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## POWER GaN

## Integrated GaN Power Stage for eMobility


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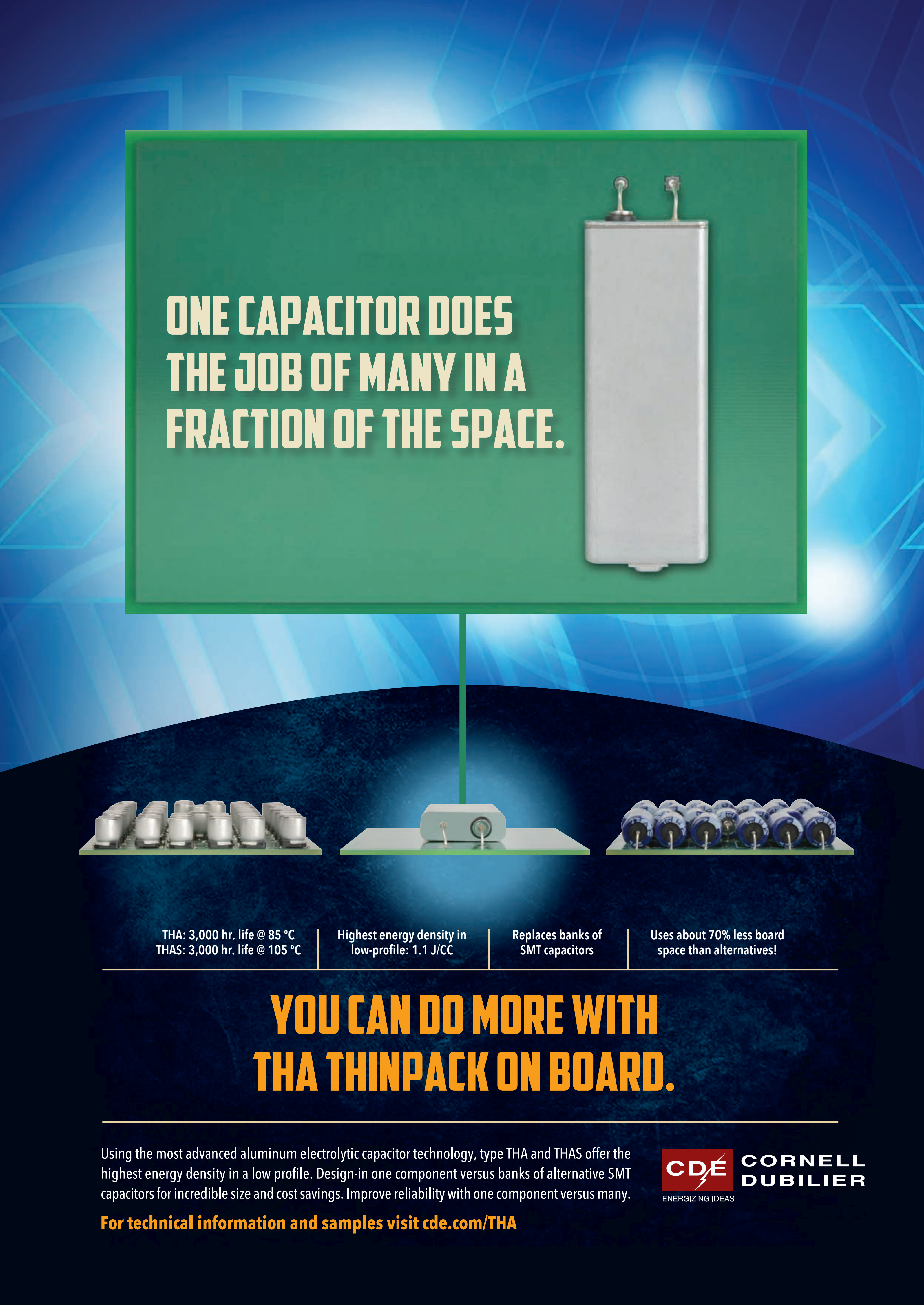
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## COVER STORY


## Integrated GaN Power Stage for eMobility

Brushless DC (BLDC) motors are a popular choice and are finding increasing application in robotics, drones, electric bicycles, and electric scooters. All these applications are particularly sensitive to size, weight, cost, and efficiency. To address these needs, inverters powering the motors need to operate at higher frequency, but require additional filtering to prevent excessive losses, EMI generation, and unwanted mechanical wear related to high frequency common mode and induced current flow. GaN FETs and ICs offer the ability to operate at much higher frequencies in hard-switching topologies without incurring significant losses. In March 2020, EPC introduced a new monolithic GaN half-bridge ePower Stage IC that is capable of 1 MHz switching and up to 15 ARMS load current per phase. This tiny IC greatly reduces PCB size. The system size, however, is further diminished because the very high frequency reduces filtering requirements, thus reducing size and weight. One application example that will be discussed is an eScooter with a 400 W BLDC motor.
More details on page 20.

# Ten Years Power GaN – A Success Story

Ten Years ago, in the year 2010, International Rectifier (IR), now part of Infineon Technologies AG, introduced the first commercially available cascoded GaN power transistor on the market, soon after followed by Efficient Power Conversion Corp. (EPC), a spin-off of IR and co-founded by former IR-CEO Alex Lidow. EPC followed a different approach to make a non-cascoded normally-off GaN power transistor – the so-called enhancement mode.

Commercially viable Si power FETs, introduced some 40 years ago, enabled the widespread adoption of switch-mode power supplies, replacing the linear regulator as the dominant power architecture, the Si power FET has become the dominant power device. The Si IGBT, combining the ease of MOS charge control with the benefits of conductivity modulated drift resistivity, has been another mainstay, especially in the lower frequency conversion systems, e.g. motor drive inverters. Of course, the same minority carrier injection that provides for lower ohmic losses also increases switching losses through the effects of subsequent tail currents. Over the last four decades significant engineering efforts have driven the improvement in the performance figure of merit (FOM) of these devices by more than an order of magnitude. However, as this technology approaches maturity, it becomes increasingly expensive to achieve even modest improvements in the device FOM.

Ten years ago GaN based power devices already provided a factor of 2 to 10 in specific on-resistance improvement over state-of-the-art silicon based devices, but at a very early stage as was the case in Silicon power device development over the last 40 years. GaN based power devices are expected by market researchers to improve rapidly over the next ten years. "Like the power MOSFET of 1976, we are beginning an exciting journey with new products and breakthrough capabilities almost monthly. The power MOSFET is not dead, but is nearing the end of the road of major improvements in performance and cost. GaN will most probably become the dominant technology over the next decade due to its large advantages in both performance and cost; advantage gaps that promise to widen as we quickly climb the learning curve", stated Alex Lidow in an article "Can Gallium Nitride Replace Silicon?" published in PEE 3/2010. Now in the year 2020 this question has been partially answered. "GaN-on-Si devices, such as the ePower Stage EPC2152, are a major step toward developing full power systems-on-a-chip. Over the next few years there will be many more such products introduced to the market, each one reducing design time while improving system efficiency and cost. The era of the discrete transistor is coming to a close", Lidow pointed out in our cover story.

Since 2010 the GaN-on-Silicon power device landscape was dominated by pure GaN start-up players like EPC, GaN Systems, Transphorm, and Navitas, which chose the foundry model and mostly used TSMC, Episil, or X-FAB. In just a few years, IR/Infineon and Transphorm have reached the strongest IP position in the patent landscape, according to market researcher Yole. Infineon has the strongest IP portfolio to front the growing of GaN power market. Transphorm is a major force in the power GaN IP arena, with a new licensee Nexperia. In a GaN power market bursting with potential, more players are expected to enter and benefit from high-volume opportunities. For example, LED manufacturers may want to leverage their GaN-on-Sapphire know-how and high production capacity to derive considerable benefit. A fierce competition is likely to break out between all of these actors and their different business models. However, everyone's ultimate goal is to gain a foothold in the lively GaN power market, earn a design win, and ramp up.

In the GaN-on-Sapphire patent landscape, Power Integrations (PI) is the best-known player. In fall 2019 they announced that it had not only shipped close to 3 million units of its new Innoswitch3 with a SiP GaN product, but also earned a design win with a major smartphone OEM. In April 2020 the number has increased to 5 million. An expansion of its Innoswitch3 CV/CC flyback switcher ICs incorporating a 750 V PowiGaN transistor making it the so far highest voltage rated GaN device on the market. Most of PI's new products incorporate GaN due to its higher efficiency and switching frequency capability, which relates to smaller and lighter power supplies. The obvious market for such products is the cell phone charger, with its increasing demand for higher power coming from 5 G and fast charging. But also the TV market is very interested in GaN due to efficiency regulations, and thirdly the appliance market looks for elimination of heatsinks in their products. Heatsinks are due their mass a weak point when vibrations occur and thus a reliability problem. And overall efficiency is here also a prerequisite. Also GaN can withstand short-term transients much better than Silicon, which makes this technology more robust. Numerous other players have also developed IP related to GaN-on-Sapphire for power applications, including CorEnergy, Powdec and Seoul Semiconductor.

Yole forecasts the GaN power business will exceed $350 million by 2024, with a compound annual growth rate (CAGR) of 85 %, making it the most attractive power semiconductor market segment. That's why we have prepared a selection of features in this issue.

Enjoy reading and stay healthy.

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

# Powering Decarbonization

Rapid technological advances, standardization and increasing adoption all continue to drive down the cost of green technologies, making them cost competitive against their fossil-fuel-era predecessors. However, this is not enough. 'Sector coupling' – ie, the electrification of more areas of the economy – would enable countries in Europe to make substantial progress toward becoming the first climate-neutral continent by 2050, a new study by Bloomberg

By 2050, the generation mix in a country like the U.K. or Germany almost fully switches to low-carbon technologies thanks to cheap renewables, according to BNEF analysis. As a result, sector coupling could lower emissions by 60 % over 2020-50 across transport, buildings and industrial. This would equate to a 71 % reduction on 1990 levels. Sector coupling may increase the greenhouse-gas output for the electricity sector itself because more fossil-fuel-fired plants are needed to provide sufficient flexibility to the system. However, economy-wide emissions will still be significantly lower because transport, buildings and industry switch away from fossil fuels. In particular, by 2030, the coupled sectors together with electricity could cut emissions to 63 % below 1990 levels compared with the EU legislated target of 40 %. By 2050, this reduction would extend to 83 % below 1990 levels.

A plausible sector coupling trajectory or 'pathway' envisages that power (directly or indirectly) supplies 50-60 % of the final energy consumed by the coupled sectors by 2050 – up from around a tenth today. The share of unabated fossil fuels drops from nearly 80% to 23 %. The speed of progress varies across the coupled sectors: transport has already begun electrification, driven by government support and the growing cost competitiveness of road-going electric vehicles (EVs). However, the pathway shows the buildings sector could overtake transport in terms of electrification by 2050. Little progress away from fossil fuels for long-haul and heavy road transport, aviation and shipping is expected.

Flexible coupling assumes that coupled sectors have some demand-side flexibility. In transport, EV charging infrastructure allows for just over half of the passenger fleet and a quarter of the commercial fleet to charge dynamically by 2050. In buildings, well-insulated homes are a source of flexibility for heat demand. Air-source heat pumps in efficient homes deliver heat three hours before it is needed, helping to even out the load profile of electricity demand in buildings. To calculate the share of the efficient housing stock, we assume an annual retrofit rate of 1 % and new build rate of 0.4 % until 2050, increasing the share of efficient homes in the archetype from around 10 % in 2018 to 40 % in 2050. Full sector coupling assumes the same assumptions as flexible coupling, but includes additional demand volumes expected for the electrification of commercial building heating demand and industrial process heating.

"Electrifying other areas of the economy will have significant repercussions for the power system. Policy makers will have to support the reinforcement and extension of the grid to handle higher power volumes and more renewables, and the deployment of batteries and other sources of flexibility to balance the system," comments Albert Cheung, head of analysis for BNEF.

**https://about.bnef.com/**

# REO Invests in Edge Winding Machines

Wound electrical components manufacturer REO UK has invested in several new edge winding machines at its German manufacturing headquarters. The new machines will allow for the development of electrical components such as chokes and transformers that are lighter by up to 10 % and with reduced power losses of up to 25 % compared to existing products.

The edge winding technique produces coils that reduce skin effect and proximity losses compared to traditional coiling techniques. Edgewound coils also boast a lower parasitic capacitance than other methods of winding, which reduces unwanted high frequency return paths to help components ensure electromagnetic compatibility (EMC). In addition, the single-layered structure of the edgewound coils allows for greater and more efficient dissipation of heat. This is especially helpful in applications that require water-cooling or that are expected to operate under high levels of mechanical and thermal stress, such as leakage transformers in the rail sector or chokes used in electric vehicles (Evs), two markets that are expected to grow in the coming years.

"Bloomberg has predicted that annual EV sales will hit 10 million over the next five years," explained Steve Hughes, managing director of REO UK. "As this market develops, the components within those vehicles need to develop as well. Electrical components such as chokes are key in this area, and introducing edge winding into our wound components allows them to be even better suited to this application. With this investment, we are now able to develop new electrical components that meet the evolving needs of this ever-evolving industry. Not only does the new technique offer greater heat dissipation and lower losses, it also allows us to optimize each product to meet the technical and budgetary requirements of customers. The improved cooling makes it feasible to use aluminium and copper conductors, providing more flexibility in meeting technical demands."

The reduced losses and undesirable parasitic elements of an edgewound coil makes it much more suitable for use around SiC and GaN semiconductors, running at higher frequencies. REO is continuing to develop electrical components using edge winding. Currently, the winding technique is best suited to products with a current between 50 and 250 A.

**www.reo.co.uk**

# Aluminium for Wire and Cables

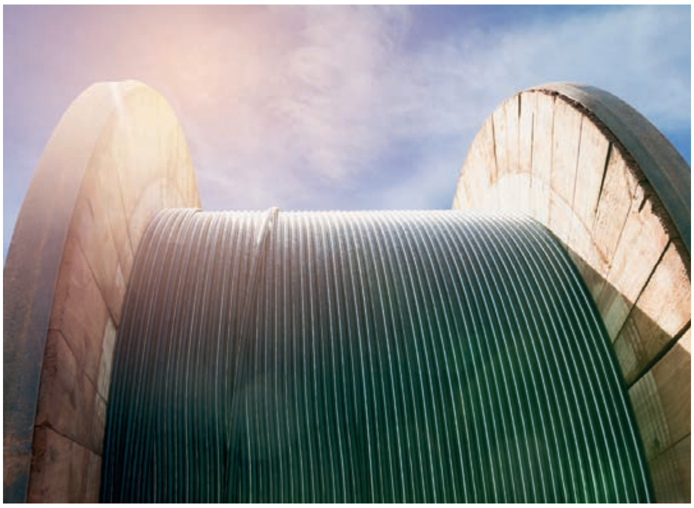
**The rising commodity price and lacking supply of copper is increasingly pushing OEMs to consider alternative metals, such as aluminium, for wire and cable applications. Despite being lighter and cheaper than copper, the widespread adoption of aluminium has historically been tainted by the drawbacks of using the material.**

Copper has the highest electrical conductivity rating of all non-precious metals and, as a result, we've seen a continuous growth in demand for it over the last 50 years. In industrial environments, copper is commonly used in high voltage and extra high voltage cables, building wire, telecom wiring and transformers. On the other hand, aluminium is used predominantly on high voltage overhead wiring, rotors on induction motors and low voltage underground cables. Some applications require a certain metal, so there is no opportunity to seek an alternative. However, in some products, aluminium can be used as a direct replacement. The most straightforward example is on the winding material used in inductors, or chokes. However, before switching material, there are a few key points to consider.

