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THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

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FEATURE STORY

Edge Computing Leverages Modular Power in Scalable Micro Data Centres

Edge computing is essential to realizing the full potential of artificial intelligence (AI), machine learning and internet of things (IoT). These technologies are being infused into every corner of our lives—autonomous driving, smart buildings, robotics, supply chain management and healthcare. To deliver on the promise of these smart technologies, faster computation and data transfer speeds are needed closer to smart devices, closer to "the edge." HIRO, a Dutch entrepreneurial technology company, leverages modular power in scalable micro data centres for low latency applications, powered by DCM power modules from Vicor. Highly compact and efficient power conversion is achieved by designing hardware running from 48 VDC power distribution, instead of 12 VD. The higher voltage reduces I?R losses across the power delivery network (PDN). While 48 VDC distribution is common in telecoms and industry, it is only now beginning to find acceptance in data centre and associated edge environments. Vicor high-density, high-efficiency power modules contribute to HIRO's solid-state, thermally adept, compact, energy-efficient EMDC designs. Legacy solutions using standard COM Express modules (computer-on-module), for example, draw 150 W per card. This equates to approximately 3 kW within one 3U chassis. The ability to handle this high-density power conversion is unique to Vicor in the market. More details on page 25.

Cover image supplied by Vicor EMEA , UK

Gallium Nitride Takes Off

After the APEC 2022 in Houston the PCIM Europe is one of the major events in power electronics highlighting the new role of wide bandgap semiconductors and particularly Gallium Nitride (GaN). One of the outstandig PCIM sessions is entitled "Advanced GaN Power Electronics".

GaN as a material has various important electrical properties that make it a suitable and promising material for power electronics application. On the other hand, construction of a lateral-current-flowing heterojunction GaN high electron mobility transistor (HEMT) on a Silicon substrate provides additional practical advantages from cost, packaging and switching speed point of view, making it an ideal candidate for high frequency power electronics applications that could not be offered by SiC power devices. Of course there are also some disadvantages of this approach, primarily related to the reliability and scalability to higher voltage/higher power. The presentation of Alex Huang, Professor, University of Texas at Austin, USA will start from a material point view and then focus on GaN device performance comparison, especially with vertical Si and SiC power devices, to highlight the key motivations for adopting GaN. Challenges related to today's device in terms of dynamic on-resistance, gate drive requirement, short circuit capability and thermal management will be discussed. Future outlook of the device technology will be discussed focusing on bidirectional GaN FET and high voltage (>1200 V) GaN FET.

GaN power devices enable dramatically increased switching speed, reduced on-state resistance, and higher operating temperature. However, the decreased turn-on and turn-off transition times can also give rise to undesirable ringing, voltage overshoot, and electromagnetic interference (EMI), if not managed properly. Thus, improvement in power device packaging, gate drive circuitry, printed circuit board (PCB) layout, and new circuit topologies are needed to fully realize the potential of GaN technology. Robert C.N. Pilawa-Podgurski from the University of California outlines the key challenges associated with power electronics design with wide-bandgap power semiconductors, and present solutions that help unleash the true potential of these groundbreaking devices. Many of the early problems of GaN power converters can traced back to this mismatch between power device, package, and circuit implementations. This work will present practical solutions that mitigate many of the key challenges associated with GaN-based power converters, with a focus on technologies to achieve extreme power density designs.

