

At PCIM Europe in May 2019 Panasonic demonstrated lateral GaN power transistors on freestanding 2-inch GaN substrates with reduced on-resistance and output capacitance ($Q_{oss}$). Owing to thicker GaN epitaxial layers grown on GaN substrates, smaller $Q_{oss}$ is achieved as compared with those on Si substrates. In addition, lower dislocation density yields high electron mobility, resulting in lower $R_{on}$. This enables boost converters to operate at MHz-region with ZVS technique.

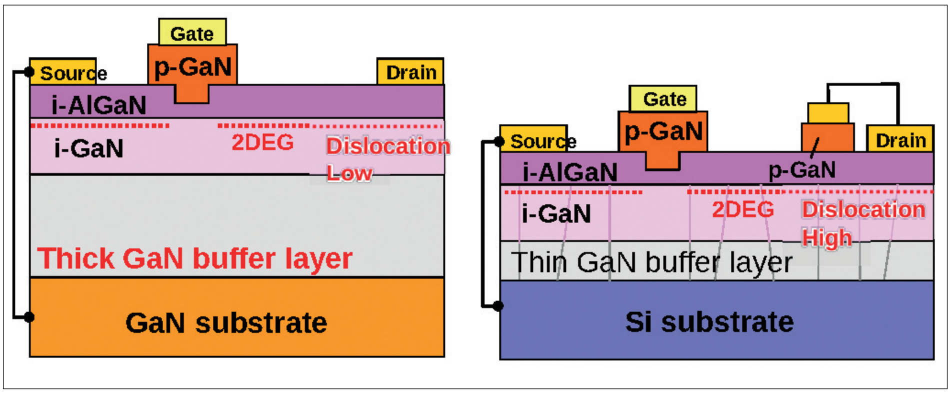
The GaN-on GaN transistor is fabricated on thick insulating buffer layers with high crystal quality to achieve not only the small output capacitance between the drain and the substrate but also a high breakdown voltage. It is difficult to grow thick GaN layers on Silicon substrates due to the mismatch of the lattice constants and the thermal expansion coefficients between GaN and Si. On the other hand, thick GaN layers can be grown on GaN substrates because there are inherently no mismatches of those kinds, and the GaN layers exhibit much lower dislocation density.

The electron mobility of the 2DEG grown on the GaN substrates is 2130cm$^2$Vs, which is improved by 45 %, while the electron density is the same as that grown on Si substrates. The higher mobility is originated from the lower dislocation density in the GaN layer.

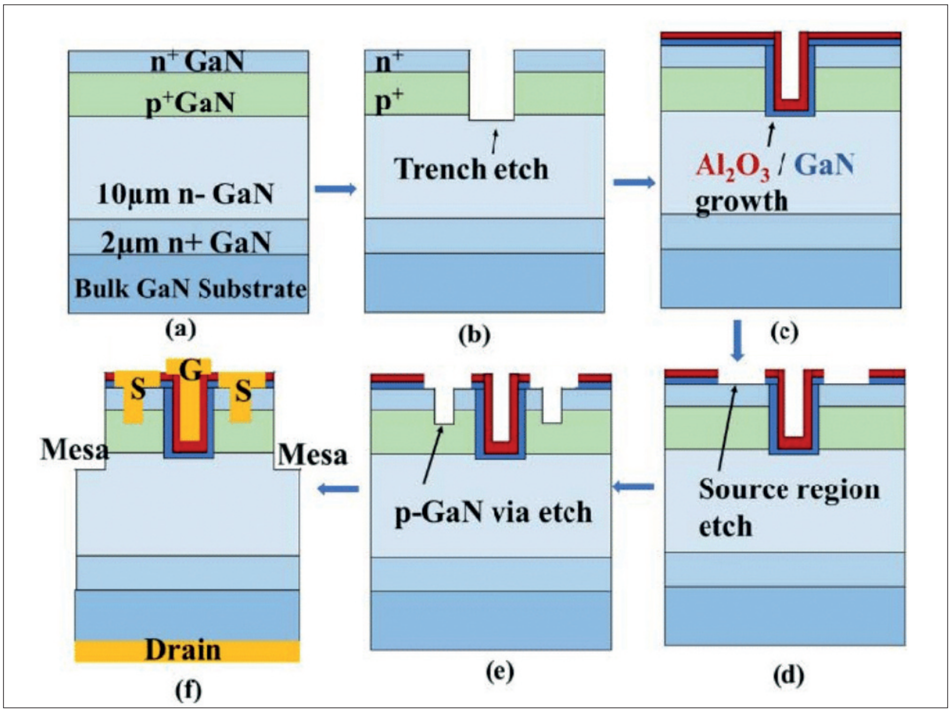
## Eliminating selective area doping

Attempts at selective area doping in vertical GaN devices in the SWITCHES program resulted in devices with large junction leakage currents, lower than breakdown voltages expected, and avalanche breakdown ruggedness not demonstrated. This is the major challenge faced by the SWITCHES projects with vertical GaN architectures. To overcome the selective area doping limitation in GaN two SWITCHES projects have investigated unique vertical GaN device designs that reduce or eliminate the need for selective area doping.

The University of California/Santa Barbara demonstrated one such novel vertical GaN devices to achieve both low on-resistance ($R_{ON}$) and enhancement mode operation in a vertical GaN device called an "in-situ oxide, GaN interlayer-based vertical trench MOSFET" or OG-FET. In the traditional trench MOSFET structure, a dielectric is deposited on an n-p-n trenched structure and the channel forms via p-GaN inversion at the dielectric/p-GaN interface. However, this results in a relatively high $R_{ON}$ due to poor electron mobility in the channel. By changing the structure to include a metal-organic chemical vapor deposition regrown un-intentionally doped GaN interlayer followed by an in-situ, $Al_2O_3$ dielectric cap on the n-p-n trenched structure, a pathway (channel) for enhanced electron mobility is created, resulting in reduced resistance. The normally-on OG-FETs fabricated by UCSB




GaN-on-GaN (left) and GaN-on-Si power transistor schematic (Souce: Panasonic/Shinji Ujita)




**GaN interlayer-based vertical trench MOSFET (OG-FET) process** **(Source: Arizona State University/Dong Ji)**

demonstrated a threshold voltage of 2 V, breakdown voltages of 990 V ($E_{BR}$ ~ 1.6 MV/cm), and an $R_{ON}$ of 2.6 mΩ-cm$^2$.

The project led by Columbia University "High-performance, low-cost vertical GaN devices through smaller devices and GaN substrate re-use" demonstrated a GaN vertical fin power field-effect-transistor structure (VFET) on bulk GaN substrates that addresses the selective area doping limitation of conventional power vertical GaN transistor device structures. The VFET consists of fin-shaped channels etched into an 8-µm-thick n- doped GaN drift layer using a combined dry/wet etching technology to achieve smooth fin vertical sidewalls. The current flows vertically from the backside drain contact to source contacts deposited on top of the fins. The sub-micron fin channels are surrounded by metal gate pads which, below the threshold voltage, pinch-off the channel. In this vertical transistor design only n-GaN layers are needed, no material regrowth or p-GaN layer is required. Fabricated VFETs demonstrated specific on-resistance of 0.2 mΩ-cm$^2$, threshold voltage of 1 V, and a breakdown voltage >1200 V with high ON current (>25 kA/cm$^2$) and low OFF current at 1200 V (<10$^{-4}$ A/cm$^2$). This amounts to a figure-of-merit ($V_B^2/R_{ON}$) of ~7.2 GW/cm$^2$. Large devices demonstrated high current up to 10 A and breakdown voltage >800 V.

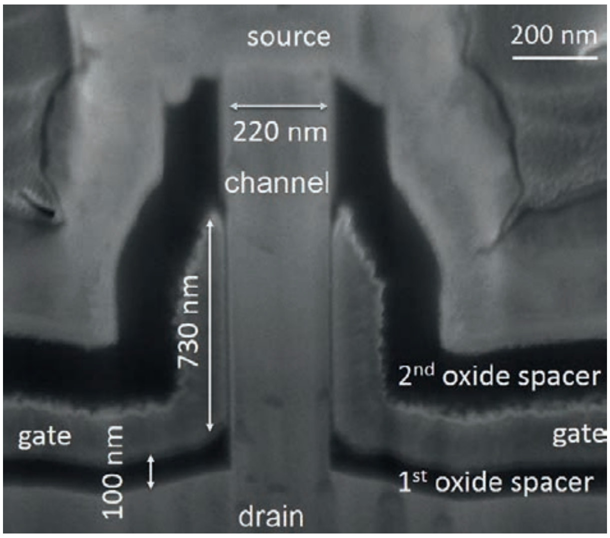
Additionally, the SWITCHES program has made advances in the area of epitaxial lift-off of GaN materials. Two projects by the MicroLink Devices and Columbia University teams focused on GaN substrate re-use and thinning. These projects demonstrated large area (>2 inch) layers released from bulk GaN wafers by epitaxial lift-off and spalling without damage to the lifted off layer.

The MicroLink Devices project "High-performance, low-cost vertical GaN devices through smaller devices and GaN substrate re-use" demonstrated wafer-scale epitaxial lift-off (ELO) using an In-GaN release layer and a bandgap-selective photo-enhanced wet etching to fully released a GaN foil from 2-inch bulk GaN substrate. Perforations spaced at 1 mm apart were used to allow for the wet chemical etch access to the InGaN release layer. The leakage current in both reverse and low-forward-bias regimes for thin-film Schottky diodes was reduced after ELO processing. This is potentially due to the elimination of leakage paths through the underlying n+ buffer layer that is removed in the ELO process.

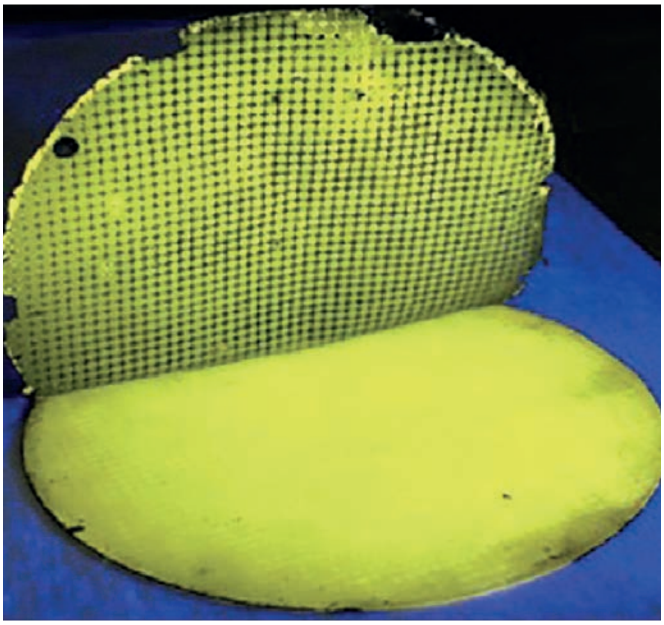
On the bulk (free standing) GaN substrate development side, Soraa Inc. developed a large diameter ammonothermal reactor capable of more than 600°C operation and a pressure greater than 3,000 atmospheres in order to grow bulk GaN crystals. The ammonothermal GaN crystal growth method is adapted from the hydrothermal method used to grow quartz crystals, which are very inexpensive and represent the second-largest market for single crystals for electronic applications (after Silicon).