"Firstly, aluminium is not available in as many winding cross-sections. Often a larger cross-section than is required must be used, increasing both the winding mass and volume. Aluminium also has a lower melting point than copper. Because it melts at 660°C compared to copper's 1085°C, aluminium cannot be used in applications where high overloads may be experienced, as this energy will not be absorbed fast enough," explains Neil Ballinger, head of EMEA sales at industrial parts supplier EU Automation. "Historically, connection and terminal technology has been another barrier in the use of aluminium cables and wires. Terminal connections between aluminium and copper can result in contact corrosion, causing an increase in electrical resistivity and a reduction in conductivity, raising losses and resulting in unit failure."

Concern about the available supply of copper is not new. In 1924, Ira B. Joralemon, a geologist and copper-mining expert, returned from his worldwide consulting work, with a warning. "The age of copper will be short. At the intense rate of production that must come, the copper supply of the world will hardly last a score of years - our civilisation based on electrical power will dwindle and die." The copper supply may not have dwindled in the way that Joralemon predicted 100 years ago, but to stay competitive, manufacturers should weigh up the pros and cons of alternative materials.

www.euautomation.com



# Keeping Cool as the Electric Vehicle Market Heats Up

Some of the biggest hurdles to widespread adoption of electric vehicles are range anxiety, battery longevity and safety. As the electric vehicle market grows and for it to reach its full potential, there is an increased need for effective thermal management of the vehicles. A new report from IDTechEx covers several aspects of thermal management for electric vehicles including the batteries, motors and power electronics.

There have been several high-profile battery related fires from well-known automotive manufacturers and in stationary energy storage from South Korea, this does little to instil confidence in potential consumers. With this in mind several new regulations have been proposed relating to safety aspects unique to electric vehicles, the likely outcome of this being that manufacturers will be required to halt thermal runaway at the individual cell level and warn the vehicles occupants, giving them at least 5 minutes to exit the vehicle once a thermal event occurs.

Several factors must be considered when designing an electric vehicle for safety, from the materials used in the battery pack construction to thermal runaway prevention and early detection. Several companies are designing methods of stopping thermal runaway between cells including flame retardant encapsulants, interweaved products and phase change materials. Effectively dissipating heat from the battery module or pack to a heat sink is also important and usually carried out using a thermal interface material, this is another area where manufacturers have adopted several strategies including gap pads, fillers and conductive adhesives.

Every manufacturer has their own methodology to thermally manage their batteries with no clear consensus on the most effective design. Companies like Tesla are set on their patented water-glycol coolant lines which "snake" their way between the cylindrical cells in the pack, whereas OEMs like Nissan and Toyota are committed to air cooling. Active cooling of batteries with fluids allows the vehicle to be kept cool in conditions where the vehicle is stationary but the batteries are in high demand (e.g. during fast charging), but also allows the batteries to be raised to optimal temperature in cold ambient conditions, these are significant advantages but come at the expense of weight, complexity and cost. Despite these caveats, IDTechEx has observed a market shift towards liquid or refrigerant cooling and foresee this trend continuing into the future, especially following the rise of charging with 350 kW sources, with the amount of liquid or refrigerant cooled batteries exceeding 500 GWh by 2030.

In addition to the batteries and motors the power electronics also have to deal with significant heat, especially with the trend towards operating at higher power densities and temperatures. The way in which wire bonds and soldering is carried out as well as the material used makes a big impact on the performance and longevity of the power electronics. Several OEMs are also shifting towards using advanced substrates and even eliminating the thermal interface material altogether. The new report from IDTechEx on "Thermal Management for Electric Vehicles 2020-2030" covers all the above topics through extensive research including primary interviews from companies in the field. The report covers the strategies used by major OEMs, emerging technologies and market forecasts for electric vehicles and their thermal management technologies.

**www.IDTechEx.com**

# First Mobility Innovation Hub in UK

Plug and Play, a pioneering US innovation platform for startups, will be partnering with MIRA Technology Park, a leading automotive R&D cluster, to create the UK's first Mobility Innovation Hub. As renowned automotive 'technology cluster', MIRA Technology Park is currently home to 40 mobility sector companies, including many iconic brands and they collectively employ over 1,200.

Headquartered in Silicon Valley, Plug and Play is the world's largest innovation platform. It specialises in corporate innovation and the development of early-to-growth stage technology startups, bringing together the best startups, entrepreneurial investors, and ambitious global corporations. Situated at the heart of the UK's automotive sector, the Mobility Innovation Hub will be located at the MIRA Technology Park. It provides R&D facilities and access to skilled engineering expertise, thereby immersing the successful startups in a rich eco-system to facilitate their rapid growth. The partnership, supported by key government bodies such as Zenzic, will enable OEM and Tier 1 corporates to fast track their innovation agendas whilst supporting startups to prove their concepts and find routes to market for their innovations. "With the global mobility industry facing unprecedented change amid megatrends in EVs and connected and autonomous vehicles, the need to accelerate innovation, through investment in talent and technology has never been greater," said Mike Olmstead, CRO at Plug and Play. ""Having already established a successful track record in the US and the rest of Europe, the high-quality of startups and academic research emerging from UK universities makes it an attractive market to enter. As such, we knew the MIRA Technology Park – with its prime location in the heart of the UK mobility sector, pioneering facilities and high-profile tenants – was the right fit for us. We look forward to achieving some great things from this collaboration."

**www.plugandplaytechcenter.com**

# GaN Market Accelerates

The GaN power business will exceed $350 million by 2024, with a compound annual growth rate (CAGR) of 85 %, according to market redearcher Yole and its sister compamies Knowmade and System Plus Consulting. But Super Junction Silicon MOSFETs will survive.

Superjunction (SJ) technology was commercially released in 1998 by Infineon. Today new players are entering the market, but the historical players keep their lead by decreasing production costs as much as possible or by introducing different technologies. The improvement of Silicon SJ MOSFETs will keep these devices on the market and drive them towards standardization and popularization.

GaN-on-Si HEMTs are good competitors for silicon SJ MOSFETs in the 600/650V power device range. They offer new capabilities, such as higher switching frequencies, higher power density and an increasingly competitive manufacturing cost.

For many years since 2010 the GaN power device landscape was dominated by pure GaN start-up players like EPC, GaN Systems, Transphorm, and Navitas, which chose the foundry model and mostly used TSMC, Episil, or X-FAB.

In just a few years, IR/Infineon and Transphorm have reached the strongest IP position in the patent landscape, according to Knowmade. Infineon has the strongest IP portfolio to front the growing of GaN power market. Transphorm is a major force in the power GaN IP arena, well ahead of the other GaN pure-players, EPC, GaN Systems, Navitas, Exagan or VisIC. In April 2020 the company launched its Gen IV GaN Platform called SuperGaN. The first JEDEC-qualified SuperGaN device will be the TP65H300G4LSG, a 240 mΩ 650 V GaN FET in a PQFN88 package. The second SuperGaN device is the TP65H035G4WS, a 35 mΩ 650 V GaN FET in a TO-247 package. These devices are currently sampling and will be available Q2 and Q3 respectively. Target applications include adapters, servers, telecommunications, broad industrial, and renewables. System designers can assess the technology in Transphorm's 4 kW bridgeless totem pole AC-DC evaluation board, the TDTTP4000W066C-KIT.

"According to our analysis, Transphorm today has the dream patent portfolio for all those who want to benefit from strategic advantages in GaN power electronics market. Some signals lead us to believe the first 650 V GaN-on-Si FETs from Nexperia announced in November 2019 may use Transphorm's patents," comments Nicolas Baron, CEO of Knowmade.

Nexperia's GAN063-650WSA is a 650 V, 50 mΩ GaN FET based on a cascode configuration of a GaN-on-Silicon HEMT with a standard low voltage Silicon MOSFET. This drives high frequency and makes a normally-off transistor from the normally-on GaN HEMT. The Silicon MOSFET is stacked on top of the GaN HEMT to connect the source contact of the bottom die to the drain contact of the upper die. The device is assembled in a TO247 package for easy integration into power electronic systems. It integrates a DCB substrate and a Gate-Source-Drain (GSD) pin-out arrangement in order to reduce the parasitic inductance and capacitance in high frequency operation.

"In the GaN-on-Sapphire patent landscape, Power Integrations is the best-known player. In 2019, their market entrance was particularly spectacular,"stated Yole analyst Ezgi Dogmus. "They announced in fall that it had not only shipped close to 3 million units of its new Innoswitch3 with a SiP GaN product, but also earned a design win with a major smartphone OEM." In April 2020 the number has increased to 5 million. Numerous other players have also developed IP related to GaN-on-Sapphire for power applications, including CorEnergy, Powdec and Seoul Semiconductor.

In a GaN power market bursting with potential, more players are expected to enter and benefit from high-volume opportunities. For example, LED manufacturers may want to leverage their GaN-on-Sapphire know-how and high production capacity to derive considerable benefit. A fierce competition is likely to break out between all of these actors and their different business models. However, everyone's ultimate goal is to gain a foothold in the lively GaN power market, earn a design win, and ramp up!

**GaN killer application**

Out of all the GaN-based power supply applications, inbox fast-charging is likely to be the killer application for the GaN power device market. Over the last two years, system-on- chip (SoC) and system-in-package (SiP) primarily from Navitas, along with Power Integrations, have managed to enter at least 50 aftermarket fast-charger brands, including Ravpower, Anker, and Aukey. One of the 2019 most significant developments was Oppo's adoption of GaN HEMTs for 65 W inbox fast charging.

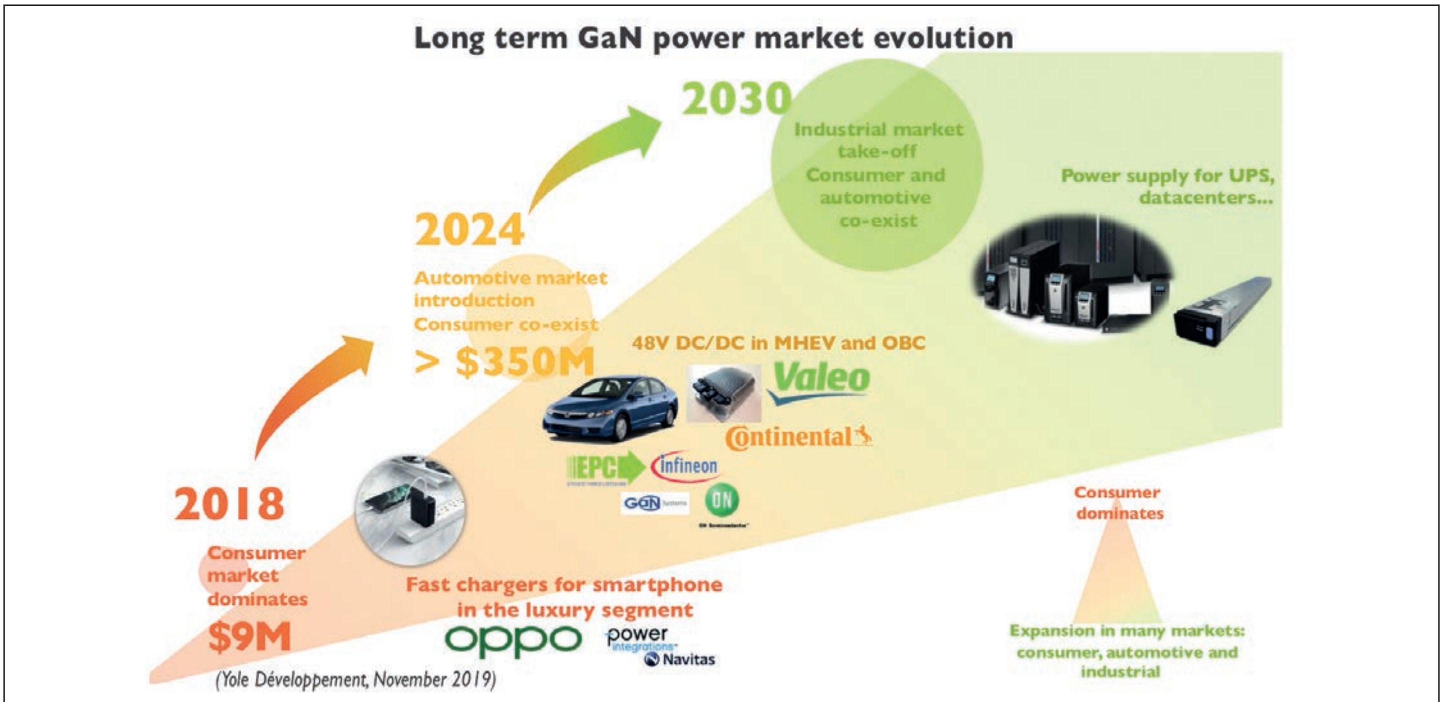
What other possible market scenarios exist for GaN adoption in this mass market? Yole anticipates proliferation of Chinese OEM challengers such as Oppo, Vivo, axnd Xiaomi in the emerging 5G luxury smartphone business, which demands significant technology differentiation. Oppo's SuperVOOC 2.0 meets these demands, with its reduced charging time and charger size. The company claims that its new fast charger has the ability to fully charge a 4000 mAh battery in around 30 minutes. The charger features a GaN-based device from Power Integrations, one of the main power device providers for the wall-charger market. The move from Silicon technology to GaN technology for power as high as 65W results in lower cost per watt.

Other Chinese OEMs have also announced very high-power fast charging (beyond 100 W), and could potentially adopt GaN devices in the coming years. In light of these prospective achievements, the overall GaN device market is nominally expected to surpass $350 million by 2024.

In a more optimistic scenario (and in addition to Chinese OEMs deploying high-power fast chargers), GaN could also be adopted by other players - including leading OEMs like Apple, Huawei, and Samsung - after achieving high maturity and market acceptance as well as cost-competitiveness compared to Si MOSFETs. In the best-case, this could create truly remarkable market opportunities. GaN is also expected to penetrate industrial and telecom power supply applications including datacom, base stations, UPS, and industrial LiDAR applications. Following the first small-volume adoption of GaN-based power supplies by Eltek, Delta, and BelPower over the last few years, Yole analysts' expect broader penetration of GaN in the near future, with increasing efficiency requirements in data centers benefiting from enhanced GaN device maturity and cost-competitiveness.