The inherent advantages of GaN devices compared to their Silicon counterparts, i.e. absence of reverse recovery charge, lower output and gate charges, etc., allow to operate power electronic systems based on GaN devices at considerably higher switching frequencies, explains Matthias Kasper from Infineon This enables the design of systems with power densities beyond the limits of state-of-the-art Silicon systems, which will be demonstrated at two very different examples: a 240 W mobile charger with two output ports covering very wide output voltages of 5V-48 V, and a three-phase 11 kW on-board charger with an output voltage range of 250 V-800 V. The number of mobile devices such as mobile phones, tablets, and laptops, has increased and driven the need for a versatile adapter that can be used for several devices. Furthermore, the latest increase of USB-PD voltages up to 48 V, together with the 5 A rating of USB cables, opens the possibility to charge devices with up to 240 W. Thus, the current generation of single port USB chargers with 65 W of output power will no longer be sufficient for the consumer market, for which a new generation of higher power adapters with dual USB-PD ports is explored. The challenges to realize such a system are the wide ranges of input voltage (90 – 265 V) and output voltage (5 – 48 V), PFC requirement, and the supply of two independent output ports. In this talk, novel concepts that allow to leverage the advantages of GaN semiconductors in high frequency operation for the next generation of ultra-high density mobile chargers with wide output voltage range and high power level will be presented. As the electric vehicles (EVs) are proliferating, the requirements for on-board chargers (OBCs) are getting ever more demanding, and the original equipment manufacturers (OEMs) are requiring a volume and weight decrease of the OBCs, in order to be able to free space for other components and make the car lighter. The state-of-the-art power density for OBCs on the market now is 2 kW/l, and as WBG devices arrive, the goal is to reach 6 kW/l,, a factor 3 improvement in power density driven by WBG devices. Here an ultra high-density OBC employing a Vienna rectifier PFC providing a regulated split DC-link is used. The split DC-link allows to connect four cascaded dual active bridges (DABs) with 600 V rated GaN HEMTs for output voltage regulation. DABs are inherently bidirectional topologies and are able to operate with ZVS over a wide voltage range, making them the preferred choice for high frequency operation in OBCs.

Luca Nela from Swiss EPFL will discuss the future perspectives of GaN devices and propose novel architectures to significantly improve the device performance and address the main challenges of this technology. Investigated are multi-channel devices to improve the on-resistance vs break-down voltage trade-off, reducing conduction losses and resulting in cheaper and more compact power devices. Demonstrated are the potential of monolithically integrating several power devices on the same chip to realize power integrated circuits (ICs) with reduced footprint and high-frequency capabilities. To address the challenging thermal management of high-power density GaN devices and ICs, embedded liquid cooling in the device substrate is proposed, which enables extracting unprecedented heat fluxes. Finally, the potential of GaN for high-frequency soft-switching applications is explored and its performance to existing Si and SiC devices is compared, with a special focus on output-capacitance hysteresis and gate-driving losses in the range of 10 MHz.

These papers illustrate the increasing role of GaN – accompanied by new entrants in the market such as start-up Innoscience from China and most recently Japanese ROHM. We have prepared a lot of details on the following pages – also a comparison between GaN and SiC.

Achim Scharf
PEE Editor

A Massive AI-Powered Automotive Transformation

In 2035, C.A.S.E (Connectivity, ADAS, Sharing, Electrification) will be a $318 billion market, and the semiconductor value at chip level in a car will reach $78.5 billion in 2026, with a 14.75% CAGR between 2020 and 2026, announced Yole in its recent Automotive Semiconductor Trends report.

ADAS technologies used to be considered a 'nice to have' feature for safety-conscious family car owners. It has now become the new frontier for technology companies. "The C.A.S.E megatrends have taken the industry by storm, the whole ecosystem including automotive companies, semiconductor manufacturers is moving to adapt to this massive transformation," commented Pierre Cambou, Principal Analyst Imaging.

Mobileye from Intel, filling for an initial public offering at an estimated value of $50 billion, is a sign of the times when the same number was achieved by Xilinx, acquired by AMD in February 2022. A few months back, Waymo, the autonomous vehicle arm of Google, was raising $2.3 billion at a value of $30 billion while Huawei was shifting 10,000 employees from mobile activities, hit by US sanctions, to autonomous vehicle technology research. Other examples can be mentioned: BMW willing to fight off Tesla by partnering with Qualcomm and Arriver, the perception venture born from the $4.5 billion acquisition of Veoneer. "There is an endless list of noteworthy news pointing toward industry reorganization. Therefore, all semiconductor and technology giants are looking into the ADAS to AD transition, the new center of gravity of the AI revolution," Cambou said.