Soraa demonstrated growth of GaN crystals that are over two inches in diameter at a rate of at least 10 microns per hour, and the fabrication of 2-inch GaN wafers from the crystal. The wafers met target specifications for LED crystal quality, dopant levels, dislocation density, miscut, and surface roughness. Soraa has also shown that with additional processing steps, they have the ability to make wafers with a dislocation density less than 1x10$^4$ cm$^{-2}$, a breakthrough that will enable higher-performing power electronics devices with a breakdown field greater than 3 MV/cm for GaN. **AS**

**www.pcim-europe.com, https://arpa-e.energy.gov/?q=arpa-e-programs/switches**




**Scanning electron microscope cross sectional view of a fabricated GaN VFET (Source: Arpa-E SWITCHES)**



**A 5-micron-thick GaN epitaxial film released by ELO from a 4-inch sapphire substrate using perforations on a 1-mm pitch. The yellow luminescence of the nitrogen face of the released film is visible under ultraviolet illumination (Source: Arpa-E SWITCHES)**

# LED Drivers from Power Integrations Use PowiGaN Technology

The new LYTSwitch™-6 family of safety-isolated LED-driver ICs for smart-lighting applications with PowiGaN™ technology enable designs that deliver up to 110 W with 94 % conversion efficiency using a simple, flexible flyback topology.

The high efficiency of the new LYTSwitch-6 ICs eliminates the need for heatsinks – reducing ballast size, weight and cooling airflow requirements. The 750 V PowiGaN primary switches provide very low on-resistance and reduced switching losses. This improvement, combined with existing LYTSwitch-6 features, increases power conversion efficiency by up to 3 % compared to conventional solutions.

**GaN-on-Sapphire across more product families**

In July the company announced new members of its InnoSwitch™3 families of offline CV/CC flyback switcher ICs. The new ICs feature up to 95 % efficiency across the full load range and up to 100 W in enclosed adapter implementations without requiring a heatsink. This increase in performance is achieved using an internally developed high-voltage GaN-on-Sapphire die that has been integrated in a commercially available device.

"GaN transistor technology is the future for power conversion. Our strategy is to enclose and protect the GaN device within our ICs. Engineers see significant performance benefits, but won't otherwise notice a change.  We anticipate a rapid conversion in many power applications. InnoSwitch3 has been the clear technology leader in the offline switcher IC market since we launched the Silicon variants 18 months ago, and the new GaN-based ICs extend both the efficiency and power capability of our flyback products," said PI's CEO Balu Balakrishnan, CEO of Power Integrations.

**LYTSwitch-6 topology**

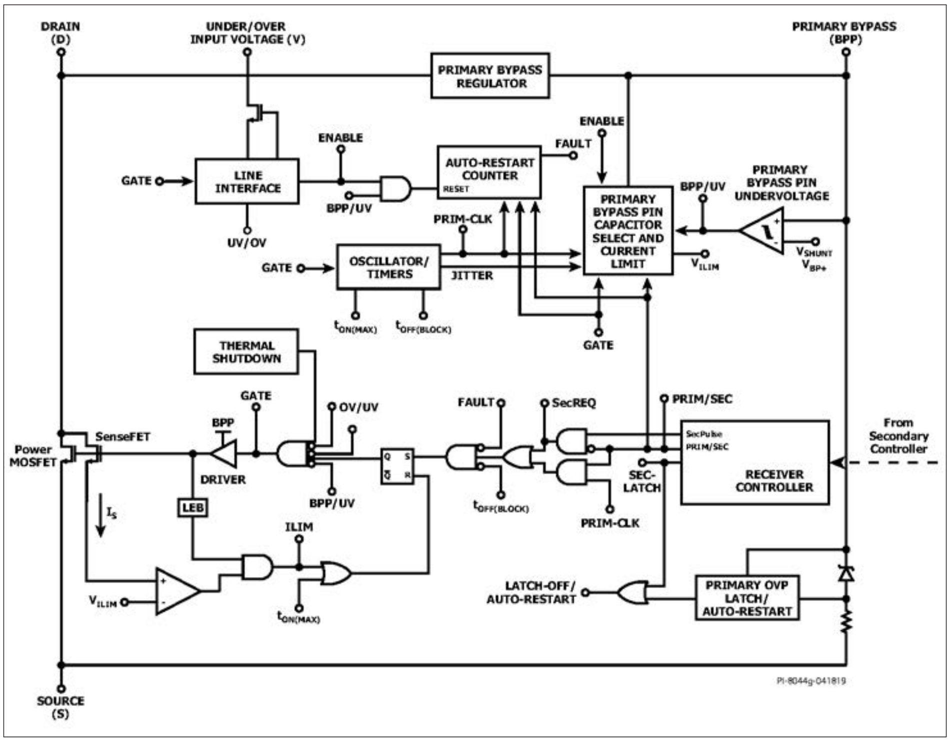
The LYTSwitch-6 combines the high-voltage power switch, along with both primary-side and secondary-side controllers in one device. It incorporates a novel inductive coupling feedback scheme using the package lead frame and bond wires (Flux-link) to provide a safe, reliable, and low-cost means to communicate accurate direct sensing of the output voltage and output current on the secondary controller to the primary controller.

LYTSwitch-6 is a Quasi-Resonant (QR) flyback controller operating in continuous conduction mode (CCM). The controller uses both variable frequency and variable current control schemes. The primary controller consists of a frequency jitter oscillator; a receiver circuit magnetically coupled to the secondary controller, a current limit controller, 5 V regulator on the PRIMARY

BYPASS pin, audible noise reduction engine for light load operation, bypass overvoltage detection circuit, a lossless input line sensing circuit, current limit selection circuitry, over-temperature protection, leading edge blanking, and a 650 V, 725 V or 750 V GaN power switch.

In order to improve conversion efficiency and reduce switching losses, the LYTSwitch-6 features a means to force switching when the voltage across the primary switch is near its minimum voltage when the converter operates in discontinuous conduction mode (DCM). This mode of operation automatically engages in DCM and disabled once


**PI's new PowiGaN™ technology enable designs that deliver up to 110 W with 94 % conversion efficiency using a simple, flexible flyback topology**



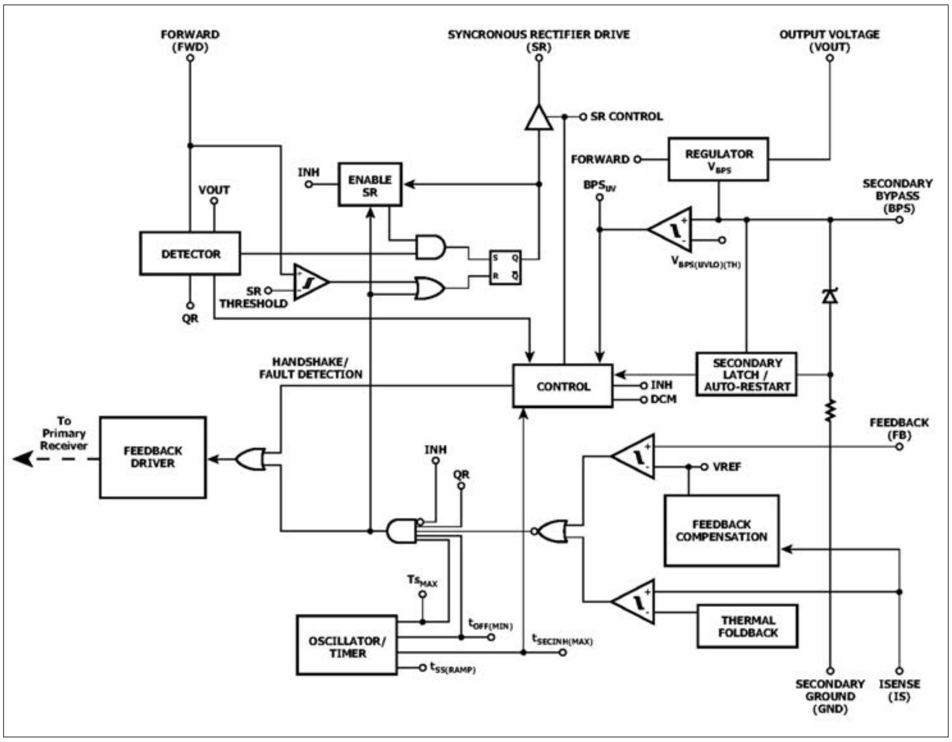

Primary controller block diagram

the converter moves to continuous-conduction mode (CCM).

Rather than detecting the magnetizing ring valley on the primary-side, the peak voltage of the FORWARD pin voltage as it rises above the output voltage level is used to gate secondary request to initiate the switch "ON" cycle in the primary controller.

Quasi-Resonant (QR) mode is enabled for 20 ms after DCM is detected or ring amplitude (pk-pk) >2 V. Afterward QR switching is disabled, at which point switching may occur at any time a secondary request is initiated.

The secondary controller consists of a transmitter circuit that is magnetically coupled to the primary receiver, a constant voltage (CV) and a constant current (CC) control circuit, a 4.4 V regulator on the secondary SECONDARY BYPASS pin, synchronous rectifier MOSFET driver, QR mode circuit, oscillator and timing functions,




Secondary controller block diagram

thermal foldback control and a host of integrated protection features. It also includes blanking of ~1 ms to prevent false detection of primary "ON" cycle when the FORWARD pin rings below ground and it detects when the controller enters in discontinuous-mode and opens secondary cycle request windows corresponding to minimum switching voltage across the primary power switch.

**Universal external LED driver application**

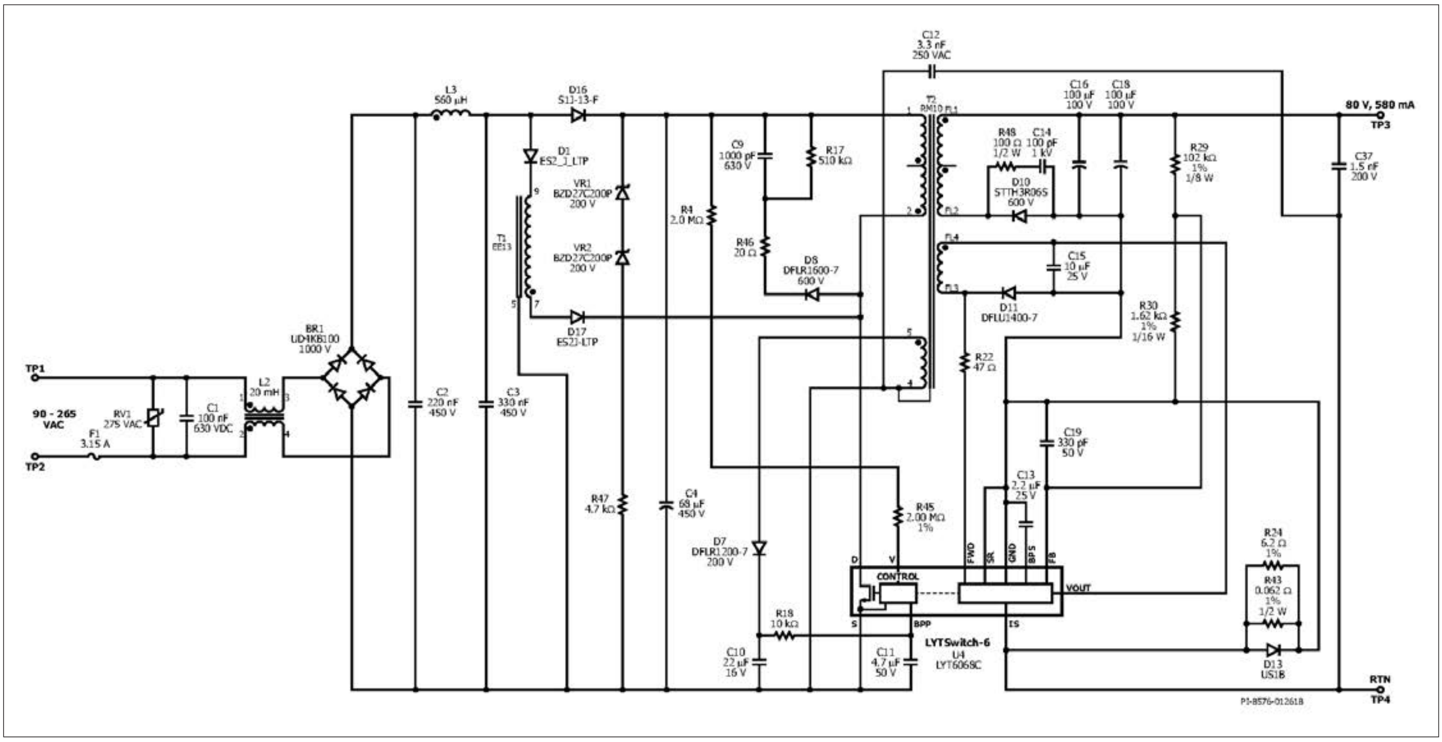
A typical application is a 46 W isolated flyback power supply with a single-stage power factor correction circuit for LED lighting. It provides an accurately regulated 80 V, 580 mA output for multi-LED-string applications where a post regulator is used – such as in RGBW smart-lighting fixtures. The design is also ideal for single string applications as it also provides a constant 580 mA output current with accurate regulation and no line-induced ripple across a load-voltage range of 80 V to 20 V. The circuit is highly efficient offering accurate load regulation and is stable over line (90 VAC to 265 VAC). The circuit also delivers a PF of greater than 0.9 with less than 20 % A-THD (measured at 230 VAC).