In either of these scenarios, Yole analysts' expect significant growth: a CAGR of at least 92 % from 2018 - 2024 for the GaN-based power supply market.

**www.yole.fr**



# Eltek's SHE is Going Greener with GaN

**The Flatpack2 60V SHE rectifier is Eltek's third model in volume production featuring GaN power transistors, allowing for super high conversion efficiency of 98 %, significantly reducing energy loss and environmental footprint.**

**With an output voltage of 60 V and power of 3 kW, the rectifier is particularly aimed at markets where 60 V applications are abundant, first and foremost Germany. Current power conversion equipment in these markets typically have conversion efficiency rates of around 90%. "Infineon's CoolGaN power transistor is the key to the rectifier's efficiency and reliability. Eltek benefits from the partnership with Infineon in the development of this potent technology, where Eltek's role has been to test its behavior and suitability in real-life applications," said CTO Lars Elstrøm. "True to the product's inherent high efficiency, three committed engineers brought the project from the drawing board to delivery within weeks. In addition to the efficiency improvement, the GaN transistor technology brings improved reliability and is very well suited for efficient, fault-free manufacturing. The product is also backwards compatible with all 3 kW Flatpack2 versions, making it simple for customers to reap the benefits just by replacing modules."**

**www.eltek.com**

# Pre-Switch Appoints Foxy Power to Support AI-Based Switching

Pre-Switch has appointed Foxy Power GmbH from Berlin, Germany as its strategic partner for business development and sales.

Founded in 2016, Pre-Switch has implemented soft-switching in DC/AC systems with varying input voltage, temperature and load conditions using AI to constantly-adjust the relative timing of elements within the switching system required to force a resonance to offset the current and voltage wave forms – thereby minimizing switching losses. "Foxy Power has efficiently approached top global automotive OEMs and automotive suppliers with our technology resulting in strategic design wins. They have also mapped these wins into further successes in industrial applications such as motor drives, battery chargers and renewables," said Bruce Renouard, CEO of Pre-Switch. "Pre-Switch's unique capability is bringing soft-switching to DC/AC and AC/DC inverters which significantly increases switching frequencies while reducing transistor costs. Their technology has shown added range for battery applications such as electric vehicle traction inverters and reduced the size, weight and system costs for industrial applications," added Christopher Rocneanu, CEO and founder of Foxy Power.

**www.pre-switch.com**

# Power Integrations Expands GaN Power Range

Power Integrations announced in March an expansion of its Innoswitch3 CV/CC flyback switcher ICs incorporating a 750 V PowiGaN™ transistor, making it the so far highest voltage rated GaN device on the market.

The new INN3x78C switcher IC enables compact, efficient power supplies delivering between 27 W and 55 W without heatsinks. The ICs are housed in the same high-creepage, safety-compliant InSOP™-24D package as larger members of the GaN-based InnoSwitch3 families, which target up to 120 W. Its exceptional efficiency – up to 94% efficient across line and load, PowiGaN technology is also extremely robust, making them resistant against line surges and swells commonly seen in regions with unstable mains voltage. This enables OEMs to specify a single power supply design to be used worldwide. Applications for the new parts include USB PD and high-current chargers/adapters for mobile devices, as well as set-top boxes, displays, networking and gaming products and appliances – especially those aiming to comply with the planned European Energy Labeling Regulation.

Comments PI's CEO Balu Balakrishnan his GaN strategy: "Most of our new products incorporate GaN due to its higher efficiency and switching frequency capability, which relates to smaller and lighter power supplies. The obvious market for such products is the cell phone charger, with its increasing demand for higher power coming from 5 G and fast charging. But also the TV market is very interested in GaN due to efficiency regulations, and thirdly the appliance market looks for elimination of heatsinks in their products. Heatsinks are due their mass a weak point when vibrations occur and thus a reliability problem. And overall efficiency is here also a prerequisite. Also GaN can withstand short-term transients much better than Silicon, which makes this technology more robust. Since we are providing system-level solutions for power supplies the GaN switch is combined with the controller in the same package, we have fully control on the switching behavior of the IC and its protection. Another point is the lossless current sensing technology which eliminates shunts, we use either the on-resistance of the GaN switch itself or we use a sense FET. Thus we can guarantee to deliver a fully protected device. Thus the future of GaN is very bright."

**www.power.com/innoswitch3**

**PI's CEO Balu Balakrishnan expects a bright future for GaN**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# SiC MOSFET Driver Achieves AEC-Q100 Automotive Qualification

Power Integration's SIC118xKQ SCALE-iDriver™, a high-efficiency, single-channel gate driver for SiC MOSFETs, is now certified to AEC-Q100 for automotive use. Devices can be configured to support gate-drive voltage requirements of commonly used SiC MOSFETs and feature sophisticated safety and protection features.

The SIC1182KQ (1200 V) and SIC1181KQ (750 V) SCALE-iDriver devices are optimized for driving SiC MOSFETs in automotive applications, exhibiting rail-to-rail output, fast gate switching speed, unipolar supply voltage supporting positive and negative output voltages, integrated power and voltage management and reinforced isolation. Critical safety features include Drain to Source Voltage ($V_{DS}$) monitoring, SENSE readout, primary and secondary Undervoltage Lock-out (UVLO), current-limited gate drive and Advanced Active Clamping (AAC) which facilitates safe operation and soft turn-off under fault conditions. AAC in combination with $V_{DS}$ monitoring ensures safe turn-off in less than 2 μs during short-circuit conditions. Gate-drive control and AAC features allow gate resistance to be minimized.

**Functional description**

The gate drivers provide up to 8 A and suit SiC MOSFETs with standard gate-emitter voltages from +15 V, with various negative voltages in the range from -3 V to -15 V. Devices exhibit high external magnetic field immunity, and are available in a compact eSOP package that provides ≥9.5 mm of creepage and clearance, using material that has the highest CTI level (CTI =600 per IEC 60112).

The logic input (PWM) command signal applied via IN and the primary supply voltage supplied via $V_{CC}$ are both referenced to GND. The working status of the semiconductor device and SCALE-iDriver is monitored via SO. Command signals are transferred from the primary (IN) to secondary-side via FluxLink isolation technology. GH supplies a positive gate voltage and charges the semiconductor gate during the turn-on process. GL supplies a negative gate voltage and discharges the gate during turn-off process.

Short-circuit protection as well as over-voltage limitation can be implemented by connecting a network between SNS and drain terminal of the semiconductor device. In case of a turn-on event

SNS senses short-circuits, which will lead to a driver initiated turn-off to protect the semiconductor device from short-circuit damage. In case of a turn-off event SNS senses turn-off over-voltages and limits them by AAC to a save value below the semiconductor devices blocking voltage. In case the semiconductor device offers a current-sense terminal, an adjustable over-current detection can be realized as alternative to a short-circuit monitoring.

The SIC118xKQ is equipped with an integrated power and voltage failure management. These features control IC power and voltage. It also generates and regulates secondary-side bipolar supply voltage.

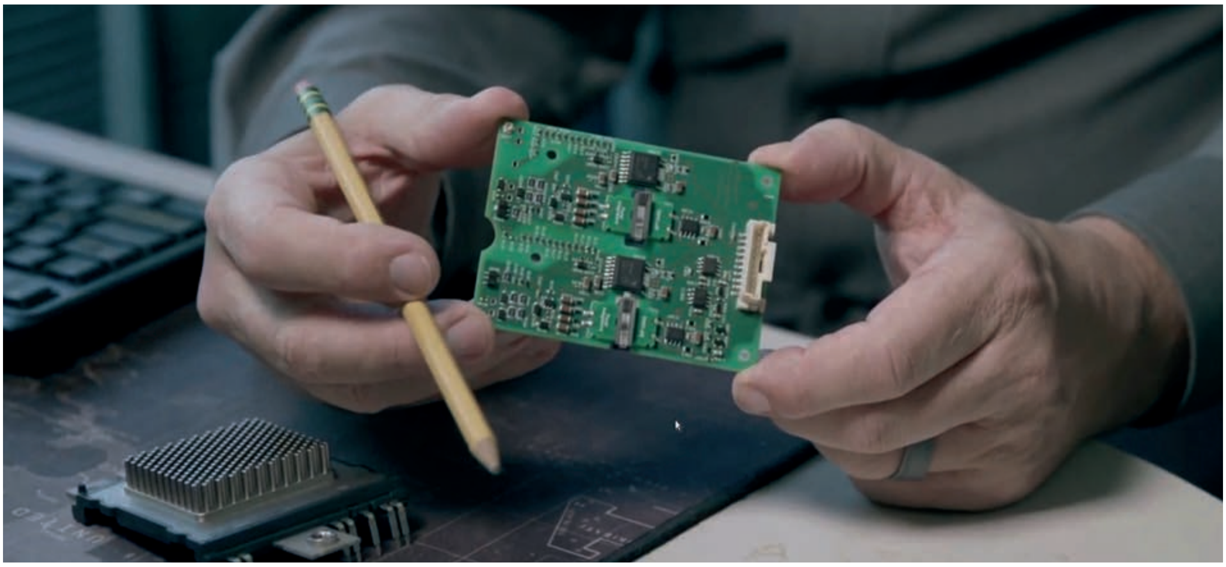
The input (IN) logic is designed to work directly with controllers using 5 V CMOS logic. It is recommended to use a pull-down resistor close to the input pin.

During normal operation, when there is no fault detected, the SO pin stays at high impedance (open drain). Any fault is reported by connecting the SO pin to GND. SO stays low as long as $V_{VCC}$ (primary-side) stays below $UVLO_{VCC}$. If a short-circuit is detected or the supply voltage $VV_{ISO}$, (secondary-side) drops below $UVLO_{VISO}$, the SO status changes with a delay time $t_{FAULT}$ and keeps status low for a time defined as $t_{SO}$. In case of a fault condition the driver applies the off-state (GL is connected to COM). During the $t_{SO}$ period, command signal transitions from IN are ignored. A new turn-on command transition is required before the driver will enter the on-state.

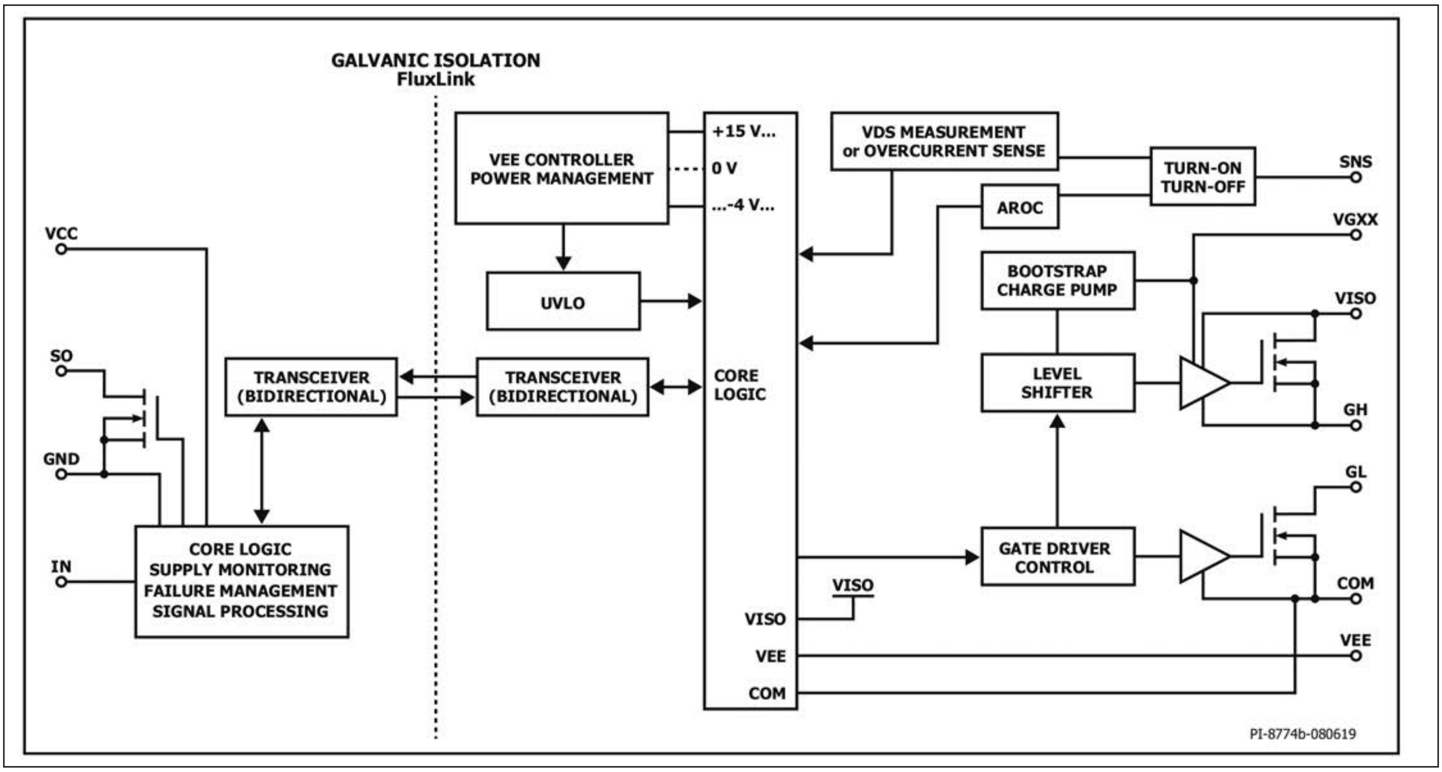
The gate of the semiconductor device to be driven can be connected to the SCALE-iDriver output via GH and GL, using two different resistor values. Turn-on gate resistor $R_{GON}$ needs to be connected to the GH pin and turn-off gate resistor $R_{GOFF}$ to GL. If both gate resistors have the same value, GL and GH can be connected together.

The SCALE-iDriver data sheet defines the $R_{GH}$ and $R_{GL}$ values as total resistances connected to the respective GH and GL. In addition to $R_{GINT,}$ external resistor devices $R_{GON}$ and $R_{GOFF}$ are specified

to setup the gate current levels to the application requirements. Consequently, $R_{GH}$ is the sum of $R_{GON}$ and $R_{GINT}$. Careful consideration should be given to the power dissipation and peak current associated with the external gate resistors. The GH pin output current source ($I_{GH}$) is capable of handling up to 7.8 A during turn-on, and the GL pin output current source ($I_{GL}$) is able to sink up to 7.3 A during turn-off. If the gate resistors for SCALE-iDriver attempt to draw a higher peak



**AEC-Q100 certified SiC MOSFET SCALE-iDriver™ PCB for ABB power module**




**SCALE-iDriver functional block diagram**

current, the peak current will be internally limited to a safe value.