Road mobility is a $10 trillion market. ADAS to AD technology could be the magic ring to command it all. This includes cameras, radars, LiDARs, and a lot of edge and cloud computing. Yole's automotive analysts predict ADAS to AD technology to grow at 12% CAGR for the 2021-2027 period, reaching, at the electronic module level $25 billion in 2027.

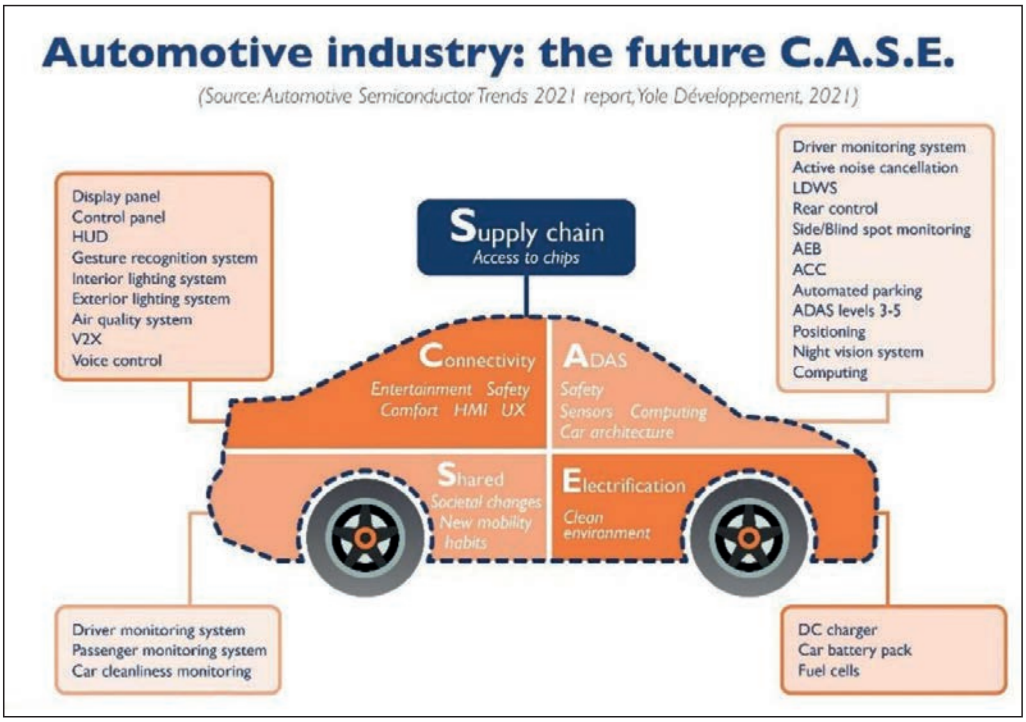
"Today, only 12 % of the 1,300 million cars on the road worldwide are fitted with ADAS technology," explains Pierrick Boulay, Senior Technology & Market Analyst, Lighting and Display at Yole. "This figure will rise to 50 % of the 1,800 million cars on the road estimated for 2030. This evolution is due to the huge increase in penetration of the technology in cars produced every year. From 21 % five years ago, ADAS is now fitted onto 65 % of all vehicle production in 2022, and this number will reach 86% by 2027."