Fuse F1 provides open-circuit protection which isolates the circuit from the input line in the event of catastrophic component failures. Varistor RV1 clamps any voltage spikes to protect the circuitry located after the fuse from damage due to over-voltage caused by a line transient or surge. Bridge diode BR1 rectifies the AC line voltage and provides a full-wave rectified DC voltage across the input film capacitors C2 and C3. The EMI filter is a 2-stage LC circuit comprising C1, L2, C2, L3, and C3 and suppress differential and common mode noise generated from the PFC and flyback switching stages.

The bulk capacitor C4 completes the input stage. It filters the line ripple voltage and provides energy storage. This component also filters differential current, further reducing conducted EMI. The input stage provides a DC voltage to the flyback converter. One end of the primary winding of transformer (T2) is connected to the positive terminal of the bulk capacitor (C4) while the other is connected to the DRAIN pin of the integrated 650 V GaN power switch in the LYTSwitch-6 IC (U1). A low-cost RCD primary clamp made up of D8, R46, R17 and C9 limits the voltage spike developed across the switch that is caused by the transformer leakage inductance. The RCD primary clamp also reduces radiated and conducted EMI.

In order to provide line over-voltage detection, the bulk capacitor voltage is sensed and converted into a current by the INPUT VOLTAGE pin resistors R4 and R45. The INPUT VOLTAGE pin line over.voltage threshold current (I OV- ) determines the input over-voltage shutdown point.

The LYTSwitch-6 IC is self-starting, using an internal high-voltage current source to charge the PRIMARY BYPASS pin capacitor (C11) when AC is first applied. During normal operation the primary-side circuitry is powered from an auxiliary winding on transformer T2. A value of 4.7 μF was selected




**Schematic of a 46.4 W, 80 V, 0.58 A universal external LED driver**

for the BPP capacitor (C11) to select increased-current-limit operation. During normal operation the output of the auxiliary (bias) winding is rectified using diode D7 and filtered using capacitor C10. Resistor R18 limits the current being supplied to the PRIMARY BYPASS pin.

The Power Factor Correction circuit comprises an inductor (T1) in series with blocking diodes (D1 and D17) and is connected to the DRAIN pin of the LYTSwitch-6 IC. High PF is achieved using a Switched Valley-Fill Single Stage PFC (SVF S 2 PFC) circuit operating in discontinuous conduction mode (DCM). In DCM the switched current from inductor T1 shapes the input current waveform to create a quasi-sinusoid when the rectified voltage on C3 is less than the DC voltage on C4, this results in a high power factor. During switch on-time, energy is stored in the PFC inductor (T1) and the leakage inductance of the flyback transformer (T2). During switch off-time, the energy from both the PFC and flyback inductors is transferred to the secondary-side through the flyback transformer T2. Diode D16 isolates the rectified AC input on C3 from C4 and provides current path for the charging of the bulk capacitor C4 – especially at low-line, which improves efficiency. Free-wheel diodes D1 and D17 provide a current path for the energy stored in the PFC inductor that must be transferred to the secondary-side during switch off-time. The series connection of D1 and D17 are able to withstand the resonant voltage ring from the PFC inductor when the switch turns off.

During a no-load or light load condition (<10 % load) the energy stored in the PFC inductor is greater than required by the secondary load. The excess energy from the PFC inductor is therefore recycled to the bulk capacitor C4 boosting the voltage level. A Zener-resistor clamp comprising of VR1 and VR2 in series with R47 is connected across the bulk capacitor C4 to clamp this voltage below the voltage-rating of C4. This Zener clamp voltage should be ≤450 V (the maximum voltage rating of bulk capacitor C4). In the event of an input line surge or transient event, the primary switch is protected from overvoltage by the INPUT VOLTAGE pin sense resistors which trigger a line over-voltage shutdown at 460 V.

The secondary-side control of the LYTSwitch-6 IC provides constant output voltage and constant output current. The voltage produced on the secondary winding of transformer T2 is rectified by D10 and filtered by the output capacitors C16 and C18. Adding an RC snubber (R48 and C14) across the output diode reduces voltage stress. In this design, the SYNCHRONOUS RECTIFIER DRIVE pin is connected to the SECONDARY GROUND pin to allow the use of a low-cost ultrafast output diode instead of an SR FET.

The IC secondary is self-powered from either the secondary winding forward voltage via the FORWARD pin, or the output voltage via the OUTPUT VOLTAGE pin. Decoupling capacitor C13 is connected to the SECONDARY BYPASS pin. In order to meet the maximum voltage limits of OUTPUT VOLTAGE pin in this design, the secondary-side of the IC needs to be powered from a low voltage auxiliary supply (winding FL3 and FL4). The FORWARD pin has to be connected to the same output to insure good regulation and high efficiency. This auxiliary supply is rectified and filtered by D11 and C15 respectively.

During constant voltage operation, output voltage regulation is achieved by sensing the output voltage via a resistor network comprising R29 and R30. The voltage across R30 is monitored at the FEEDBACK pin and compared to an internal reference voltage threshold of 1.265 V. Bypass capacitor C19 is placed across the FEEDBACK and SECONDARY GROUND pins to attenuate high frequency noise that would otherwise couple to the feedback signal and cause unwanted behavior such as pulse bunching.

During constant current operation, the maximum output current is set by the sense resistors R43 and R24. The voltage across the sense resistor is applied to the ISENSE pin internal reference threshold of 35 mV to maintain constant current regulation. Diode D13 in parallel with the current sense resistors clamps the voltage across the ISENSE and SECONDARY GROUND pin. This shunts the high current surge from the output capacitor seen during an output short-circuit and prevents damage.

The GaN-based LYTSwitch-6 LED-driver ICs are available now, priced at $3.14 in 10,000 quantities.

**https://www.power.com/lytswitch-6/**

SEMIKRON
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# IGBT Generation 7

## The New Benchmark for Motor Drives

SEMIKRON offers Generation 7 IGBTs from two different suppliers, designed specifically for the needs of motor drive applications.

**Benefits**

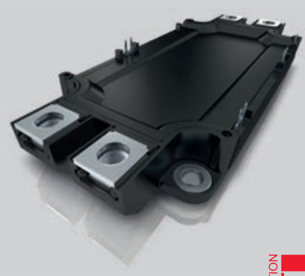
- Higher power density
- Lower overall system costs
- More efficient motor drives

MiniSKiiP and SEMiX 3 Press-Fit will be the first modules to feature Generation 7 IGBT technology, with SEMiX 6 Press-Fit and SEMITOP E1/E2 to follow.

**Features**

- Lower on-state voltage $V_{ce,sat}$
- Higher overload capability up to 175°C
- Switching losses and dv/dt optimized for motor drives
- Higher nominal currents in the same housing (e.g. 50A CIB in size 2 MiniSKiiP housing)
- Up to 45% higher output power in the same power module

MiniSKiiP



SEMiX 3 Press-Fit

GENERATION IGBT 7

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# Power Semiconductors Reduce CAV Emissions

Commercial, Construction and Agricultural Vehicles (CAV) have been the focus for new technologies that improve safety, reduce carbon- and particularly matter emissions, as well as improving operating and fuel efficiency. Electrification is the obvious way forward and the technologies required span all electrical and electronic disciplines, from motors and their drives, through power to computing, to sensing and communications. With power, sensing, communications and a range of controller products, Infineon serves as a single point for sourcing solutions for this most challenging world of e-CAV.

According to the European Commission CAVs alone account for 25 % of EU's $CO_2$ emissions and 5 % of the total greenhouse gas output. They also consume far more diesel than a car per kilometer and are typically operational for longer each day. Regulatory pressure is also present around the world. A recent EU ruling states that emissions from new trucks must be, compared to 2019, 15 % lower by 2025 and 30 % lower by 2030.

## Electric drives in the CAV market

The efficiency and endurance of the electric drivetrain for e-CAVs is key if zero-emission vehicles are to establish themselves as reliable alternatives to today's fossil-fuel transport. As an example, city e-busses in Korea achieve a range of 290 km and can reach a top speed of 93 km/h using 256 kWh Li-ion batteries. Their powertrain utilizes two 120 kW electric motors driven by a pair of inverters using IGBT technology for the lowest cost. In the application the IGBT switching devices are subject to extreme thermal cycling, transient voltage spikes from load-dumps and mechanical stress due to vibration. To withstand these stress levels, three Infineon FF1000R17IE4P PrimePACKTM 3 devices were used for each inverter, rated at 1700 V and 1000 A featuring IGBT4.

The German StreetScooter application also makes use of TRENCHSTOP IGBTs for the traction inverters together with AURIX automotive-grade microcontrollers and gate drivers from the EiceDRIVER family. The EasyPACK IGBT module rated at 650 V/100 A, is also featured in the vehicle's DC/DC converter.

Electric busses are designed for heavy use of up to 16 hours/day, 300 days/year with more than 60 start/stop cycles per hour anticipated. Here, the PrimePACK with IGBT5/.XT interconnection technology can demonstrate all its advantages. Employing copper rather than aluminum bond wires, sintering for the die attach and a high-reliability solder system for the substrate to baseplate connection, reliability is increased. The higher power cycling performance of the .XT compared to standard technology increases the number of cycles-to-failure by a factor of 10, avoiding over-dimensioning and delivering an improved TCO. Compared to IGBT4 technology, the IGBT5 devices demonstrate a 25 % improvement in power density along with reduced losses.