## Short-circuit protection

The SIC118xKQ uses the semiconductor device drain to source voltage to detect a short-circuit utilizing a sensing resistor network. With the help of a well stabilized $V_{VISO}$ and a Schottky diode connected between semiconductor device gate and VISO the $V_{GS}$ is clamped to the regulated VISO and the short-circuit current as well related SiC semiconductor energy will be limited.

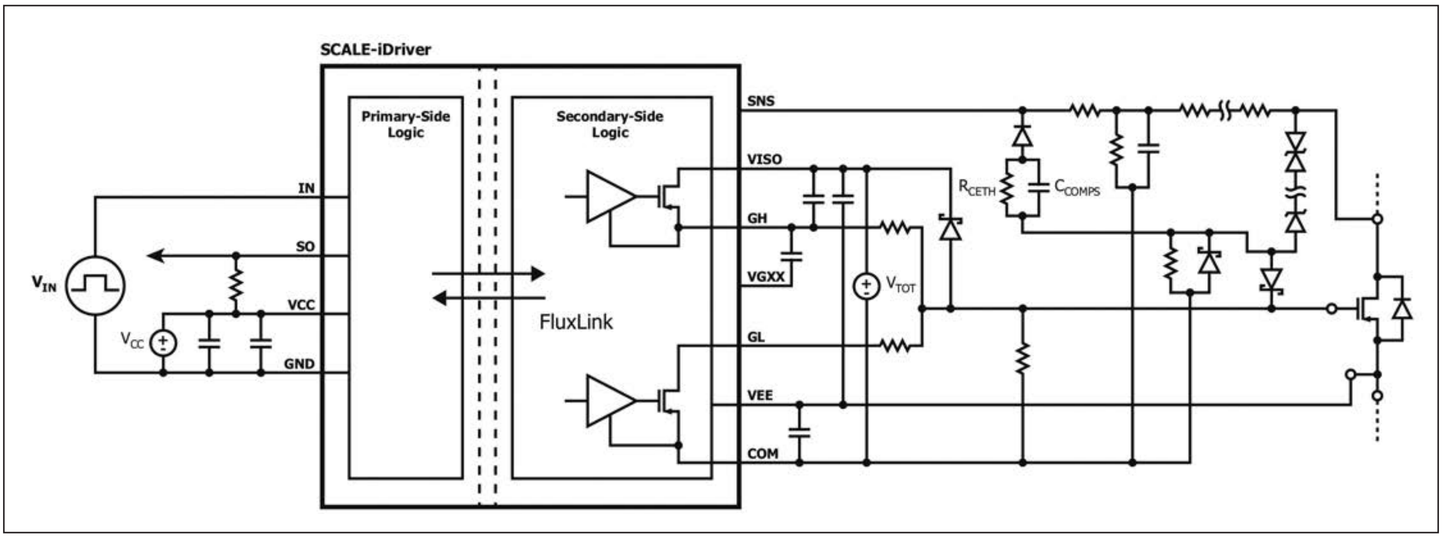
During the off-state, SNS is internally connected to the COM pin. In case an optional filter-capacitor is applied between SNS pin and COM this capacitor is discharged.

When the driver is in turn-on transition or in on-state, the short-circuit detection algorithm through SNS is activated after an ASIC internally blanking time has elapsed. If now a voltage drop of about 0.4 V (typically) is detected at SNS referenced to VEE, this is interpreted as a detected short-circuit. The driver initiates a short-circuit turn-off without receiving a primary-side command. A fault command is sent to the primary side and SO is pulled to GND for typically 10 µs. During this time the driver ignores any command signal at the IN pin. In parallel to the short-circuit turn-off transition phase, the iDriver's internal Advanced Active Clamping over-voltage limitation scheme is activated.

If the driver is in turn-off transition or in off-state the over-voltage limitation algorithm is activated at SNS and the internal reference is COM. In case a current of typically 440 µA (turn-off transition) to 520 µA (off-state) is feed to SNS, the driver will regulate the gate current to limit the turn-off di/dt and therefore the over-voltage at drain to source during turn-off.

In case the semiconductor device offers a so called current-sense terminal, this signal can be fed into SNS with reference to VEE. A voltage of about 0.4 V at SNS with reference to VEE will now be handled as an over-current. That leads to an over-current turn-off, following the same scheme as for a short-circuit condition.

More details:
**www.power.com/products/scale-idriver-ic-family/sic118xkq/**




**SCALE-iDriver typical application diagram**

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# A Technology Conquers Power-Hungry Applications

Gallium nitride (GaN) power devices have opened many new applications since their commercial availability began in 2010. The superior switching speed of GaN devices and, as a result, their low switching losses, gave the starting signal for the development of new applications such as lidar (light detection and ranging) sensors and resonant wireless power. In the midst of a multitude of such innovative applications, a strong value chain with low production costs and extremely reliable products grew up. As a result, even more conservative, budget-conscious developers in cost-sensitive application areas, such as power supplies and the automotive industry, felt motivated to evaluate GaN power devices for their designs. **Tobias Herrmann, FAE and Jieyi Zhu, Line Manager EPC at Finepower, Ismaning, Germany**

**For a new technology to establish itself** on the market, it must meet four criteria: It must enable new applications, be easy to use, be lower cost, and be highly reliable.

Available GaN components today are 5 to 50 times better than state-of-the-art silicon solutions. This performance advantage has led to new applications that only became possible with GaN technology. One such application is lidar, a high-resolution sensing technology used for autonomous cars, augmented reality, industrial automation and drones. The second attribute that a new technology needs to establish itself is its ease of use. GaN-based power converters offer higher efficiency, higher power density and lower total system cost than Silicon-based alternatives. The ecosystem of supporting components such as gate drivers, controllers and passive components is growing continuously.

Cost is equally important for a new technology to displace an entrenched technology. GaN transistors and integrated circuits are produced using processes similar to silicon power MOSFETs, have many fewer processing steps than MOSFETs, and more devices are produced per manufacturing run because GaN devices are much smaller than their Silicon counterparts. In addition, lower voltage (<500 V) GaN transistors do not require the costly packaging needed to protect their Silicon predecessors. This packaging advantage alone can cut the cost to manufacture in half and, combined with high manufacturing yields and and smaller device size, has resulted in the cost of a GaN transistor from EPC to be lower in cost than a comparable (but lower performance) Silicon power MOSFET.

Finally, GaN components easily meet the reliability criterion: they not only pass the JEDEC standard tests for semiconductors, but in many cases also the more stringent qualification requirements of the automotive industry (AEC Q101). In addition, EPC's eGaN® transistors and ICs in chip-scale packaging are free from the typical failure mechanisms inherent in traditional MOSFET packaging techniques.

### Entering conservative and cost-sensitive applications

These superior properties are increasingly prompting developers in more conservative and cost-sensitive applications such as power supplies and automotive to take a closer look at GaN devices. An example of such an application is 48 V DC/DC converters.

Such converters are used in many areas of the electronics industry. For example, the advent of 5G and the explosion of data for hyperscalers, cloud-based data centers, and artificial intelligence demand more power in much smaller form factors. Due to the significant improvements GaN offers in switching performance and size reduction, power supply designers are realizing that GaN FETs and ICs make higher power density and more efficient 48 V power supplies.

Likewise, in the automotive industry, GaN transistors are becoming the power technology of choice for the design of compact systems for 48 V supply in hybrid, mild hybrid, and plug-in hybrid vehicles. They enable the development of lighter and at the same time more cost-effective systems.

### Why 48 V for cars?

With the emergence of autonomous cars

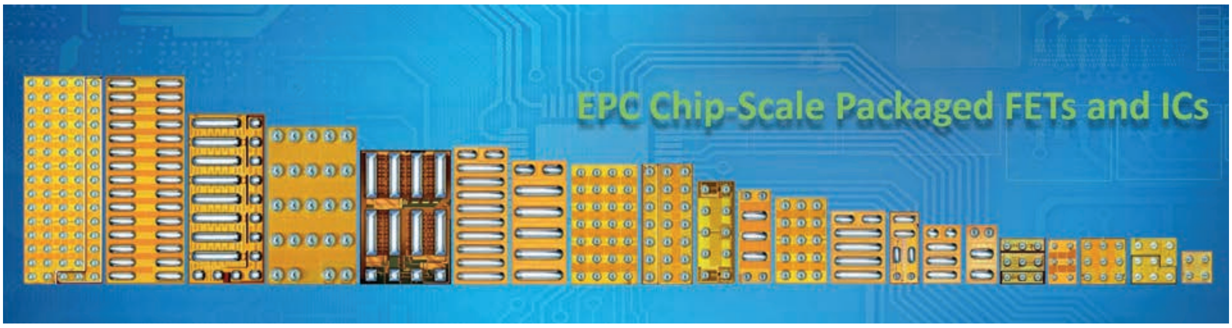


**Figure 1: Line-up of EPC's chip-scale GaN power FETs and ICs**

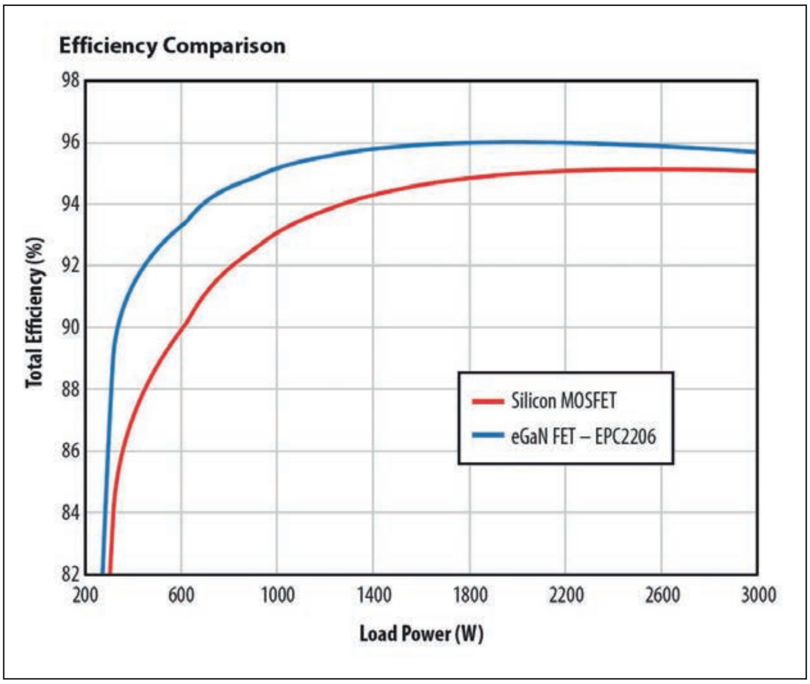


Figure 2: **Efficiency comparison of eGaN FET vs. Silicon MOSFET in a 48 V to 12 V, 3 kW system**

and electric propulsion, the automotive industry is facing a massive transformation. IHS Markit estimates that 12 million cars will drive autonomously by 2035. According to Bloomberg New Energy, 32 million cars are expected to have electric drives by that year. Both trends will significantly increase the demand for power semiconductors.

In the car, it is the innovative but power-hungry electronically controlled functions and features that require a 48 V power supply. These include start/stop systems, electric steering, and turbochargers, electronic chassis controls, and electronically controlled air conditioning, to name just a few examples. The intelligent control systems of (partially) autonomous vehicles also require sophisticated sensor technology such as lidar, radar, and cameras, as well as powerful graphics processors. All these systems increase the power consumption in the car. In particular GPUs are very energy-hungry and represent a major additional load on the car's traditional 12 V power supplies. For 48 V automotive power systems, GaN technology increases the efficiency, shrinks the size, and reduces system cost (Figure 2).

For applications in autonomous and assisted driving, where lidar systems serve as the "eyes" of the vehicles, very short laser pulses of the order of a few nanoseconds are used to achieve the required distance resolution. These pulses are typically generated by a laser diode. To achieve a sufficient range, the optical peak power must be high, i. e. current peaks of a few 10 A up to a few 100 A are involved. Until now, this has required complex circuits and exotic, expensive semiconductors.

A typical lidar pulsed laser driver uses a semiconductor switch in series with the laser source and a power supply. Limiting factors for system performance are stray inductances and the speed of the semiconductor power switch. In recent years, low-cost GaN power FETs and ICs have come on the market that offer significantly lower inductance while providing switching frequencies up to 10 times higher than comparable Silicon MOSFETs.

The advent of GaN FETs and ICs makes it possible to achieve the desired performance with simple, space-saving circuits at low cost. The greatly improved performance of GaN FETs compared to Silicon MOSFET technology results in much faster switching for a given peak current capability, enabling currents >100 A and pulse widths <2 ns with one laser load.

Automotive electronics can now take full advantage of the improved efficiency, speed, smaller size, and lower cost of eGaN devices. EPC has a growing line of products that have achieved AEC Q101 qualification. To complete AEC-Q101 testing, these eGaN FETs had to undergo rigorous environmental and bias-stress testing. Of particular note is the fact that these wafer level chip-scale devices passed all the same testing standards created for convention packaged parts.

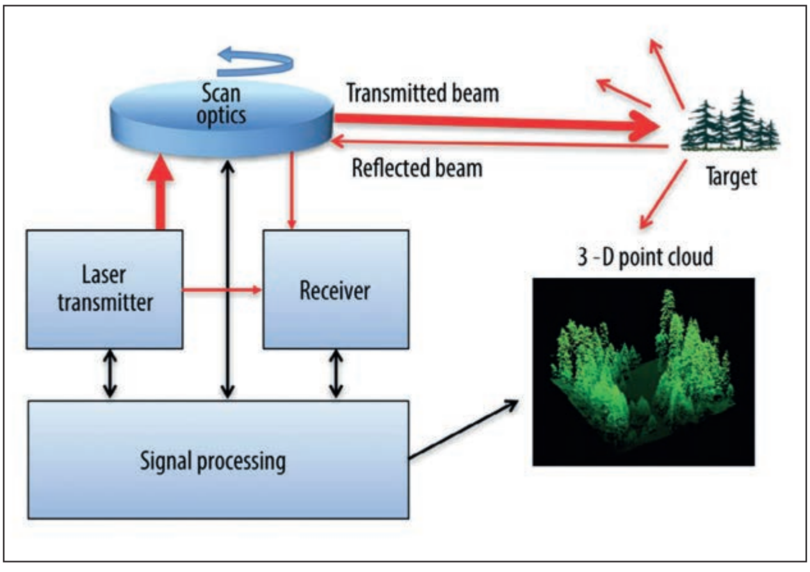


**Figure 3: Overview of a typical lidar system**

## GaN in precision motor drives

Low cost, high-precision motor drives are finding expanding use in applications such as industrial automation, robotics, drones, and emobility such as scooters and ebikes. The brushless direct current (BLDC) motor offers these applications a lot of power in a small installation space, precise control, and a high electromechanical efficiency while generating only minimal vibrations.

BLDC motors are driven by inverter circuits, most of which are multiphase and traditionally use MOSFETs. The higher switching speed of GaN FETs and ICs compared to Silicon MOSFETs allows the construction of converters with a much higher switching frequencies. This not only benefits efficiency, but also

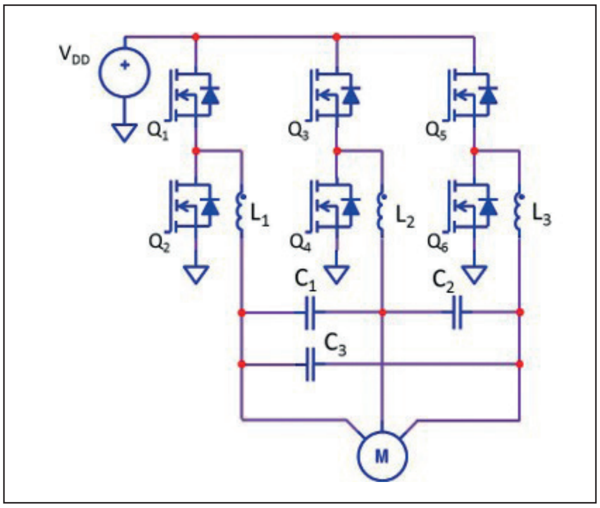


**Figure 4: Typical 3-phase motor drive with filter**

enables higher positioning accuracy. The advantages of GaN for high precision motor drives include the ability to get higher output in a smaller sized solution, faster response time, lower torque ripple, lower EMI generation, and lighter weight motors.

## GaN integration

The greatest opportunity for GaN to impact the performance of power conversion systems comes from the intrinsic ability to integrate both power-level and signal-level devices on the same substrate. EPC has been been developing GaN technology from the original discrete devices to monolithic half-bride deivces to power FETs that include their own monolithically integrated driver.

Additionally, EPC has been developing customer specific GaN ICs for the past several years. The general release of more complex monolithic GaN solutions will offer in-circuit performance beyond the capabilities of Silicon solutions and enhance the ease of design for power systems engineers.

## Conclusion

All in all, GaN components serve a wide range of technically challenging applications with very high growth potential. Today's GaN FETs are improving rapidly in performance and the current benchmark devices are still 300 times away from their theoretical performance limits. EPC has been shipping GaN transistors for a decade with over 100 billion hours of field experience with fewer failures than the mature power MOSFET.

Finepower supports developers in technical questions regarding EPC components as well as logistical issues with an appropriate stock level and demand-oriented delivery for series production.



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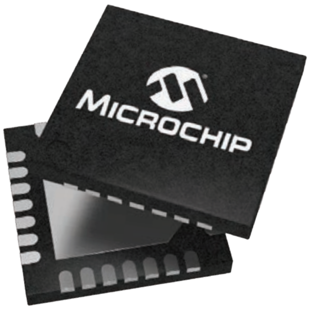


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# Integrated GaN Power Stage for eMobility

Brushless DC (BLDC) motors are a popular choice and are finding increasing application in robotics, drones, electric bicycles, and electric scooters. All these applications are particularly sensitive to size, weight, cost, and efficiency. To address these needs, inverters powering the motors need to operate at higher frequency, but require additional filtering to prevent excessive losses, EMI generation, and unwanted mechanical wear related to high frequency common mode and induced current flow. **Alex Lidow, CEO and Michael de Rooij, VP of Applications, Efficient Power Conversion (EPC), USA**

**GaN FETs and ICs offer the ability to** operate at much higher frequencies in hard-switching topologies without incurring significant losses [1]. In March, EPC introduced a new monolithic GaN half-bridge ePower TM Stage IC [2] that is capable of 1 MHz switching and up to 15 $A_{RMS}$ load current per phase. This tiny IC greatly reduces PCB size. The system size, however, is further diminished because the very high frequency reduces filtering requirements, thus reducing size and weight. One application example that will be discussed is an eScooter (Figure 1) with a 400 W BLDC motor.

## High-frequency switching drives for BLDC motors

Due to the structure of the brushless DC (BLDC) motor, most will be powered by a three-phase inverter also known as a motor drive. Different applications place different requirements on the motor and drive system; for example, drones require efficiency, speed, and must be lightweight; while e-bikes require high efficiency and high torque capability.

Many motor drives operate at 20 kHz but can go as high as 60 kHz, and selection for a given application is driven by cost constraints, power losses, audible limitations, EMI regulations and maximizing mechanical life for the motor. Some other application requirements, such as precision, may be difficult to achieve when limited to using 20 kHz, necessitating a higher switching frequency.

Additional benefits of operating at a higher switching frequency include:


**Figure 1: eScooter powered by a 400 W BLDC motor driven by EPC2152 ePower Stage ICs**

- Lower AC component magnetic losses due to lower ripple current magnitude and thus higher motor efficiency and lower operating temperature,
- lower filtering requirements thus reducing filter size, volume, and weight of the inverter,
- lower THD at higher motor frequencies that keeps audible emissions low,
- supports newer class of low inductance motors such as slot-less motors [3].

## Inverter switching with GaN FETs and ICs

Higher inverter switching frequency does have the disadvantage of higher inverter operating losses, particularly when using MOSFETs. This is in large part due to reverse recovery charge ($Q_{RR}$) and other dynamic characteristics of MOSFETs. GaN FETs, with zero reverse recovery and low hard-switching losses, can overcome these high frequency inverter limitations and have already been demonstrated in several motor drives [4 – 8]. EPC is now taking it to the next level by using a monolithically integrated GaN half-bridge power stage that can reduce the inverter size, weight and increase operating frequency further.

The next evolution for GaN FETs is monolithic integration of the power FETs and complete half-bridge gate driver. There are many benefits to monolithic integration of the power stage such as:

- It virtually eliminates common source inductance (CSI), and reduces the power loop and gate loop inductances [1].
- The gate drivers are matched to the FETs and can be designed to optimize switching speed against EMI, voltage spikes, and efficiency resulting in the shortest practical transition times.
- It improves thermal power dissipation distribution allowing optimized FET scaling that yield higher efficiencies. This feature is more useful for high step-down ratio converters.

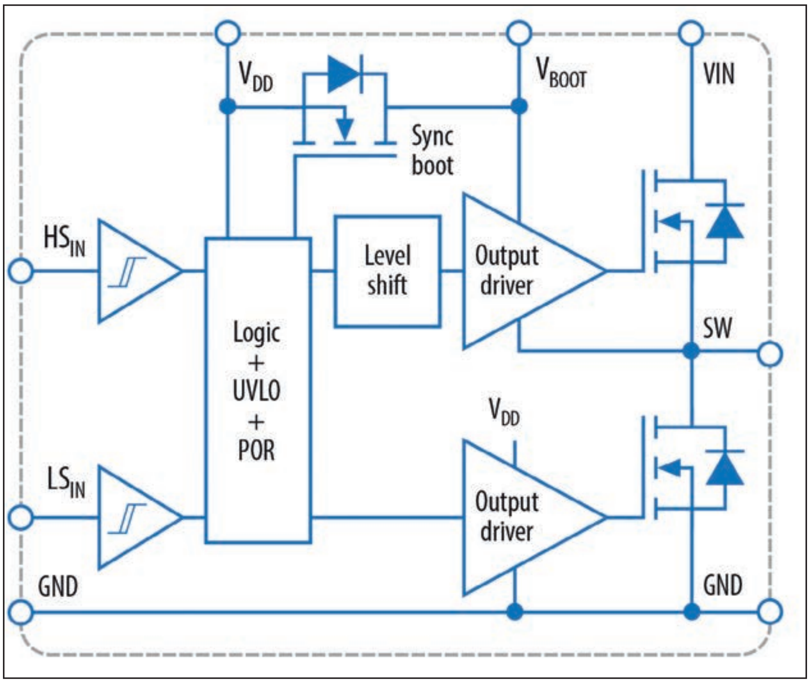
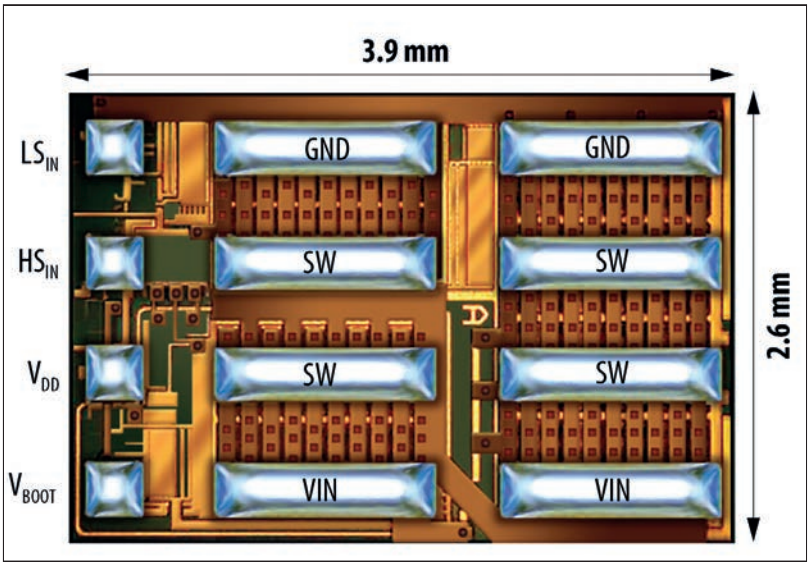
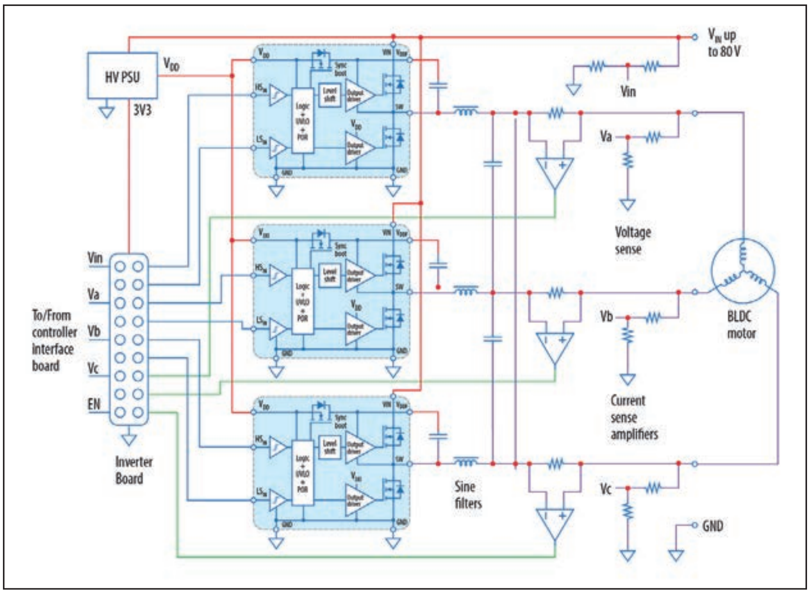



**Figure 2** **(a) above: Block diagram of the monolithic GaN ePower Stage, (b) below: die of the EPC2152 [2]**




- It improves dv/dt immunity that covers all eight types of switch-node transition events [9].
- It simplifies PCB layout and reduces assembly component count for the converter solution.

## eGaN ePower™ stage

Figure 2(a) shows the block diagram of the EPC2152 GaN ePowerTM Stage [2]. The main FETs are controlled by gate drivers within the IC that includes input buffers, a logic interface with Power-On-Reset (POR), Under-Voltage-Lockout (UVLO) functions, a high voltage, high dv/dt capable control signal level-shifter and a synchronous bootstrap [10, 11] that ensures proper high side voltage for the high side gate driver.

The EPC2152 device is capable of interfacing to digital controllers that use standard CMOS or TTL logic levels, allowing it to be driven directly from a digital controller with 3.3 V signal levels, or from analog controllers that use voltage levels up to 12 V.

Figure 2(b) shows a die photograph of the monolithic GaN power stage with pin allocations. It measures only 3.9 mm by 2.6 mm, or 10 mm$^2$ . Both FETs are rated at 80 V, and each has a typical $R_{DSon}$ of 10 mΩ. This IC can conduct peak motor phase load currents up to 15 A. Figure 3 shows a block diagram of a BLDC motor drive inverter featuring all the essential elements required for a high-performance drive ideal for electric mobility.

Each of the half-bridge power stages use one EPC2152 ePower Stage and require only a few support capacitors, as can be seen in Figure 4 (top side) and is shown in a zoomed-in image in Figure 5. The motor phase currents are measured using shunts where the voltage is amplified using a high-performance shunt amplifier. Voltage measurement is from each phase to ground using a simple voltage divider resistor network. The same technique is used for the supply voltage measurement.

Due to the high dv/dt's generated by the GaN FETs, an LC-filter is included that can be configured as either a harmonic filter or EMI filter and comprises a line inductor and shunt capacitor. When configured as an EMI filter, a resistor is placed in series with the capacitor. This LC-filter is shown in Figure 4 (top side).