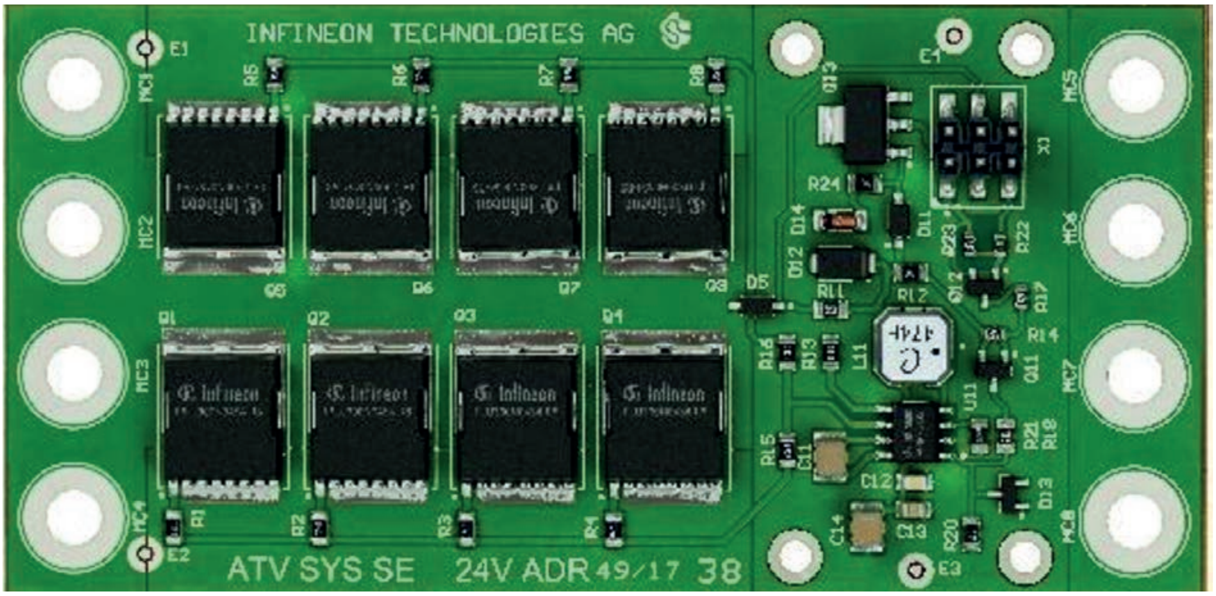
The most prominent IGBTs that have found a home in these applications are the cost-efficient EconoDUAL3 half-bridges rated at up to 900 A and 1700 V. The majority of electric buses is equipped with this module family. The HybridPACK drive module can also be used in EV applications. For example, the 820 A/720 V device FS820R08A6P2B is specifically targeted to achieve low partial-load losses for extended driving range in typical conditions. It is a six-pack module, optimized for 150 kW inverters operated at up to 10 kHz. Further devices to extend the portfolio are currently in development.

Silicon Carbide (SiC) devices are an up-coming technology for power switches that can also be considered for e-CAV applications. Providing similar headline specifications to IGBTs, the devices can switch at much higher frequencies. Exceeding a switching frequency of 50 kHz enables the use of smaller passive components and filters. Even when switched at lower frequencies, SiC devices can reduce the sum of losses by up to 80% compared to IGBTs. The Infineon 1200 V CoolSiC range is such an example with both, modules and leaded parts available.

## Auxiliary power conversion

Auxiliary power converters are necessary for a range of applications such as water or hydraulic pumps or HVAC compressors. Drives might also feature in steering control for semi- or fully autonomous driving. In these applications, the space, weight and efficiency gains through using SiC can be very attractive. Cabin heating and cooling are good examples of functions that run continuously where high-power conversion efficiency translates directly to lower battery drain and longer driving range. High-efficiency IGBTs can be used such as the Infineon IKP, IKW and IKB ranges in leaded TO-247 packages. Use of a CoolSiC device in a lower loss $D^2$PACK package enables surface-mounting and assembly cost

**Electric busses benefit from the most robust IGBT5.XT technology**




**Battery circuit breaker demo-board 24 V, 300 A continuous current**

savings. In motor drives, the higher efficiency of CoolSiC – based devices results in smaller heatsinks, if any are required at all, while the higher switching frequency means, that smaller EMI filters and decoupling capacitors can be used.

Electrified CAVs also feature on-board AC/DC battery chargers and DC-DC converters for auxiliary power rails for lighting, infotainment, and other legacy functions. For chargers and converters, the gains from using CoolSiC for power switches and diodes are even greater than in motor drives. This is thanks to the dramatically smaller isolation transformers and inductive storage elements required at high switching frequencies. This contributes to an overall decrease in system cost compared to IGBT-based solutions.

IGBTs and CoolSiC devices need supporting drivers and potentially feedback or sensing circuitry to operate. The EiceDRIVERT family includes a range of automotive-grade IGBT gate drivers available as single- and dual-channel types with galvanic isolation and bi-directional signal transmission.

## Battery and power management

With the long service life expected of e-CAV applications, maintaining the health of the battery is critical to TCO. Battery management systems monitor temperature and discharge over time to provide the e-CAV an accurate prediction of remaining charge and indirectly range. As batteries are charged cyclically, the individual cells of the battery pack age differently to one another and must be periodically balanced back to a common state of charge. Battery management systems cover all these functions with dedicated battery monitoring ICs such as the TLE9012/9015. This device can monitor up to 12 series-connected cells, measuring the cell's voltage with 12-bit ADC resolution. It can also handle a balancing current of up to 1.5 A. Cell temperature is monitored and security is assured by two independent internal voltage references, end-to-end CRC-secured communication at 2 Mbps, internal diagnostics and an emergency communication mode.

A particular difference in e-CAV requirements compared to private electric vehicles is the need for a battery disconnect function, used in cases of emergency or when loading or unloading hazardous goods. This takes the form of an emergency stop switch which can be operated from the cab or from outside the vehicle. Semi- or fully-autonomous vehicles will have a redundant, typically 24 V, battery supply that can be switched in or out at currents which might peak at over a thousand amps.

The traditional solution has been a mechanical relay but this can be replaced by a bi-stable smart circuit breaker using MOSFETs as the switching element. A circuit breaker demonstrator developed by Infineon and Schweizer Electronic AG using eight IPLU300N04S4-R8 OptiMOS devices in parallel has shown an end-to-end resistance of just 110 μΩ at 25°C and 160 μΩ at 120°C. The continuous current rating is 300 A, and over-current can reach 500 A for ten minutes with 50 $cm^3$/min airflow.

The AUIR3242S MOSFET gate driver is used in the demonstrator to drive the 8 MOSFETs in parallel. The driver operates down to voltages as low as 3 V, has an idle current of only 50 μA, and includes diagnostic and protection features like gate current monitoring. The MOSFETs use the Infineon leadless TOLL package, which, compared to $D^2$PACK types, occupies 30 % less board space, is half as high and provides a 50 % larger soldering area for lower thermal resistance, leading to higher reliability. The packages are AEC-Q101 qualified, lead-free and suitable for 40 V and 80 V MOSFETs.

## Battery charging

e-CAVs will make use of differing charging solutions. Busses, construction, agricultural and service vehicles are likely to utilize larger batteries, returning daily to a main harbor where AC-, wireless or fast DC-charging is available. Trucks may charge prior to and at the end of each journey. Time may be limited, so fast DC-charging would be preferred. Smaller commercial vehicles for local deliveries will have multiple opportunities to fast-charge throughout the day and therefore could have smaller, lighter batteries.

For AC-DC on-board chargers, designers can consider utilizing CoolMOS, IGBTs, or CoolSiC with EiceDRIVER devices for the power stages. Automotive-grade AURIX microcontrollers and OPTIGA security chips provide functional control, meeting the safety integrity levels needed, along with secure authentication and billing. Infineon OPTIREG parts will also find applications in chargers with the range including power management ICs (PMIC), switching and linear regulators, all of which are automotive-grade and ISO 26262 compliant.

## Safe power for safe systems

Electronics such as controllers are only as safe as their power supply, so the TLF35584 multiple output system power supply chip, is part of the PRO-SIL range. This ISO 26262 compliant device enables system design up to ASIL-D with multiple user-protected safety features such as rail monitoring, failure detection with a flexible watchdog concept, as well as a safe state controller that provides secondary safety paths. Built-in test is included to ensure that all features are operating correctly. The device has a maximum input of 40 V so a pre-regulator is needed when powered from a 24 V truck supply which, according to standard LV124, can peak at 60 V. This can be a simple linear active regulator but then efficiency suffers. A better solution is the low-cost, automotive-qualified TLE6389xx active DC/DC pre-regulator which allows flexibility and efficiency with a fixed or adjustable output. The device has under-voltage monitoring on input and output and very low quiescent and shutdown current.

## Literature

The changing face of CAV – how electrification is changing the commercial vehicles business, Infineon White Paper 07-2019

**www.infineon.com**

# Die Attach Adhesives Impact Product Quality

Die attach adhesives serve a critical role in (power) semiconductor assembly and throughout the product lifecycle. Beyond their ability to form a tight bond between die and various substrates, these adhesives help minimize the impact of mechanical and thermal stress, enhancing long-term

product reliability. Among available die attach materials, epoxy adhesives in particular offer a broad range of characteristics designed to meet the unique requirements of even pecialized applications.

The continued trend toward greater functionality packed into smaller die translates into correspondingly greater challenges for efficient assembly and continued lifecycle reliability. During manufacturing, these tiny die must be reliably assembled into IC packages, die-on-board systems, or complex stacked die-on-die assemblies. In the field, these packages, systems and assemblies must remain resistant to mechanical and thermal conditions that can degrade performance and, ultimately, lead to product failure.

Support broadly diverse requirements

Adhesives have emerged as the preferred solution for meeting these demands with their ability to support broadly diverse requirements for assembly, manufacturing, and product lifecycle. Along with their ability to tightly bind die to different materials, adhesives are able to meet complex combinations of requirements for electrical and thermal conductivity as well as a host of other physical characteristics including viscosity, thermal stability, and more.

Among the diverse types of adhesives, epoxies are particularly effective in enhancing product reliability with their ability to provide high strength bonds while reducing effects of thermal cycling and mechanical stress. These polymeric materials react with one part heat curing epoxies or with two part heat curing epoxies during the curing process, forming a bond that is mechanically robust and thermally stable. Epoxies are among the strongest and most durable adhesives, offering mechanical strength, superior dimensional stability and excellent adhesion to similar and dissimilar substrates. Manufacturers can find highly specialized epoxy adhesives designed to address the unique demands of individual applications for thermal and electrical conductivity, temperature range, outgassing, and many additional requirements.

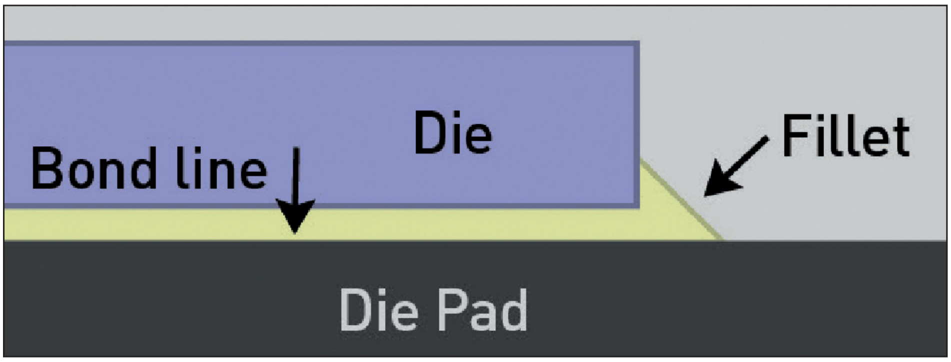
## Facilitating assembly

Die attach adhesives serve an integral role in semiconductor assembly and manufacturing. After semiconductor wafer fabrication, individual die are separated from the wafer by a precision dicing saw or laser. High-speed die bonders are used to lift each die and place it on a layer of die attach material spread onto the substrate itself by specialized material dispensers. These dispensers precisely control the volume of material placed on the substrate, typically using vision control systems to ensure proper placement. As the die bonder places the die on the adhesive, it adds a slight and carefully controlled amount of pressure to mate the die to the adhesive-treated substrate.

In this process, the application of the adhesive is critical. Too much adhesive, and the resulting fillet can flow up the sides of the die and contaminate the circuits etched on the die. Too little and the die could lift from the substrate or even crack. Depending on the nature of the process and the characteristics of the adhesive, the substrate might be heated during this placement process to partial cure the die attach material. In the final step, the die/substrate assemblies will typically be subjected to a final curing process using heat or UV treatment. For heat-sensitive circuits, UV-cured epoxies offer rapid volatile-free curing that reduces the chance of substrate warping or shrinkage.

The UV curing systems require access to UV light without shadows for curing.

Successful assembly depends critically on the nature of the die attach adhesive itself. The adhesive must be able to form a tight, uniform bond between die and substrate. Still, an adhesive's cohesive strength is only one of many necessary characteristics. For example, an adhesive must exhibit appropriate viscosity (resistance to flow) and thixotropic index (ability to hold its shape) to ensure proper formation of bonds. Adhesives must be able to flow smoothly over irregularities in die and substrate surfaces. Despite the precision of the semiconductor fabrication process, die can nonetheless exhibit micrometer-size peaks and valleys. Incomplete filling of valleys or flow around peaks can lead to voids that weaken the bond, even resulting in delamination and eventual separation of the die from the substrate.




**Die attach adhesives are designed to provide tight bonds of uniform thickness with minimal extruded fillet**

## Enhancing product lifecycle

The adhesive's ability to provide a uniform but very thin bond becomes important throughout the product lifecycle. Minimum thickness means fewer chances of air voids that can lead to eventual bond failure. Minimum thickness is also important in ensuring maximum heat transfer from the die.

Along with its responsibility for tightly bonding the die to the substrate, die attach material typically serves as a primary path for die heat dissipation. The efficiency of that heat-transfer path depends on the thickness of the die attach layer, the thermal conductivity of the die attach material, and the thermal resistance between the die attach material and the two surfaces it bonds. By providing an efficient path for heat dissipation, the die attach adhesive plays a central role in thermal management – and ultimately in long-term product reliability.

Indeed, the thermal characteristics of the die attach material directly impact long-term reliability. In fact, manufacturers can find die attach adhesives with CTE characteristics designed to accommodate specific types of substrates.

## Meeting unique requirements

Every die attach application faces common requirements for bond strength, heat dissipation and CTE matching – and epoxy die attach adhesives are well-suited for meeting these requirements. Beyond their fundamental characteristics for strength and thermal performance, however, these adhesives offer unique advantages for meeting the more specialized requirements found in every application.

Different epoxy die attach adhesives can provide electrically insulated bonds or electrically conductive bonds such as those required for exposed pad devices, for example. For applications targeted for outer space, high vacuum or optical applications, manufacturers can find epoxies with low outgassing characteristics. Most applications must deal with more mundane environmental factors such as high temperature and humidity, which can erode semiconductor reliability. Specialized epoxies designed for very humid environments resist absorption of moisture that can lead to fractures in the bond or weakening at the bonded interfaces and eventual delamination and failure.

Temperature stability is important for any die attach application but particularly so for devices targeted for high temperature applications. Adhesives are available across a very wide temperature, supporting requirements ranging from cyrogenic applications to those operating at hundreds of degrees. Of course, manufacturers face a very wide range of requirements beyond thermal stability both during assembly and throughout the IC's lifecycle.

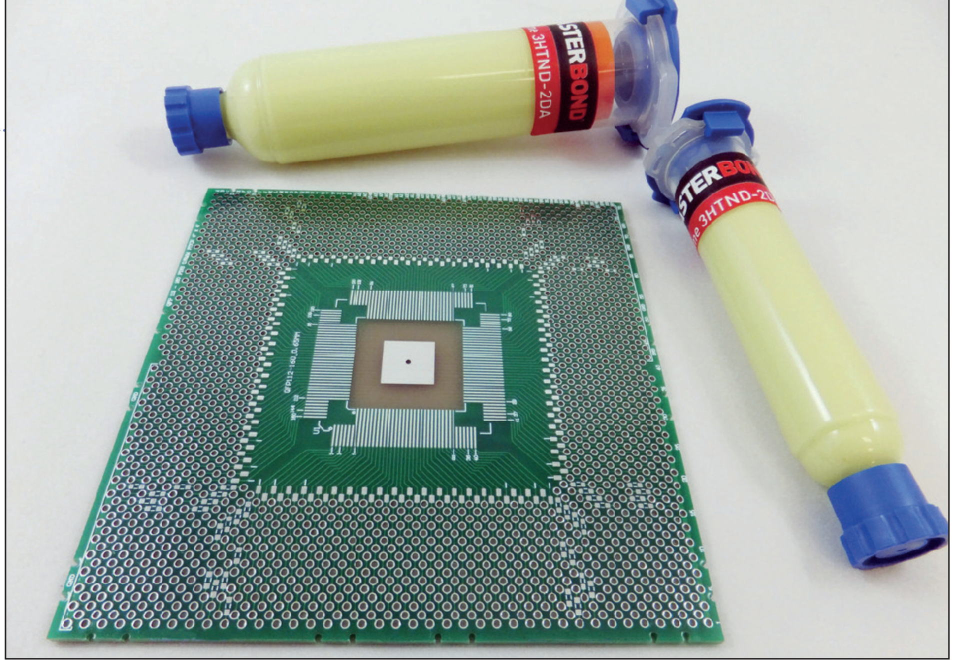
During assembly, the ability to minimize curing temperature can be vital for achieving acceptable manufacturing yield. Similarly, the ability to meet very specific requirements for bond strength, thermal conductivity, and avoiding CTE mismatches can spell the difference between early failure and extended lifetime of semiconductor products.

Indeed, each application brings a unique combination of requirements, requiring an equally diverse complement of available die attach materials that are well-matched to those specific requirements.

**Diverse solutions**

Manufacturers can find die attach epoxies designed to meet a very wide range of specialized requirements for assembly and lifecycle performance. Die attach epoxy systems such as Master Bond's offer characteristics suited to a wide range of lifecycle requirements for strength, thermal and electrical conductivity, thermal stability, and more. Specialized epoxies can meet demands as varied as low outgassing performance for space applications to biocompatibility for medical applications as well as continued reliability in applications exposed to mechanical vibration, impact, and shock.

To meet different assembly requirements, epoxies are available with a wide range of delivery options. Today's two part epoxies go beyond traditional epoxy systems with a range of resin and hardener combinations designed for specific handling times as well as different curing times and temperatures. One part systems such as Master Bond Supreme 3HTND-2DA further simplify the assembly process. Delivered as a non-premixed and frozen system, these one part systems help eliminate potential problems such as air entrapment during preparation or concerns about limited potting time. Formulated specifically for die attach applications, 3HTND-2DA is delivered in syringes to simplify handling and cures in only 5-10 minutes at 150°C.




**One-step epoxy systems such as Master Bond Supreme 3HTND-2DA die attach adhesive are delivered pre-mixed in**

Along with their inherent strength and durability, epoxies offer an additional advantage. Epoxies can be combined with specialized filler materials to meet specific requirements. For example, epoxy vendors can add glass microbeads to enhance uniformity of bond thickness; silver fillers to dramatically enhance electrical conductivity; special thermally conductive fillers to enhance thermal conductivity; and other filler materials to optimize individual characteristics such as CTE.

**www.masterbond.com**

# Simple Isolated Power Semiconductor Driver

Analog Devices launched a simple power solution that maximizes efficiency and minimizes electromagnetic (EM) emissions of motion systems as customers migrate to higher density automation. The ADuM4122 is an isolated, dual-drive strength output driver that empowers designers to harness the benefits of higher efficiency power switch technologies.

Electric motor-driven systems account for 40 % of global electricity consumption, according to the International Energy Agency, and improvements in motor efficiency can have wide-reaching economic and environmental benefits. With the increased adoption of industrial automation and IoT within smart factories, there is a growing demand for intelligent technology and features within systems to ensure maximum efficiency. The ADuM4122 is a simple solution that accomplishes this by controlling how fast or slow a MOSFET or IGBT turns on or off by user command, on the fly, thereby controlling motor currents.

The ADuM4122 uses iCoupler® technology to provide precision isolation up to 5 kV rms in the wide-body, 8-lead SOIC package. These isolation components combine high speed complementary CMOS and monolithic transformer technology to provide performance characteristics superior to alternatives (such as a combination of pulse transformers and gate drivers). The device provides reliable control over the switching characteristics of IGBT and MOSFET configurations over a wide range of switching voltages, allowing for simple slew rate control. The ADuM4122 operates with an input supply voltage range from 3.3 V to 6.5 V, providing compatibility with lower voltage systems.

**Control scheme**

Gate drivers are required in situations where fast rise times of switching device gates are desired. The gate signals for enhancement type power devices are referenced to a source or emitter node. The gate driver must be able to follow this source or emitter node. Thus isolation is necessary between the controlling signal and the output of the gate driver in topologies where the source or emitter nodes swing, such as a half bridge.

Gate switching times are a function of the drive strength of the gate driver. Buffer stages before a CMOS output reduce total delay time and increase the final drive strength of the driver. The ADuM4122 achieves isolation between the control side and the output side of the gate driver by using a high frequency carrier that transmits data across the isolation barrier with iCoupler chip scale transformer coils separated by layers of polyimide isolation. Positive logic on/off keying (OOK) encoding is used, in which a high signal is transmitted by the presence of the carrier frequency across the iCoupler chip scale transformer coils. Positive logic encoding ensures that a low signal is seen on the output when the input side of the gate driver is unpowered. A low state is the most common safe state in enhancement mode power devices and can drive in situations where shoot-through conditions are present.

The ADuM4122 includes two output pins (see typical application schematic) that facilitate slew rate control of two output drive strengths. The VOUT pin follows the logic of the VIN+ pin, while the boosting output, VOUT_SRC, can be toggled to follow the VIN+ pin or to go high-Z. The toggling of the slew rate is controlled by the primary side. Slew rate control can allow for EMI mitigation and voltage overshoot control. An internal thermal shutdown sets outputs low if internal temperatures exceed the thermal shutdown temperature.