## BLDC motor drive for eScooter

The motor drive is designed to operate from 15 V through 60 V DC input and power a 400 W BLDC motor such as the

**LEFT Figure 3: Block diagram of the BLDC motor drive inverter**

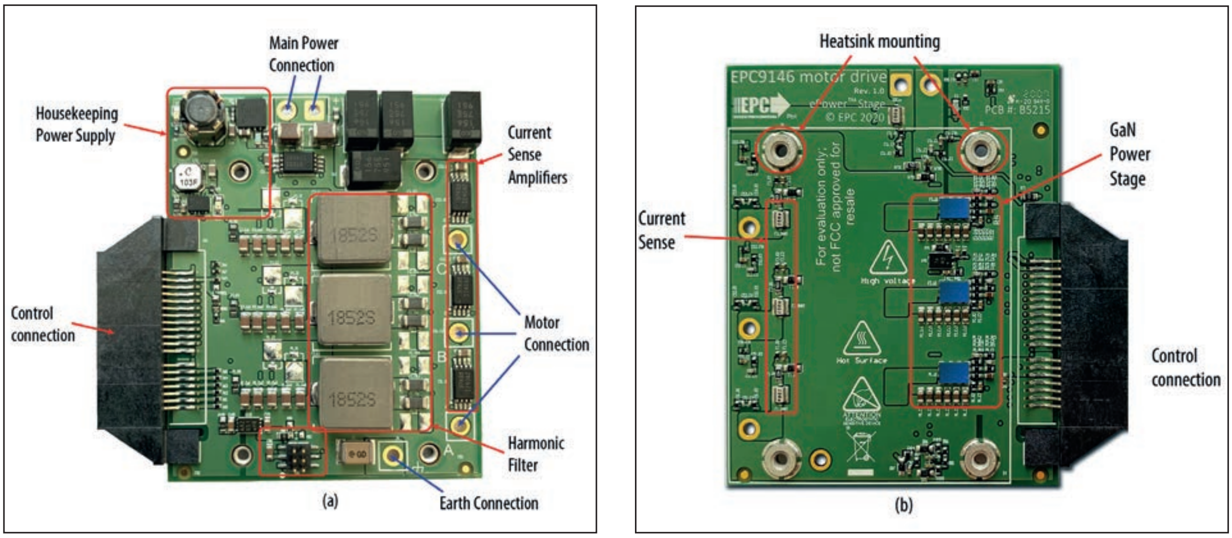



**Figure 4:** PCB (top and bottom side) of the 3-phase experimental BLDC motor drive (expl: a top, b bottom side)

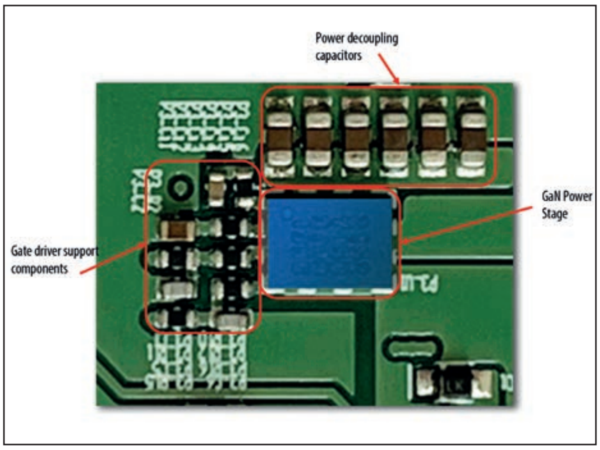



**Figure 5:** Zoomed-in photograph of the EPC2152 ePower Stage with support components as designed in the inverter PCB

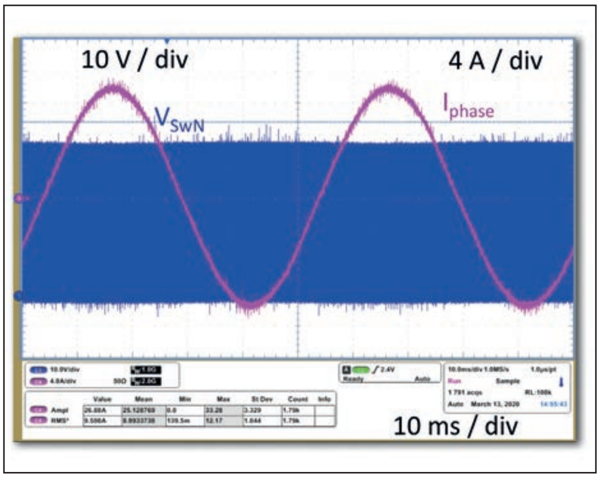



**Figure 6:** Motor modulation frequency (20 Hz) timescale measured switch-node and phase-current waveforms of the drive when operating from a 48 V DC supply and delivering 10 ARMS per phase into the motor

one used in the eScooter shown in Figure 1. It can operate from 20 kHz through 1 MHz switching frequency and deliver a peak current of 15 A into each phase of the motor when a heatsink is attached. The board measures just 45 mm x 55 mm.

To demonstrate the achievable performance of this BLDC drive, the inverter was operated from a 48 V DC supply voltage while switching at 100 kHz to power a 400 W motor with a sinusoidal modulation frequency of 20 Hz (rotational speed of the motor). The dead times for the half bridges were set to 10 ns for both the rising and falling edges and are very short when compared to MOSFETs that start at 50 ns.

Figure 6 shows the measured waveforms on a motor modulation frequency time scale. The drive is operated in an open loop and thus there is no controller to compensate for operation-induced distortions. The measured power loss as a function of one-phase RMS motor current for this drive is expected to exceed 98.4 % in real world conditions.

## Conclusion

GaN FETs have demonstrated high switching frequency capability in BLDC motor drives, and the advent of a monolithically integrated half-bridge FET with full-function gate driver was demonstrated by powering a 400 W capable BLDC motor. The monolithic integration of the FETs and the gate driver ensures low switching losses and enables high switching frequency for the drive. Higher switching frequencies for the drive, together with simple EMI filtering reduces motor loss, keeps audible emissions low even at high speed, and saved significant weight and space. The result is a compact drive solution that could easily be integrated inside the motor housing for further cost, size, and weight savings.

GaN-on-Si devices, such as the ePower Stage EPC2152, are a major step toward developing full power systems-on-a-chip. Over the next few years there will be many more such products introduced to the market, each one reducing design time while improving system efficiency and cost. The era of the discrete transistor is coming to a close.

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# EPC's 11th Reliability Report

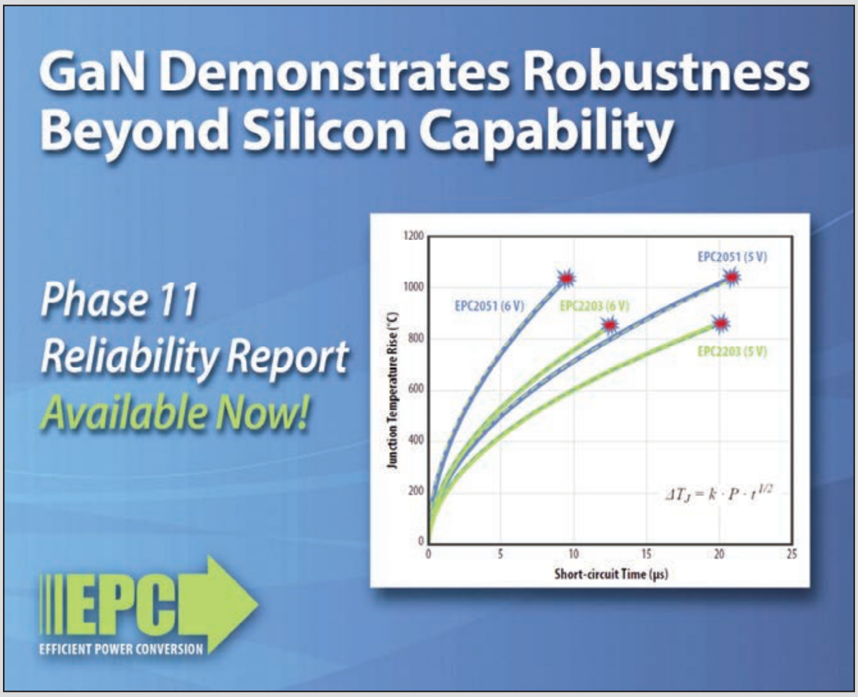
**EPC's Phase Eleven Reliability Report adds to the knowledge base published in the first ten reports. Here the company demonstrates field experience of 123 billion device hours.**

**EPC's strategy relied upon tests forcing devices to fail under a variety of conditions to create stronger products to serve demanding applications such as lidar for autonomous vehicles, LTE base stations, vehicle headlamps, and satellites to name just a few.**

**Testing devices to the point of failure creates an understanding of the amount of margin between data sheet limits and products in application. More importantly, intrinsic failure mechanisms of devices are identified. The knowledge of these intrinsic failure mechanisms is used to determine the root cause of failures. Knowledge of the behavior of a device over time, temperature, electrical or mechanical stress can provide users with an accurate representation of the safe operating life of a product over a more general set of operating conditions.**

**The report is divided into seven segments, each dealing with a different failure mechanism:**
**Section 1: Intrinsic failure mechanisms impacting the gate electrode of eGaN® devices**
**Section 2: Intrinsic mechanisms underlying dynamic RDS(on)**
**Section 3: Safe operating area (SOA)**
**Section 4: Testing devices to destruction under short-circuit conditions**
**Section 5: Custom test to assess reliability over long-term lidar pulse stress conditions**
**Section 6: Mechanical force stress testing**
**Section 7: Field reliability**

**"Our eGaN devices have been in volume production for over ten years and have demonstrated very high reliability in both laboratory testing and high-volume customer applications. The release of the 11th reliability report represents the cumulative experience of millions of devices over a ten-year period and five generations of technology. These reliability tests have been undertaken to continue our understanding the behavior of GaN devices over a wide range of stress conditions," comments EPC CEO Dr. Alex Lidow. "The results of our reliability studies show that GaN is an extremely robust technology that continues to improve at a rapid pace."**



# GaN for Power-Hungry 5G Base Stations

There is a significant change currently underway in the world of mobile telecommunications: the rollout of the fifth generation of cellular network technology, otherwise known as 5G. Consumers are only just beginning to experience the benefits of 5G technology, which will not only enable ultrafast download speeds to rival fixed-line broadband, but will in future also support a much higher density of mobile and connected IoT devices within cellular network areas. But that 5G will consume more power than 4G is an inescapable reality. GaN in SMD packages are a perfect match for the particular requirements of 5G network infrastructure. **Francesco Di Domenico, Principal Application Engineering, Infineon Technologies, Neubiberg, Germany**

**There is a significant change currently** underway in the world of mobile telecommunications: the rollout of the fifth generation of cellular network technology, otherwise known as 5G. Consumers are only just beginning to experience the benefits of 5G technology, which will not only enable ultrafast download speeds to rival fixed-line broadband, but will in future also support a much higher density of mobile and connected IoT devices within cellular network areas.

Exciting as this development may be for the consumer, behind the scenes the industry's move to 5G has been challenging, costly and controversial. Issues such as the allocation of radio frequency spectrum licenses [1], ill-informed myths stoking panic about the health risks of 5G for users [2], and the fallout from cybersecurity fears between international trade rivals[ 3] have dogged the migration process throughout.

Although 5G will no doubt be a profitable venture for cellular carriers and network operators, it will require an exponential upfront investment to upgrade, improve and replace the existing cellular network infrastructure. However, it is not just the upfront cost of the network overhaul that is likely keeping network operators awake at night, but the ongoing operational expenditure as well. The fact that 5G will consume more power than 4G is an inescapable reality; in fact, power consumption is predicted to rise by almost 70 percent as a consequence (Figure 1). For example, where a 4G base station might require around 7 kW of power, a 5G base station will need over 11 kW - and some stations carrying multiple channels could even consume up to 20 kW.

## More of everything is needed

Even though the technology behind 5G networks are generally more efficient than 4G, the increased capacity of each cell will result in an overall increase in power consumption. The reason for this is the use of Massive MIMO (Multiple-Input, Multiple-Output) antennas over a single radio channel to improve signal quality. In comparison with 4G base stations, which typically use 4T4R (4 transmitters, 4 receivers), 5G base stations employ 64T64R.

It is thus no mystery to see why the demand for power is so much higher. Some 5G network providers struggling with the mechanics of delivering it are even debating the possibility of limiting the number of transceivers at base stations to 32T32R in order to save power, even though this would effectively throttle the capacity of the network.

To compound the issue of increased power demands at existing base stations, the other challenge is the need for more base stations than ever before. This is partly because the radio wavelengths particular to 5G technology have a more limited range, meaning that a greater concentration of base stations will be needed to provide given areas with effective coverage. The cost of building these new base stations and installing the power grid that will support them will be enormous.

Finally, there is the problem of power supplies; the industry standard of 3 kW 48 VDC will be woefully inadequate, even if the total amount of power required only doubles. Power density will therefore need to be increased significantly to deliver the same amount of power using a comparable amount of space.

## Moving to the edge

5G networks will see the network map undergo significant change as increased processing power migrates closer to the edge where data collection actually takes place

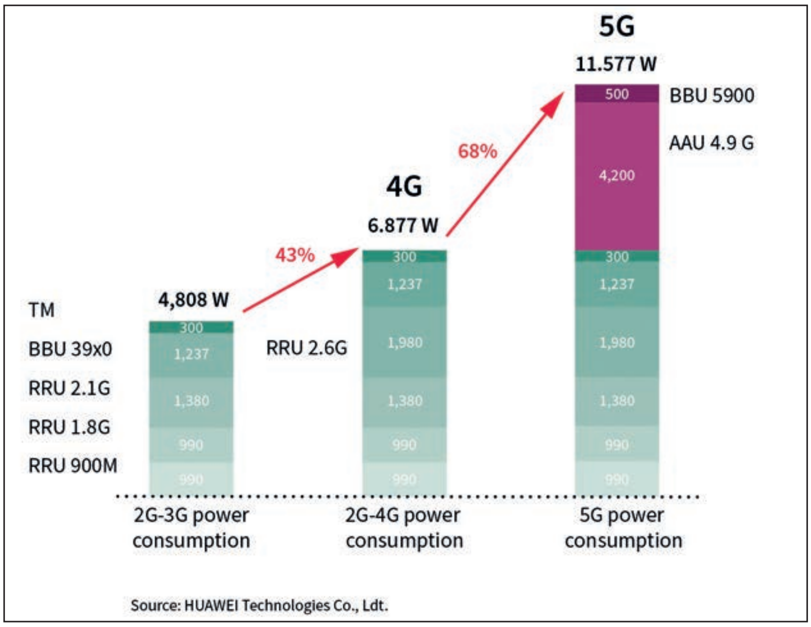



**Figure 1: The power consumption of a typical 5G telecom site (Source: Huawei Technologies)**

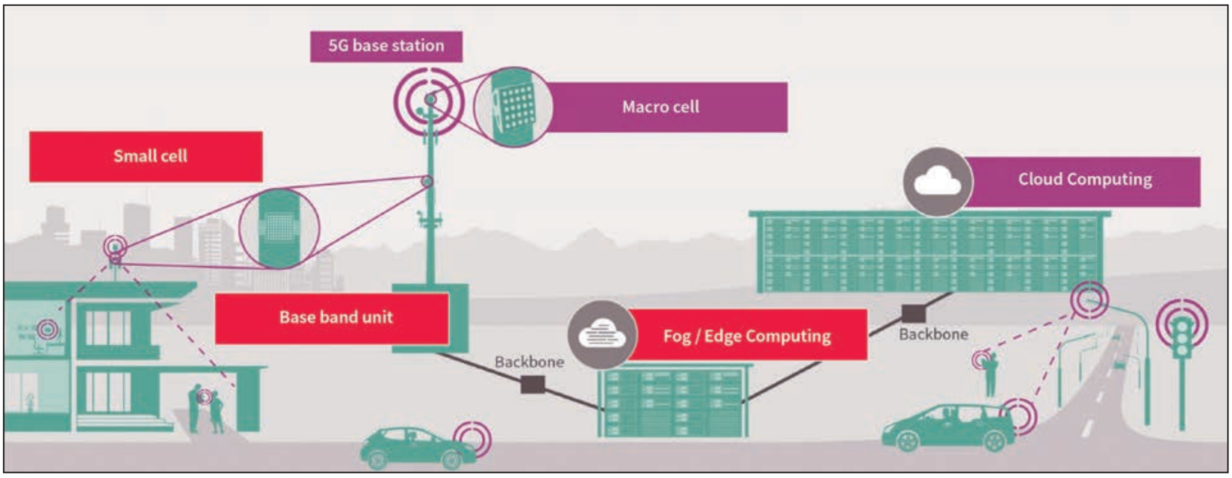



**Figure 2: SMPS in the 5G ecosystem**

(Figure 2). Not only will additional hardware be required to implement 5G, but the stations themselves will require more compute power to support the wider range of services that the new generation of mobile broadband will offer. As operators begin to deploy edge computing, the power architecture for each station will need careful consideration.