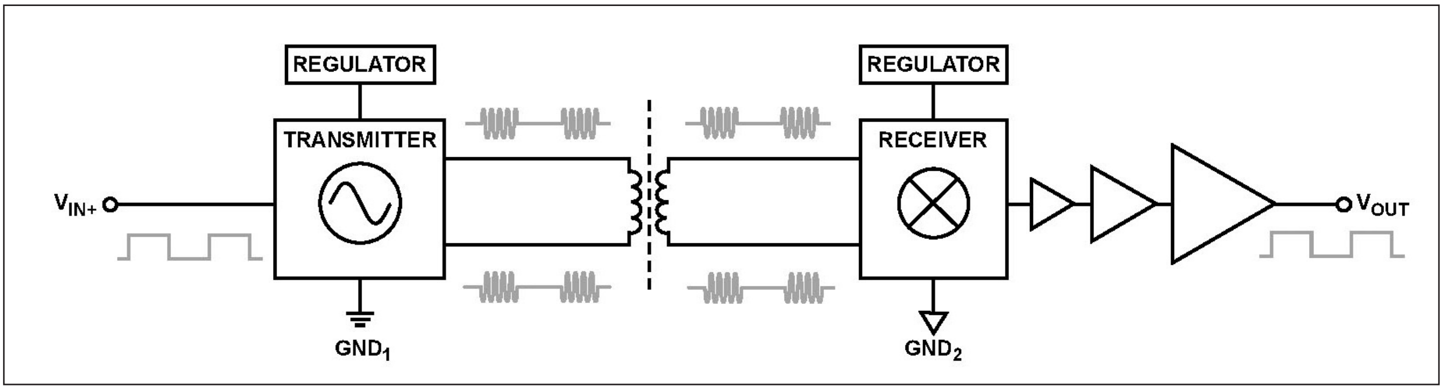
The architecture of the ADuM4122 is designed for high CMTI and high immunity to electrical noise and magnetic interference. Radiated emissions are minimized with a spread spectrum OOK carrier and differential coil layout.

When driving a MOSFET or IGBT gate, the driver must dissipate power. This power is not insignificant and can lead to TSD if considerations are not made. The gate of an IGBT can be approximately simulated as a capacitive load. Due to Miller capacitance and other nonlinearities, it is common practice to take the stated input capacitance of a given MOSFET or IGBT ($C_{ISS}$) and multiply that by a factor of 3 to 5 to arrive at a conservative estimate of the approximate load being driven.

**Insulation lifetime**

Insulation structures eventually break down when subjected to voltage stress over a sufficiently long period. The rate of insulation degradation is dependent on the characteristics


**New isolated, dual-drive strength output driver well suited for industrial applications**




Operational block diagram of OOK encoding

of thevoltage waveform applied across the insulation. In addition to the testing performed by regulatory agencies, Analog Devices carries out an extensive set of evaluations to determine the lifetime of the insulation structure within the ADuM4122.

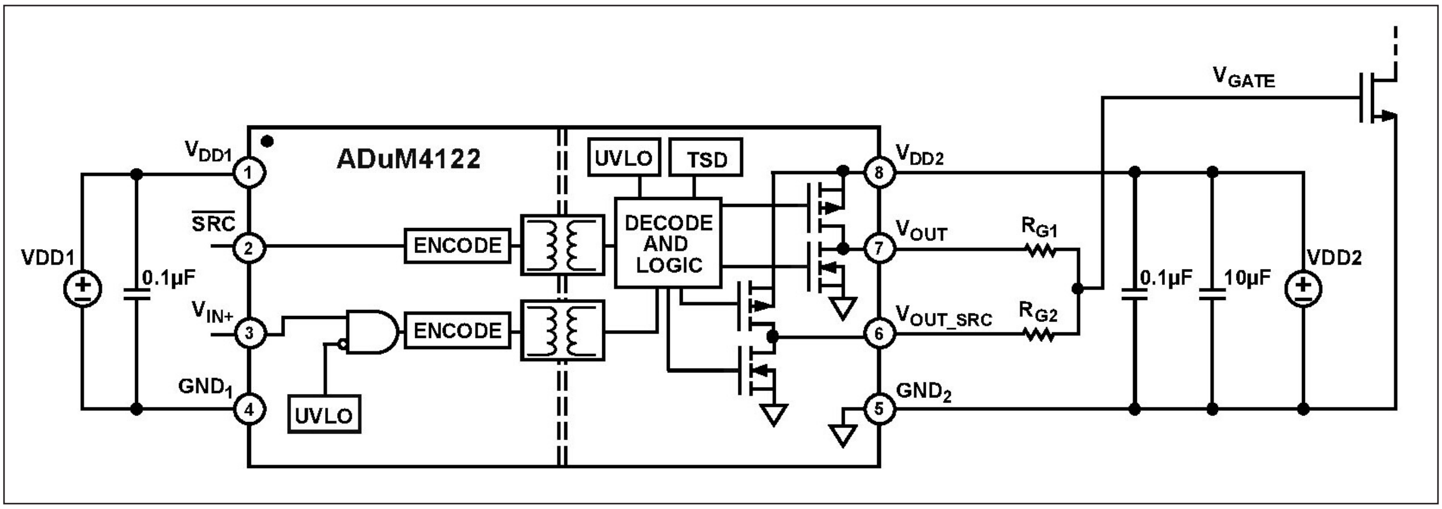
Analog Devices performs accelerated life testing using voltage levels higher than the rated continuous working voltage. Acceleration factors for several operating conditions are determined. These factors allow calculation of the time to failure at the actual working voltage. In many cases, the approved working voltage is higher than the 20-year service life voltage. Operation at high working voltages can lead to shortened insulation life in some cases. The iCoupler insulation structure degrades at different rates depending on whether the waveform is bipolar AC, unipolar AC, or DC.

A bipolar AC voltage environment is the worst condition for iCoupler products and is the 20-year operating lifetime that Analog Devices recommends for maximum working voltage. In the case of unipolar AC or DC voltage, the stress on the insulation is significantly lower. Unipolar AC or DC voltage operation allows operation at higher working voltages while still achieving a 20-year service life.

**Typical application**

In a typical application of the ADuM4122 regular drive strength is dictated by the external series gate resistor $R_{G1}$. When the SRC pin is held low, there is a second charge and discharge path available through the external series gate resistor $R_{G2}$, providing higher drive strength to the gate of the power device. When the SRC pin is held high, the VOUT_SRC output goes into a high impedance mode so that the only charge and discharge path is through $R_{G1}$.

**www.analog.com/ADuM4122**




Typical application schematic3ADI519Industry.JPG

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# Thermal Management Help Hardworking Chips

Elevated temperatures being the enemy of component reliability, thermal management demands careful attention to ensure the end product will achieve the required design lifetime. Effective thermal management begins at the semiconductor level, with careful component selection, focused on efficiency to minimize power dissipation, and judicious use of power-down modes. Hardworking components can be expected to require a heatsink. **Mark Patrick, Technical Marketing Manager EMEA, Mouser Electronics, UK**

Today's electronics designers face unrelenting pressure to increase system power density, or to add new and more impressive functionality within smaller product dimensions. Either way the result is that components may be working harder, or crammed within a smaller space, or both – placing upward pressure on operating temperatures (Figure 1).

## Design for thermal management

Design for thermal management can, and should, begin at an early of the project. It is possible to minimize thermal challenges later by selecting components carefully at the beginning: in power applications this could include choosing the latest and most efficient MOSFETs or IGBTs. More generally, system-level power management, taking advantage of chip idle modes and opportunities to power-down unused components or subsystems minimizes the quantity of heat that must be dealt with through dedicated thermal management.

Ultimately, high-power or high-performance systems typically require heat to be removed from hardworking Silicon junctions into the ambient atmosphere using a mechanism such as a heat spreader, cold plate, or one or more heatsinks. Moreover, the full extent of any thermal-management challenges may not be known until later in the project, as the design becomes finalized. At some point, inevitably, engineers will find themselves needing to design-in a heatsink and optimize its performance to get the maximum heat out in relation to its size and cost.

## Removing the heat

Ultimately, high-power or high-performance systems typically require heat to be removed from hardworking Silicon junctions into the ambient atmosphere using a mechanism such as a heat spreader, cold plate, or one or more heatsinks. Moreover, the full extent of any thermal-management challenges may not be known until later in the project, as the design becomes finalized. At some point, inevitably, engineers will find themselves needing to design-in a heatsink and optimize its performance to get the maximum heat out in relation to its size and cost.

To ensure the heatsink is as effective as possible, it is first important to minimize the thermal impedance at the join between heatsink and package surface so that heat can transfer efficiently out of the package into the heatsink. The second important consideration is to maximize the heatsink surface area in relation to its volume for optimum dissipation, working within PCB-area and assembly-height restrictions.

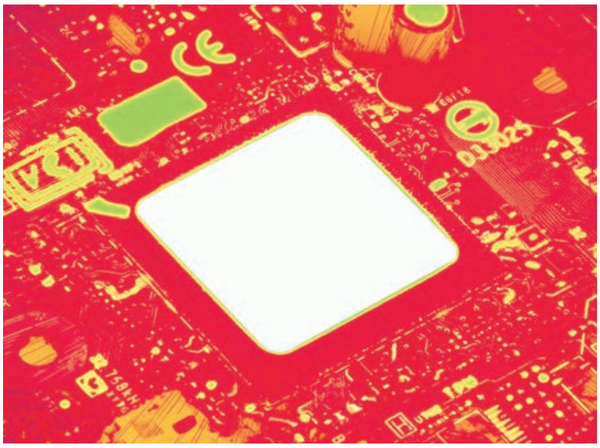


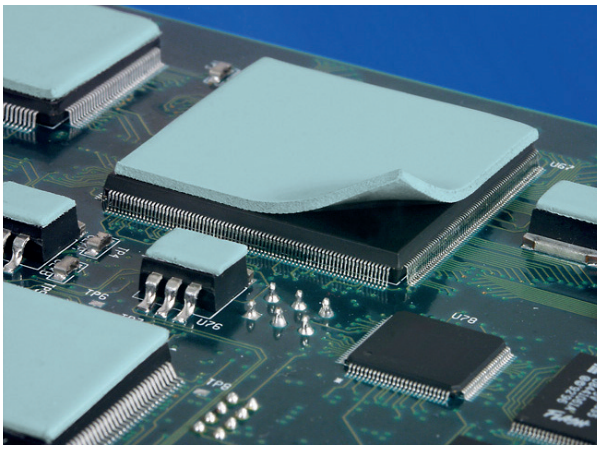
Figure 1: **Today's electronics face upward pressure on operating temperatures**

## Optimizing thermal interfaces

Where the heatsink is attached to the component, surface roughness and non-planarity displayed by both parts unavoidably trap pockets of air that prevent efficient transfer of heat into the heatsink. A thermal interface material (TIM) is applied at the join to eliminate the air. The TIM must have good flow and wetting characteristics to counter the effects of the surface roughness. To correct for non-planarity, the TIM must conform to both surfaces with low external stress to avoid placing excessive pressure on the component.

A wide variety of TIM types and formulas is available, including thermal greases, phase-change materials, liquid dispensed cure-in-place fillers, thermal adhesives, films, laminates, and pads. These present designers with many options to satisfy not only the thermal-performance requirements but also compatibility with automated assembly processes, physical performance such as response to long-term thermal cycling, and special requirements of the application – such as silicone-free materials that are often required to prevent fogging of optical products or automotive lighting. Other factors to consider are electrical isolation, tear resistance, and whether the chosen material is capable of being re-used or replaced/re-applied if the assembly is subjected to rework in the factory or repair in the field.

Among the variety of TIM types available, thermal gap-filler pads are a convenient solution that can be supplied as bulk sheets or in custom sizes to fit specific component packages. Pads can be placed by hand or using an automated mounter, and so can be integrated with inline surface-mount assembly if required. Inherent natural tack on one or both sides of the pad



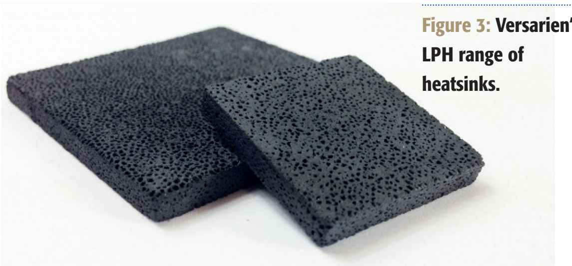


**Figure 3: Versarien's LPH range of heatsinks.**

**LEFT Figure 2: Gap Pad from Bergquist helps to significantly improve thermal performance**

enables placement without requiring an adhesive, which not only simplifies manufacturing but also saves a potentially thermally-impeding extra layer.

A wide range of formulas is available, offering numerous combinations of thermal conductivity, softness, wetting characteristics, and cost. Among them, Gap Pad® 5000S35 is a recent addition to Bergquist's S-class (Soft) highly conformable materials. Gap Pad® 5000S35 has the highest thermal conductivity within the S-class, at 5.0 W/m.K, with a low modulus of 121 kPa to minimize the stress placed on components when compressed as the heatsink is clipped or bolted in place.

For even more stress-conscious applications, Bergquist also has HC (High-Compliance) and ULM (Ultra-Low Modulus) Gap Pad families with thermal conductivity up to 5.0 W/m.K and 3.5 W/m.K respectively. There are also Value Performance as well as Extended Performance (VO, VO Soft, or VO Ultra-Soft) Gap Pad families, offering a broad spectrum of cost, conductivity, and conformability options.

On the other hand, specialty Gap Pad families give designers extra options including silicone-free (SF) product lines with thermal conductivity up to 3.0 W/m.K. While the S-class range have extremely low extraction values compared to other silicone-based materials, Gap Pad 1000SF, 2000SF, 2202SF, and 3004SF provide the ultimate protection for silicone-sensitive applications.

The thermal properties of gap fillers can also be combined with suppression of electromagnetic interference (EMI) to provide a convenient two-in-one solution; electrical noise issues being another commonly encountered source of last-minute headaches for product developers. Gap Pad EMI 1.0, also produced by Bergquist, is electrically isolating, absorbs interference such as cavity resonances and crosstalk at frequencies of 1GHz and higher, and is at the same time highly conformable with low hardness, good wetting properties, and thermal conductivity of 1.0 W/m.K.

## Designing with heatsinks

As far as the heatsink is concerned, a huge variety of sizes and shapes are available off the shelf from manufacturers such as Aavid, Cincon, Wakefield Vette and others. Manufacturers' standard product ranges typically include models that are designed specifically to fit common semiconductor packages, such as LGA, QFN, or BGA packages, popular power outlines including D2PAK or TO-220, or standard power modules such as quarter- or half-brick. Choices also include heatsinks optimized for standard System On Module (SOM) sizes such as SOM-4461, or designed for fitment to IGBT modules of various sizes.

The thermal resistance, quoted on the datasheet in K/W, helps designers calculate the operating junction temperature of the chip, assuming the power dissipated and the ambient temperature are known, and the thermal resistances of the package and TIM are also taken into account. If the calculation indicates the junction temperature will be above the desired target to ensure the required reliability, a heatsink with lower thermal resistance may be needed.

Alternatively, forced air cooling using a fan may be applied to increase thermal performance. Although improvements to fan materials and construction, and new electronic drivers, have extended the typical lifetime of cooling fans, they still have appreciably shorter lifetime than the silicon-based components they are cooling. There are other drawbacks, too, such as increased bill of materials and engineering costs, and the fact that sealing the enclosure is not possible. If a filter is provided, to prevent the fan drawing dust into the equipment, this must be regularly cleaned to maintain cooling effectiveness. Hence, if possible, passive cooling without a fan is usually preferred.

The typical approach to reduce the IC's junction temperature without resorting to a fan is to specify a larger heatsink. This, too, may be undesirable, or even unworkable if the space inside the enclosure is not accommodating. A custom heatsink may be designed to provide a larger cooling-surface area within the prevailing space constraints, but can be an expensive solution that may delay the project.

## Advanced heatsink Materials

There is an alternative: an innovative new copper-based foam material, VersarienCu™, created using a process developed at the University of Liverpool. Its structure, featuring fine, open, interconnected pores, is highly suited to thermal transfer applications. Heatsinks made from VersarienCu outperform comparably-sized heatsinks by up to 6 K/W. Versarien Technologies heatsinks are also coated with a thin, hard layer of high-temperature copper oxide, which increases emissivity thereby increasing the heatsink's radiant properties.

The large surface area of the interconnected pores, combined with the high thermal conductivity of copper, gives designers freedom to specify a smaller or lower-profile heatsink, or to gain the advantage of improved thermal performance in the same physical envelope.

There are 10 standard products in the current Versarien LPH range of low-profile heatsinks, covering sizes from 10 mm x 10 mm x 2 mm up to 40 mm x 40 mm x 5 mm. The largest size has a thermal resistance of 17.4 K/W at an applied load of 5 W.

## Conclusion

Effective thermal management begins at the Silicon level, with careful component selection, focused on efficiency to minimize power dissipation, and judicious use of power-down modes. Hardworking components can be expected to require a heatsink, and a wide variety of thermal interface materials and off-the-shelf metal heatsinks are available to help extract heat as effectively as possible. Designers targeting an extremely small outline or low profile, or facing difficult thermal problems late in the project, can now turn to new and advanced VersarienCu heatsinks to overcome their challenges.

# Integrated Battery-Charging Solution with Power Path Management

A new single-cell power management IC with flexible configuration, rich functions, and high efficiency integrates as many analog circuits as possible, and operates with a simple, economical single-chip microcontroller to provide a compact solution for mobile power products. Compared to a traditional solution, it can save one switching charger, one inductor, and one USB interface IC. **Min Xu, Staff Application Engineer, Monolithic Power Systems, USA**

**To achieve compact design for** battery-powered devices, the battery is usually not removable and the capacity is limited by the space reserved for the battery. As a result, the operation time of the device is a major concern as devices are built with more and more power-consuming functions. To improve the portability of battery-powered devices, another auxiliary charging device with greater battery capacity is often used, such as power banks.

Power banks have been popular as an auxiliary charging device for many years because of the conflict between the increased demand for portable device performance and the limits on battery size and capacity. However, for a power bank to be considered to have good performance, compact design (for lower weight) and higher efficiency (for longer operation time) have become more necessary. There is a similar pattern with charging cases for other devices.

The conventional solution is to use a separate charging device – either a linear charger IC or switching charger IC – and a boost converter with a blocking FET to serve as power input and output, respectively (see Figure 1). However, this is not an ideal solution for meeting consumer or manufacturer demands.

## New innovation

The MP2696A is a single-cell power management IC with flexible configuration, rich functions, and high efficiency. The IC integrates as many analog circuits as possible, and operates with a simple, economical single-chip MCU to provide an incredibly compact solution for mobile power products (see Figure 2).

Compared to a traditional solution, it can save one switching charger, one inductor, and one USB interface IC. The MP2696A offers a number of features that improve efficiency and performance:

- Bidirectional operation mode to support charge and discharge using single inductor
- Integrated pass-through path with protection and independent control
- Programmable JEITA battery temperature protection thresholds
- Integrated FETs with low conduction resistance
- Integrated programmable input current limit and input voltage limit
- Automatically enters sleep mode when no load is connected
- Automatically INT output when a smartphone is connected
- Integrated enumeration interface to output maximum power for smartphone