## More power density, less heat?

It's clear from the points covered that some tough design challenges lie ahead. Support for the necessary power input can only be achieved by increasing the efficiency of the power conversion stage and will be instrumental to delivering more power in the same footprint. The key to this efficiency lies in a combination of gallium nitride (GaN) wide bandgap semiconductor technology and cutting-edge surface-mount design (SMD) packaging.

Unlike through-hole devices (THDs), SMDs are mounted directly on the surface of the PCB. The elimination of through-holes and leads as well as increased function density makes more space available on the board, thereby increasing power density capabilities.

However, increased power density can be a double-edged sword as it is usually delivered hand-in-hand with corresponding heat density. Packing more power into a given area can only be advantageous when heat density can be kept the same or, if possible, be decreased. SMD packaging offers a significant benefit in this regard as it allows for top-side cooling by putting the top of the package in direct contact with the enclosure, which is usually made of aluminum. This offers a much shorter thermal path for the heat to escape from the transistor junction to ambient air.

Using traditional Silicon semiconductors in SMDs will not be able to deliver lower heat density. Even though packaging technology continuously improves to offer better thermal conductivity, the device will still be limited by the operating temperature unless the semiconductor material inside switches more efficiently. Although Si MOSFETs have reached their upper limits of efficiency, new wide bandgap semiconductors such as silicon carbide (SiC) and GaN offer much higher efficiency.

In SMD packaging, GaN has certain physical properties that allow it to switch higher powers at higher frequencies than its Si counterparts, as well as offering a lower on-resistance ($R_{DS(on)}$) and significantly lower switching losses. Because the power converter can operate at higher frequencies, the power supply topology is simplified due to the lower number of magnetic discrete components required in the circuit, thereby allowing for greater power density. Moreover, GaN's inherent high efficiency means heat density can, in most cases, be reduced.

Figure 3 shows a Pareto analysis of all possible power density and efficiency combinations of a 3 kW 48 V PSU at 50 % load. It demonstrates that using Infineon's CoolGaN in power conversion solution could either result in higher efficiency, higher power density or a combination of both when compared to even the most state-of-the-art Si MOSFET solutions.

It is clear therefore to see that GaN in SMD packages are a perfect match for the particular requirements of 5G network infrastructure and enable network operators to deliver the power of 5G even in the most challenging places

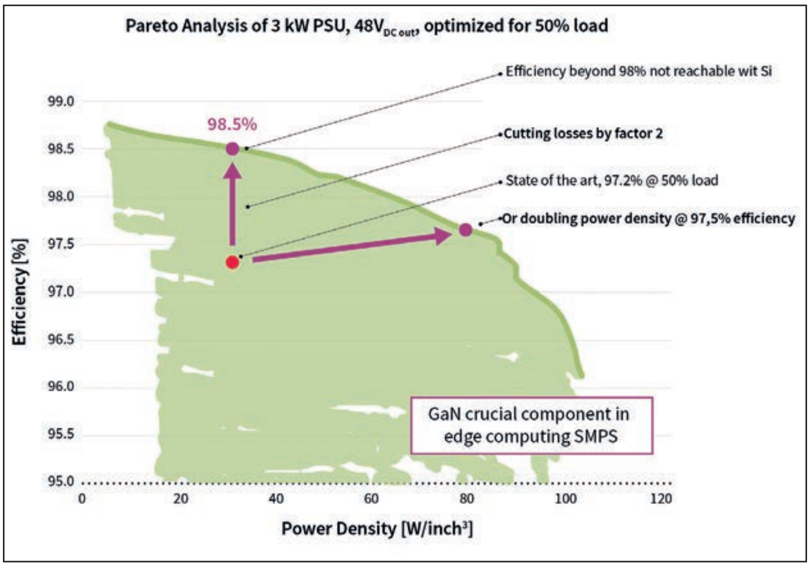



**Figure 3: GaN can provide higher power density and greater conversion efficiency**

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# The Landscape of Isolated DC/DC Bias Power Supplies

Moving signals and power across an isolation barrier is a common challenge for designers. Isolation might be required for safety, noise immunity or large potential differences between system domains. Understanding system-level specifications like the number of outputs, regulation requirements, output power, insulation rating, operating temperature and input voltage range are critical. From there, designers can derive the lowest-cost solution that meets all of the system requirements. **Ryan Manack, Business Lead, Texas Instruments, USA**

**For example, a cellphone charger is** internally isolated to prevent humans from becoming electrically tied to the mains if the connector short-circuits. In factory robots, sensitive control circuitry sits on a separate ground and is isolated from the motors that draw large DC currents and create noise and ground bounces. Communication and sensing are commonly implemented across an isolation barrier.

Traction inverters and motor drives take a PWM signal from the motor controller and pass it through an isolator to tell the gate driver to turn an power transistor on or off. Isolated bias converters enable isolated communication and sensing by providing bias power from one side of the isolation barrier to the other. Current and voltage sensors, digital isolators and gate drivers typically require less than 15 W and as little as tens of milliwatts of power. Figure 1 shows an example of each of these applications.

### Isolated DC/DC bias supply requirements

There are many solutions that can provide isolated bias power, from controllers, which have external power switches, to converters, which integrate a controller with power switches, to finally power modules, which integrate controllers, power switches and transformers in one package. Because of this wide variety of bias power solutions and diverse applications that they go into, it is important to fully understand the application requirements in order to meet the specifications at the lowest cost.

At a minimum, the designer should understand the bias supply input voltage range, the output voltage and the output power requirements. Some applications will require more than one bias voltage so it is important to define the acceptable regulation for each output. System requirements such as insulation rating,

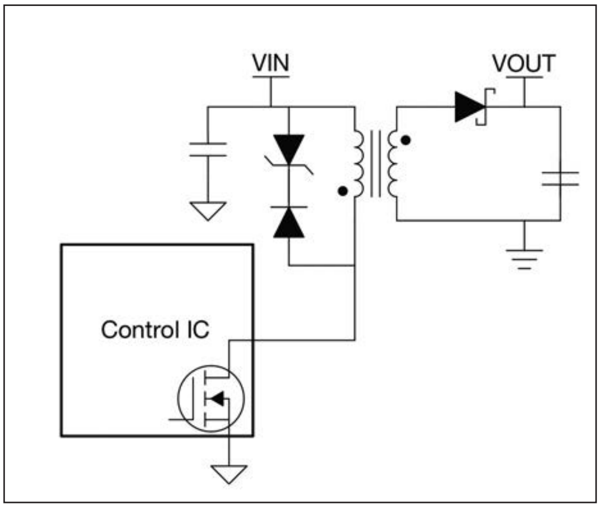


Figure 2: **Simplified schematic of the flyback converter**

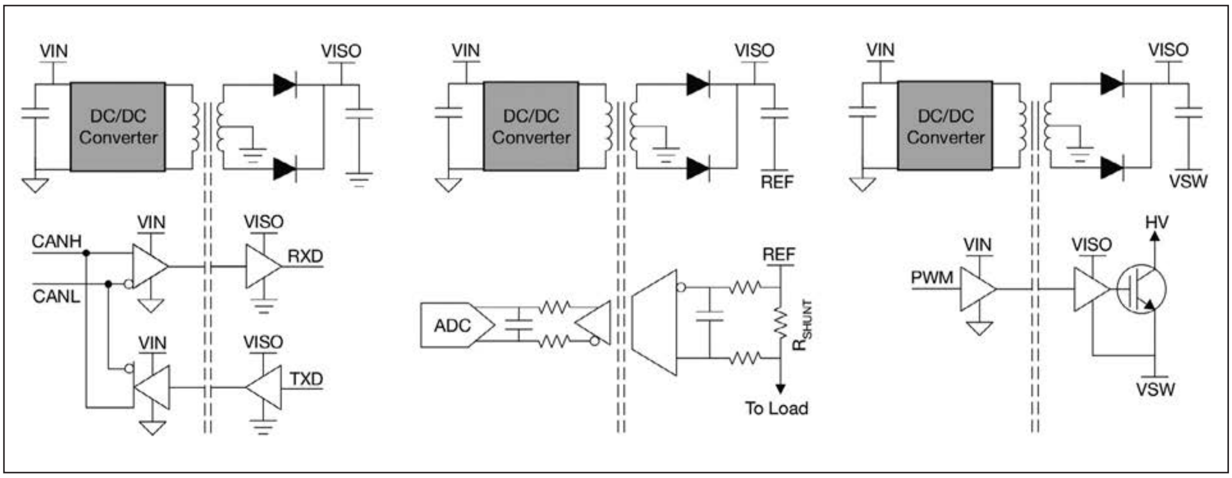


Figure 1: **Isolated bias applications**

ambient operating temperature range, electromagnetic interference (EMI) and electromagnetic compatibility (EMC) will further drive design decisions. Let's review some example isolated bias supply topologies.

### Flyback converter

The flyback converter is a well-known topology that has been widely used for decades. This power converter can support a wide variety of applications due to its flexibility and low cost. Advancements such as FET integration and primary-side control make this topology even more attractive.

Compared to buck-derived topologies like forward, push-pull and half-bridge, the flyback topology requires only one primary switch, one rectifier and one transformer-like coupled inductor (Figure 2). When the primary switch is on, the input voltage is applied across the primary winding, storing energy in the transformer's air gap. The output load is supported only by the output capacitor in this state. When the primary switch turns off, the energy stored in the transformer is delivered to the secondary through the rectifier to supply the load and recharge the output capacitors.

A flyback converter performs well as a bias converter for a number of reasons. It provides regulation and isolation in one conversion stage. Its flexibility is also useful for multiple outputs. The number of output windings and wind the transformer support a chosen configuration.

The corresponding voltage on the output windings is a function of the duty cycle and the primary-to-secondary windings' turns ratio. It is also possible to reference each output to a different ground in order to meet system isolation requirements. Other flyback benefits include its relatively low cost and wide input-to-output operating range.

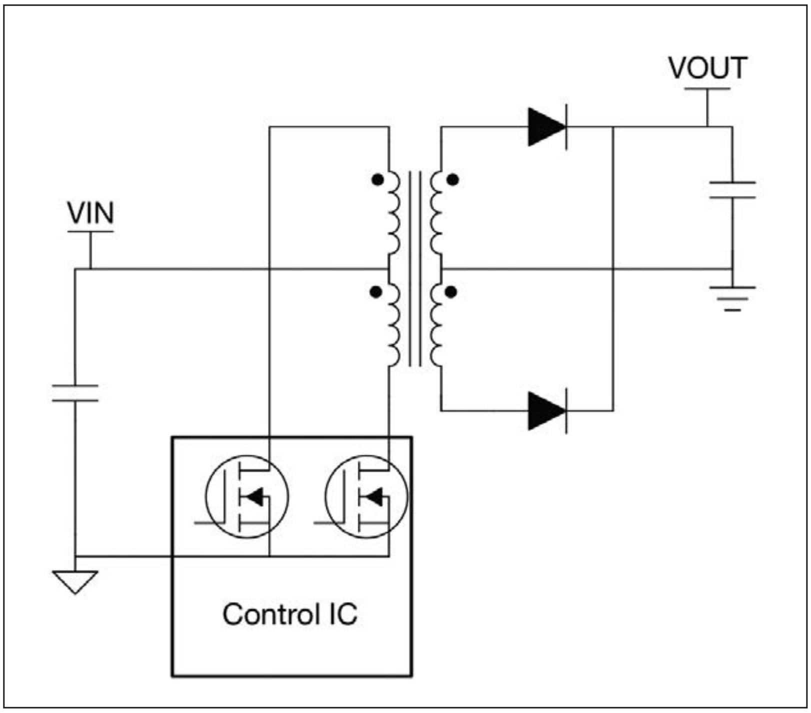


**Figure 4: A push-pull transformer driver**

It is important to properly design a flyback transformer for best performance. The transformer should be very well-coupled, with low leakage inductance for the highest efficiency and best regulation, especially in multiple outputs. However, it is also necessary to limit the parasitic capacitance from the primary to secondary in order to prevent excessive EMI.

### Fly-Buck converter

A Fly-Buck converter is a TI-specific topology used to create an isolated bias supply. It is capable of operating from input voltages as high as 100 V. Like a flyback converter, MOSFETs are typically integrated inside the IC, and it is very simple to realize primary-side control (Figure 3). The topology uses a synchronous buck converter with a coupled inductor to create one or multiple isolated outputs. When the high-side switch is on, the primary side works like a buck converter and the secondary winding current is zero. In the off-state when the low-side switch is on the secondary side is driven from energy stored in the primary.

Synchronous buck converters are widely available, making the Fly-Buck converter an attractive topology. The converter does not require an additional auxiliary winding or optocoupler for control as the feedback loop can be closed on the primary output voltage. The coupled-inductor construction is flexible. The turns ratio, insulation rating, number of secondary windings and PWM duty cycle are controllable for use in a wide variety of applications.

Like the flyback converter, the coupled inductor must be properly designed. It is important to manage the leakage inductance while limiting the parasitic capacitance from primary to secondary. For applications requiring greater than 100-V inputs, a Fly-Buck converter can be used with an external MOSFET.

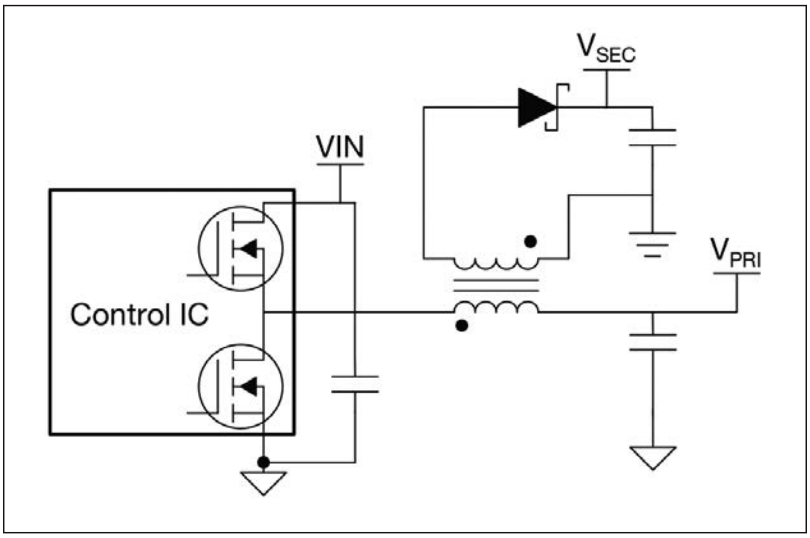


**Figure 3. A Fly-Buck™ converter**

### Push-pull transformer driver

A push-pull transformer driver is a commonly used solution for low-noise, small-form-factor isolated power supplies. It is supplied from a tightly regulated input rail and operates in an open loop at a fixed 50 % duty cycle. MOSFETs are integrated into the IC, enabling a compact solution (Figure 4). The push-pull topology is a double-ended variant of the forward topology with both MOSFETs ground-referenced, eliminating the need for external bootstrap circuitry. Similar to the single-ended forward converter, the voltage stress at the FETs is two times the input voltage. The MOSFETs switch at a 50 % duty cycle during alternate half cycles, driving the center-tapped winding of the transformer.

The push-pull transformer driver is a prevalent isolated bias power-supply solution for many reasons. It offers flexibility and the ability to support multiple outputs. The open-loop configuration provides design simplicity by eliminating the feedback loop. The push-pull transformer offers lower primary-secondary capacitance, which enables a reduction in common-mode noise compared to flyback and Fly-Buck converters. Additionally, the push-pull topology more efficiently uses the transformer core magnetizing current, resulting in a smaller magnetic solution compared to flyback and Fly-Buck converters.

Although the transformer driver carries a number of advantages, it is also important to take into account the trade-offs. Unlike the flyback and Fly-Buck converters, the transformer driver cannot support a wide input voltage range, and instead requires a tightly regulated input voltage.

Meeting the output-voltage regulation requirements for feedback can be challenging due to the absence of a closed loop and may require a low-dropout post-regulator (LDO).

### Power modules

Power modules have existed for decades. These solutions are widely available and offer significant integration compared to discrete implementations. Power modules exist in many varieties, with input voltage, output voltage, output power, number of outputs, isolation rating and regulation options. Figure 5 shows the block diagram of the inner workings of one power module. The topology includes a transformer driver similar to the discrete version. Some devices may integrate an output LDO for regulation.

With many options available, a power module can be used in most isolated bias converter applications. They greatly simplify the design process because there is no need to specify, design or choose a transformer; to include an input and output decoupling capacitor is sufficient to start the design. Other options like synchronization, output voltage selection, enable and error signaling are available as well.

Some flexibility with modules will be lost, specifically to configure the number of outputs and transformer turns ratios. The selection of modules rated for a 125°C ambient temperature range is less than for the 55°C and 85°C options. Similarly, the number of modules available with fully reinforced insulation ratings is less than those modules available with functional or basic isolation.

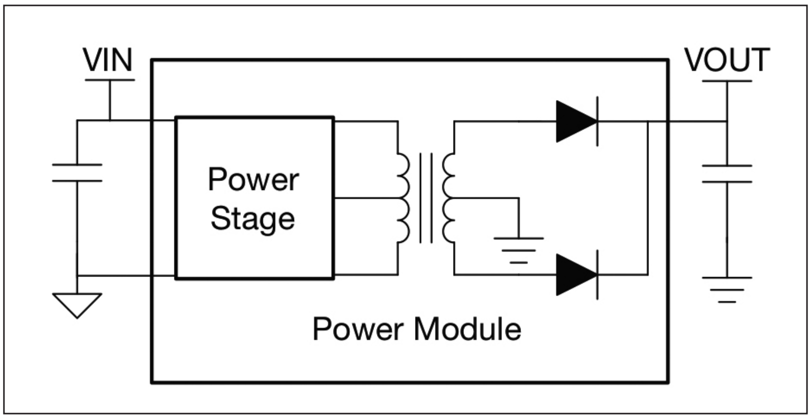


Figure 5: Block diagram of the inner workings of a power module

### A next-generation bias solution

Innovations in transformer design and higher frequency topologies have enabled IC designers to integrate a transformer and Silicon into one IC. For the end user a small, lightweight isolated DC/DC bias power supply is available without having to design a transformer or compromise on system performance.

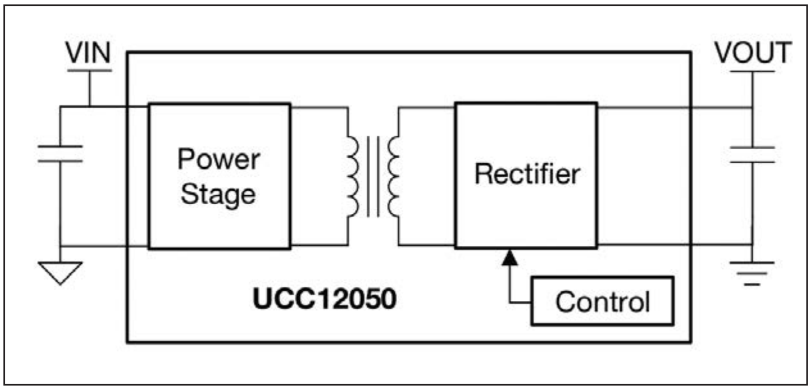


Figure 6: UCC12050 isolated DC/DC bias power supply

Figure 6 shows the block diagram of the UCC12050. Though it looks similar to a power module with integrated power stage and rectifier, a closer look at the operation shows that the switching frequency is much higher compared to power modules. This allows significant height and weight reduction versus lower switching frequency alternatives. The internal topology control scheme runs closed-loop without an LDO or external feedback components.

The UCC12050 brings many benefits to the wide variety of isolated DC/DC bias supply applications. It is designed with an EMI-optimized transformer with only 3.5 pF of primary-to-secondary capacitance and a quiet control scheme. On its own the solution can pass CISPR32 Class B on a two-layer PCB without ferrite beads or LDOs. The device is rated for reinforced isolation of 5 kVrms and 1.2 kVrms working voltage and will operate at 125°C ambient temperature. The family of devices also includes UCC12040, which is rated for basic isolation of 3 kVrms and 800 Vrms working voltage.

UCC12050 is targeted for 5-V input, 3.3-V to 5.4-V output applications requiring 500 mW. Applications requiring higher input or output voltages will need to provide pre-or-post conversion. Also, for designs requiring power above the UCC12050's derating curve, alternative topologies should be explored.

### Literature

Power Through the Isolation Barrier: The Landscape of Isolated DC/DC Bias Power Supplies; Texas Instruments, APEC 2020 Presentation.

# Stabilizing Voltage the Right Way

Bypass capacitors are frequently needed in electronics development. Placement of bypass capacitors on the board in a switching regulator is very important for achieving the greatest possible effectiveness for these components. **Frederik Dostal, Field Applications Engineer, Analog Devices, Munich, Germany**

Figure 1 shows a switching regulator that can generate a lower voltage from a high voltage. In this type of circuit, the bypass capacitor ($C_{BYP}$) is especially important. It has to support the switched currents on the input path so that the supply voltage is stable enough to enable operation.

Because the input capacitor in a buck converter is part of the critical paths (hot loops) for this topology, $C_{BYP}$ has to be connected with as little parasitic inductance as possible. Thus, the placement of this component is important.

The left side of Figure 2 shows a layout that is not very useful. Thin traces are routed to the bypass capacitor. The current flowing into the voltage converter also does not flow directly from the bypass capacitor. The bypass capacitor is only connected with additional thin contacts. This increases the parasitic inductance of the capacitor and reduces the effectiveness of this component. A suggested layout in which the effectiveness of the bypass capacitor is very high can be seen on the right side of Figure 2. The connection is made with very little parasitic inductance. It can also be seen that the pinout of the component being supported, for example, a switching regulator, has an effect on the board layout options. On the right side of Figure 2, the $V_{IN}$ and GND pins are closer together than in the poor example on the left side. This results in a smaller loop area between the bypass capacitor and the integrated circuit.

## Low parasitic inductance

Because the bypass capacitors should be connected with as little parasitic inductance as possible, it is recommended that they be placed on the same board side as the switching regulator is on. However, there are

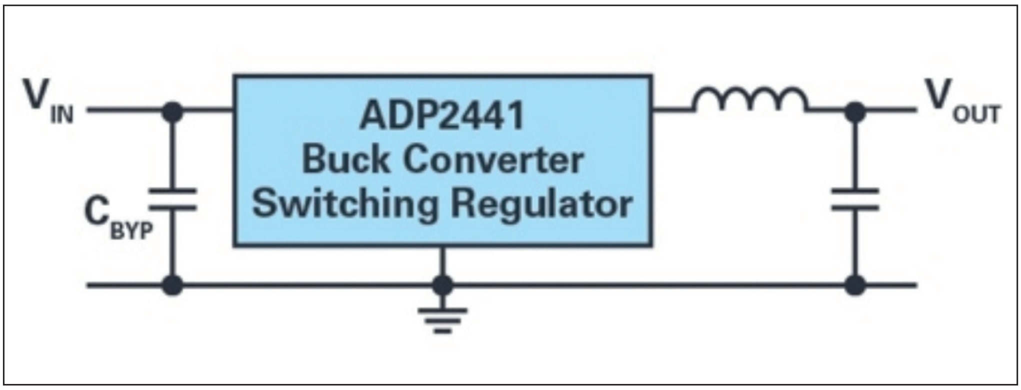


**Figure 1: ADP2441 switching regulator with the bypass capacitor CBYP at the input**

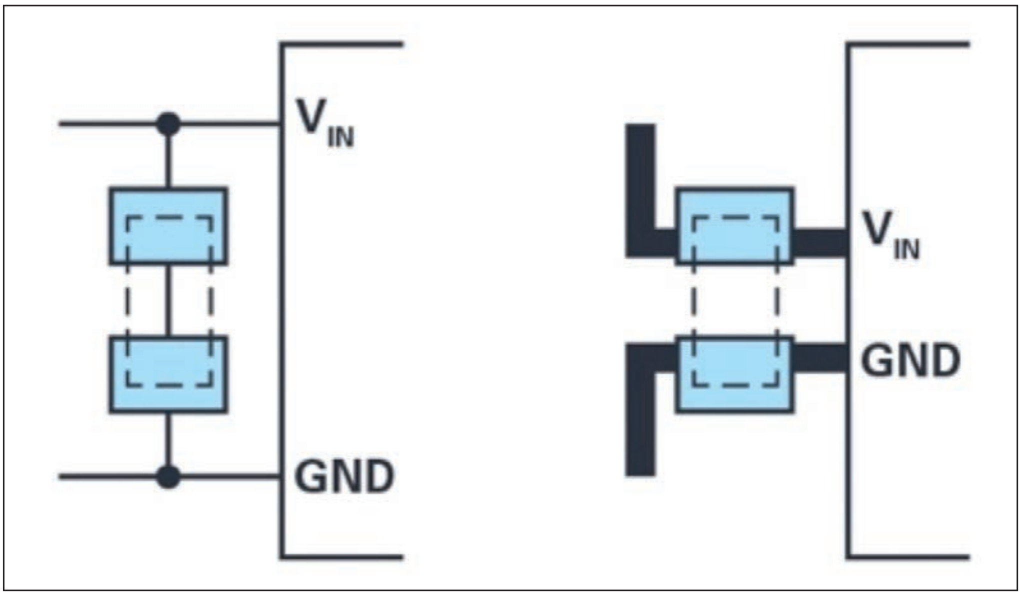


**Figure 2: Bypass capacitor connected unfavorably (left) and advantageously (right)**

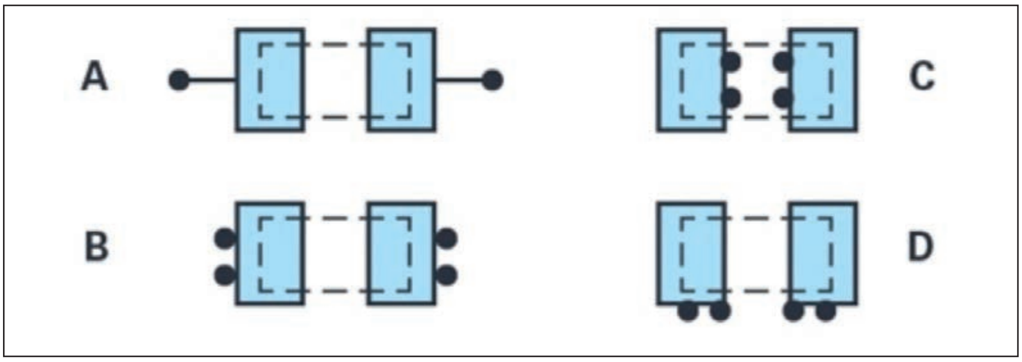


**Figure 3. When bypass capacitors are connected with vias, there are various options**

applications in which decoupling with a bypass capacitor is only possible on the bottom side of the board. One example is when there is not enough space for a large decoupling capacitor. In such cases, vias are used to connect the capacitor. Unfortunately, they have a few nanohenries of parasitic inductance. To keep this connection impedance as low as possible, various proposals for connection are given, as shown in Figure 3.

Version A is not particularly advantageous. Here, thin traces are used between the vias and the bypass capacitor. Depending on where on the other side of the board the paths to be supported run, the geometrical arrangement can also lead to increased parasitic inductance. In version B, the vias are brought much closer to the bypass capacitor, thus this is a much better connection. Also, two vias are used in parallel. This reduces the total inductance of the connection. Version C is a very good connection in which the loop area for the connection can be very small, thus there is only a very small amount of parasitic inductance here. However, with very small bypass capacitors and low cost manufacturing processes, vias underneath components are not possible or permissible.

Example D can be an interesting connection. Depending on how a specific ceramic bypass capacitor is designed, lateral connection to the board can represent the path with the lowest parasitic inductance.

## Conclusion

Placement of bypass capacitors on the board is very important for achieving the greatest possible effectiveness for these components. Here, connection with as little parasitic inductance as possible is important. The most suitable connection uses the same side of the board as the circuit being supported is on, as shown in Figure 2. In exceptional cases in which connection of the bypass capacitor on the back of the board is necessary, a connection with as little parasitic inductance as possible, as shown in examples B, C, and D in Figure 3, should be selected.

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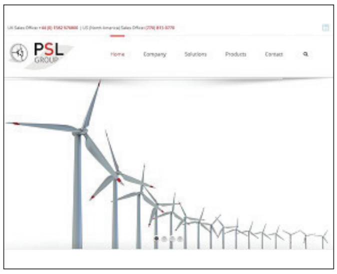

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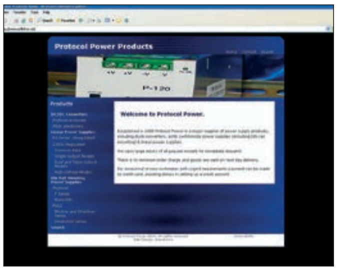

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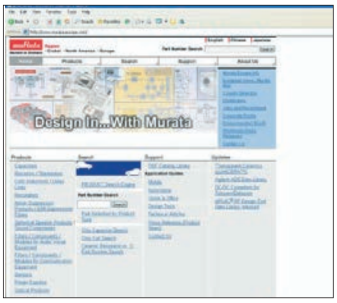

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