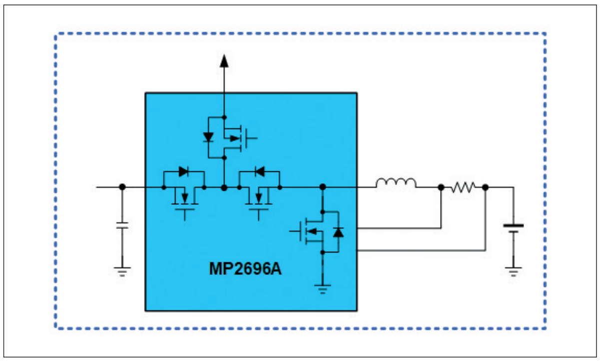



**Figure 2: High integration with bidirectional operation mode**

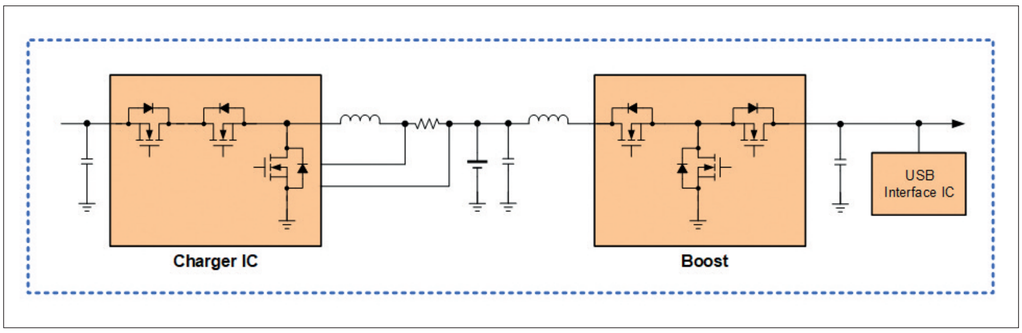



**Figure 1: Conventional IC charger and boost converter**

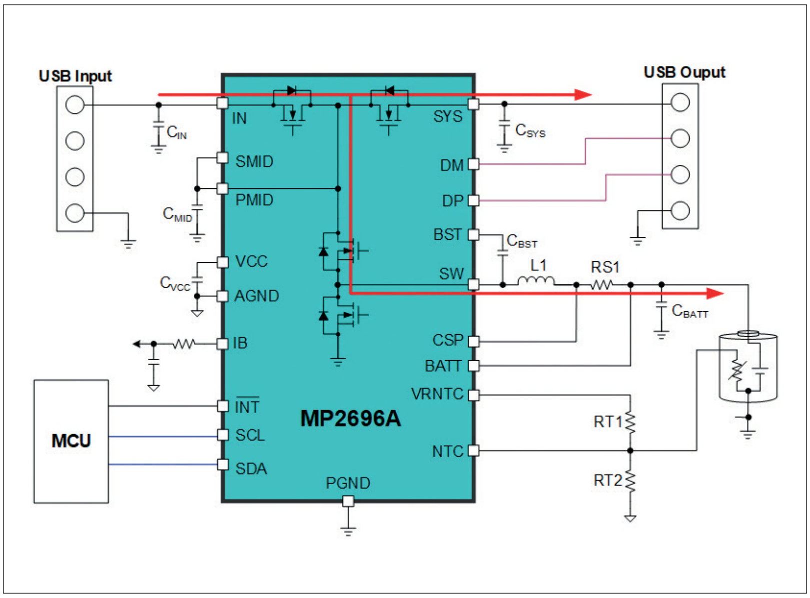



Figure 3: **Power flow in charging mode**

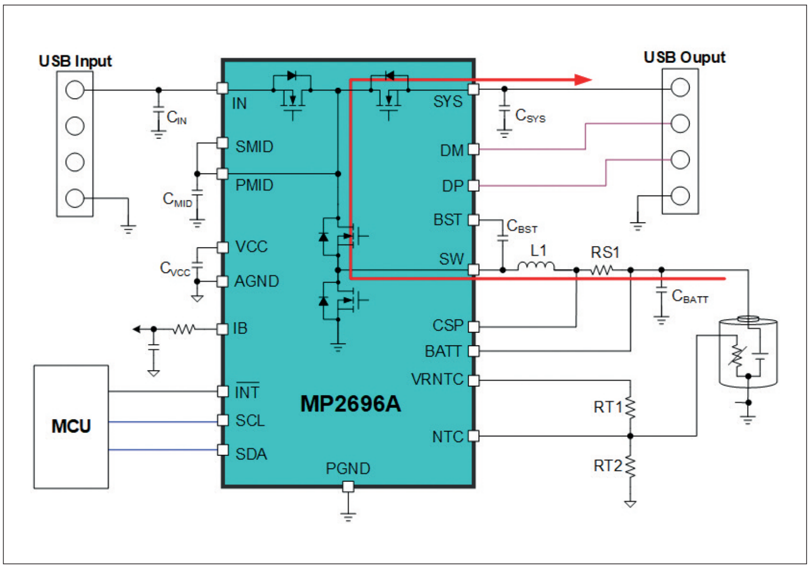



Figure 4: **Power Flow in discharge mode**

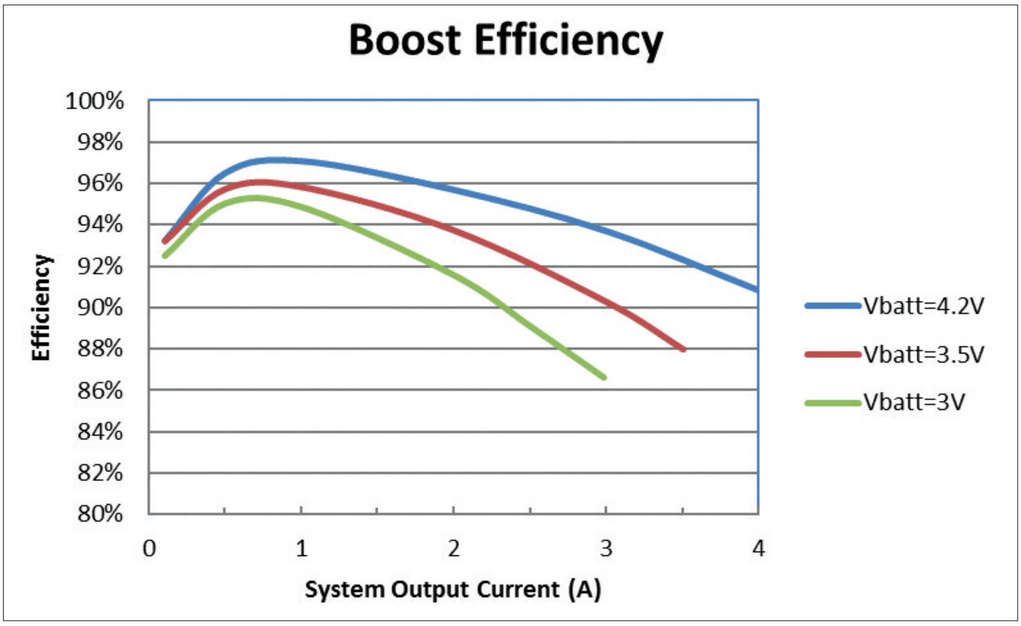
The MP2696A communicates with the MCU through the I²C interface. It is capable of bidirectional operation in charge mode or boost discharge mode, which makes it very suitable for power bank and charging case applications. The operation mode and parameters can be flexibly set by the MCU. The operation status and any fault event are also indicated through status and fault registers.

## Charging mode

The MP2696A is designed for a USB input, and can withstand up to 16 V input voltage. As the typical input voltage of the USB port is 5 V, the voltage rating of the device guarantees the robustness of the power bank even if a high surge voltage is generated at the cable plug.

The device has a programmable input current limit and input voltage limit. Up to 3 A input current limit allows to be compliant with 15 W Type-C port electrical characteristic requirements (see Figure 3). Together with the MCU, it limits the input current based on the input power supply, which ensures that it meets BC1.2 and USB Type-C specifications. Thanks to an additional input voltage limit, the MP2696A charges the battery with an optimized charge current, reducing the charge time regardless of what type of adaptor is applied.

The MP2696A can operate reversely in boost mode to provide 5 V output with up to 3.6 A at the SYS terminal (see Figure 4). It also has an output cable voltage drop compensation function, and an output current loop to regulate the output current when the load current exceeds the output current limit setting. When the load current increases, the IC slightly increases the output voltage to ensure that the output voltage after the cable is constant, and the




LEFT Figure 5: **Efficiency in discharge mode**

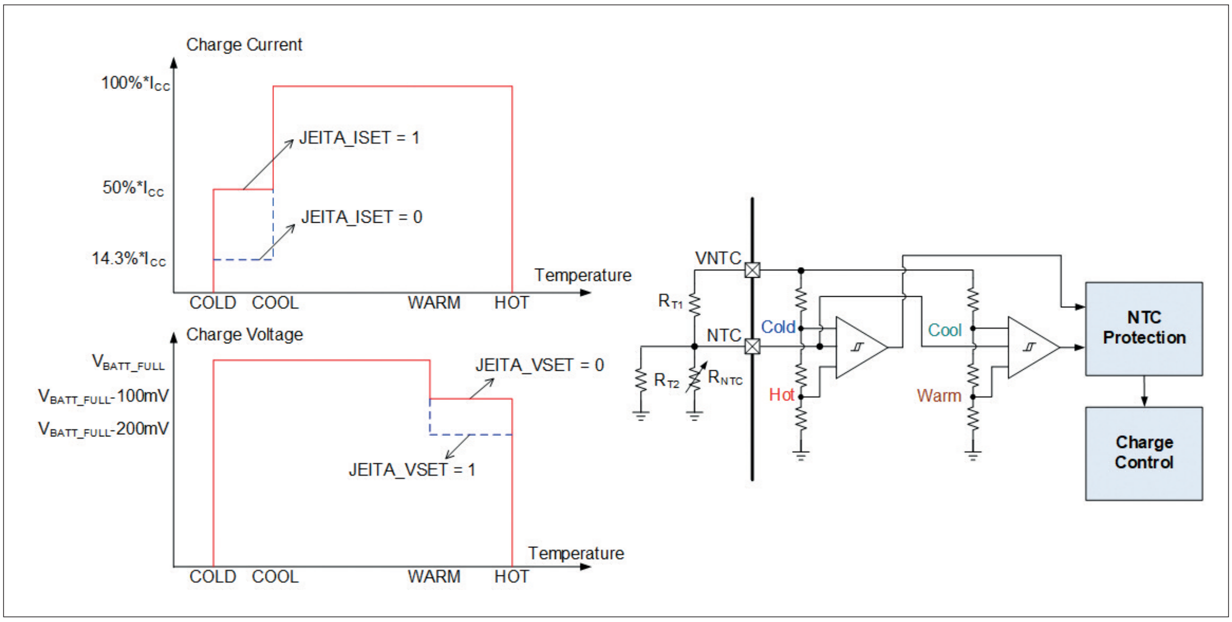



**Figure 6: Temperature protections**

compensation value can be programmed.

The extreme low on resistance of integrated FETs mean the MP2696A performs with outstanding efficiency, and makes it suitable for application in highly compact designs (Figure 5).

### Protections and smart detection

The MP2696A offers robust protections in all modes. In charge mode, it has input over-voltage protection, battery over-voltage protection, a charge safety timer, and a watchdog timer. In discharge mode, it has battery under-voltage lockout and output short-circuit protection. These hardware protections guarantee safe charging in the event that the MCU software fails.

Battery temperature monitoring and protection are becoming increasingly critical in battery-powered portable devices. The Japan Electronics and Information Technology Industrial Association (JEITA) standard to optimize charging in different battery temperature conditions is becoming a mandatory feature in battery charging applications. The MP2696A not only supports this JEITA standard, but also provides programmable protection temperature points and actions within warm and cool temperature ranges (see Figure 6).

The MP2696A monitors the voltage ratio between the NTC and VNTC pins for battery temperature information, since the thermistor values change with temperature. Then the IC compares the measured ratio to its internal ratio difference to determine what the temperature range is, and how to adjust charge voltage and current. Therefore, the customer can change the $I^2C$ register to adjust the temperature thresholds without having to change the resistor divider on the board. Configuring the I?C register this way allows software engineers to save a great deal of effort on MCU coding.

When the load current falls below the programmable threshold, the IC notifies the MCU that the load is removed so that the MCU can disable boost discharge and enter standby mode. The device also detects the load connections and reports to the MCU, at which point the MCU responds and wakes up the boost discharge. This eliminates the need for many external discrete components to detect the load connection. The IC also provides an analog output at the IB pin to provide real battery current information during charging or discharging, which helps the MCU estimate the battery's capacity more accurately.

### Conclusion

Together with simple MCU, the MP2696A provides a compact design solution for power bank or charging case applications. It integrates power FETs with low on resistance to support bidirectional operation, as well as a load connection detection circuit and a USB downstream enumeration interface. This allows for a very compact design and lower BOM cost. The device has a programmable JEITA temperature protection threshold to easily meet battery characteristic requirements from different vendors, outstanding efficiency performance, and lots of hardware protections. Best of all, the MP2696A is easy to use and saves design effort according to the provided reference design.

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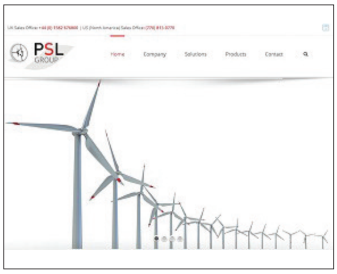

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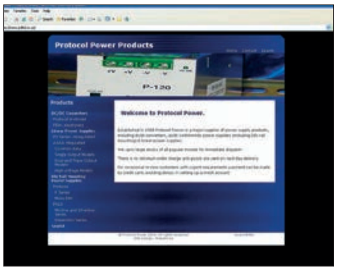

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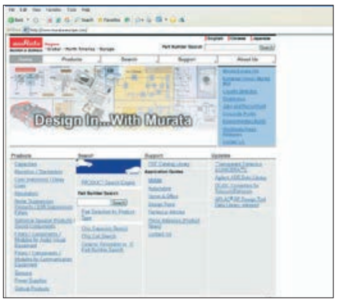

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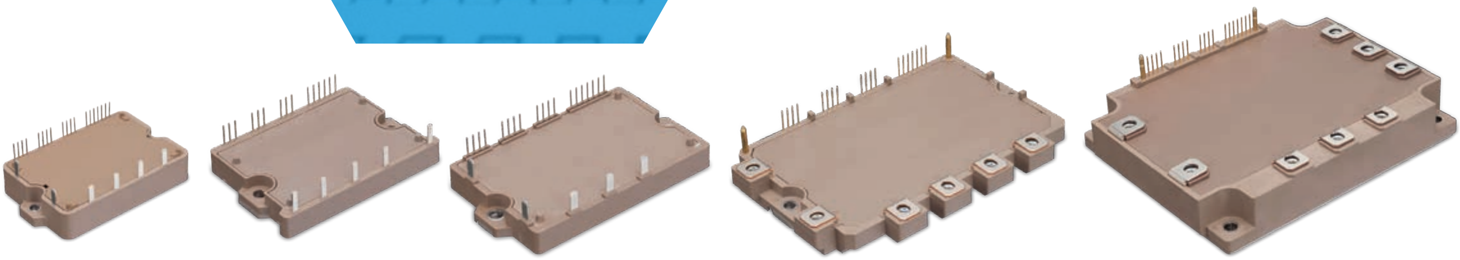

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## with Fuji Electric's VR "on chip sensing" IGBT

### FEATURES

- VR IGBT-Chip with on chip $T_j$ and current sensing
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- Embedded driver, control and protection functions
- 1 wire provides 3 alarms: over-current, over-heating and under-voltage
- Temperature sensor analog output
- Dead time down to 1 µs (low distorsion)
- 6 in 1 and 7 in 1 topology (full inverter + brake)
- Suited for industrial application