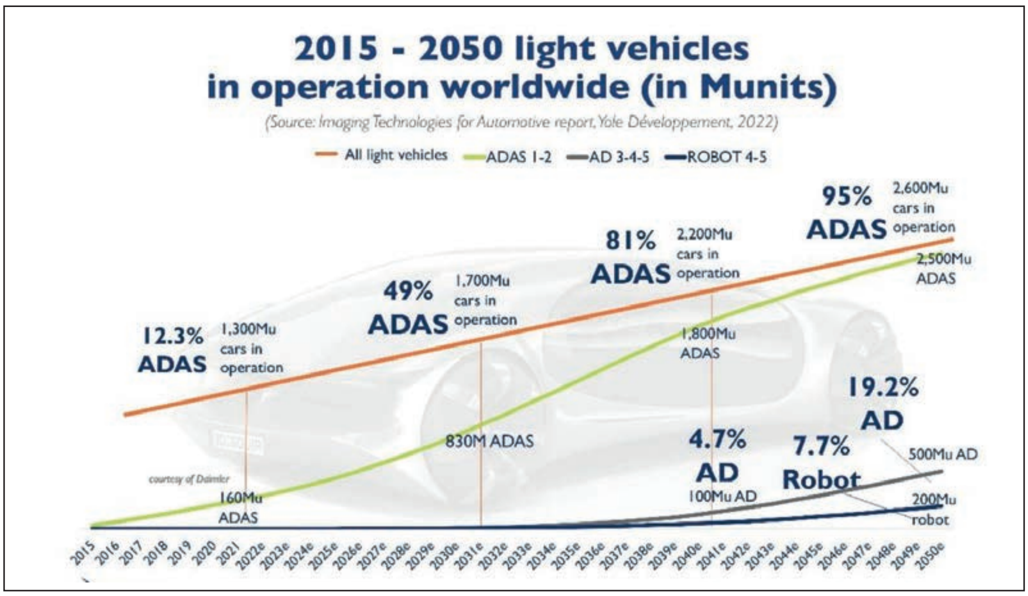
While quantitatively the transition is almost total, the qualitatively new generations of hardware are dubbed with 'Level of autonomy' increments, originally Level 1. Level 1 includes improved cruise control that could provide warnings to drivers. Then a transition came to Level 2 in different flavors:

Level 2+ and now Level 2++ for cars with automated steering and braking, under supervision; in certain ideal conditions, and we cannot yet call it "autonomous driving", but it is clearly at the top end of "advanced driving assistance", states Yole's analysts. The excitement is therefore palpable at Level 2. Key enabling technologies that benefit from this evolution are cameras, radars, LiDARs, and computing chips.

In the Imaging for Automotive report, Yole's imaging team describes the $440 worth of electronic content needed for Level 2+ cars of 2017, which is jumping toward $3,270 for state-of-the-art Level 2++ cars such as top-end Tesla, the recently released Honda Legend, and upcoming Mercedes S-class.

The threshold toward completely removing the eyes of the driver from the road is nearby. This is the indication that Level 3 has been reached, the Kàrmàn line for autonomy which then extends to Level 4 and even Level 5.





www.yole.fr

II-VI Accelerates SiC Substrate and Epitaxy Investments in the USA and Sweden

II?VI Incorporated announced that it is accelerating its investment in 150 mm and 200 mm SiC substrate and epitaxial wafer manufacturing with large-scale factory expansions in Easton, Pennsylvania, and Kista, Sweden. This is part of the Company's previously announced $1 billion investment in SiC over the next 10 years.

The global urgency to decarbonize energy consumption is accelerating the "electrification of everything" and driving a sea change in power electronics technology with the adoption of SiC. To meet the accelerating global demand for SiC power electronics, II-VI will significantly build out its nearly 300,000 square foot factory in Easton, to scale up the production of its state-of-the-art 150 mm and 200 mm SiC substrates and epitaxial wafers. Easton's 150 mm and 200 mm SiC substrate output is expected to reach the equivalent of 1 million 150 mm substrates annually by 2027, with the

proportion of 200 mm substrates growing over time. The expansion of the epitaxial wafer capacity in Kista is aimed at serving the European market. "Our customers are accelerating their plans to intersect the anticipated tidal wave of demand for SiC power electronics in electric vehicles that we expect will come right behind the current adoption cycle in industrial, renewable energy, datacenters, and more," said Sohail Khan, Executive VP. "The Easton factory will increase II-VI's production of SiC substrates by at least a factor of six over the next five years, and it will also become II-VI's flagship manufacturing center for 200 mm SiC epitaxial wafers, one of the largest in the world."

The Easton factory will be powered by an uninterruptible and scalable microgrid based on fuel-cell technology to provide high assurance of supply.

II-VI will leverage its industry-leading epitaxial wafer technology developed in Kista. This technology is differentiated by its ability to achieve thick layer structures in single or multiple regrowth steps, which is suited for power devices in applications above 1 kV.

https://ii-vi.com/

China's Share of Global Wafer Capacity Climbs

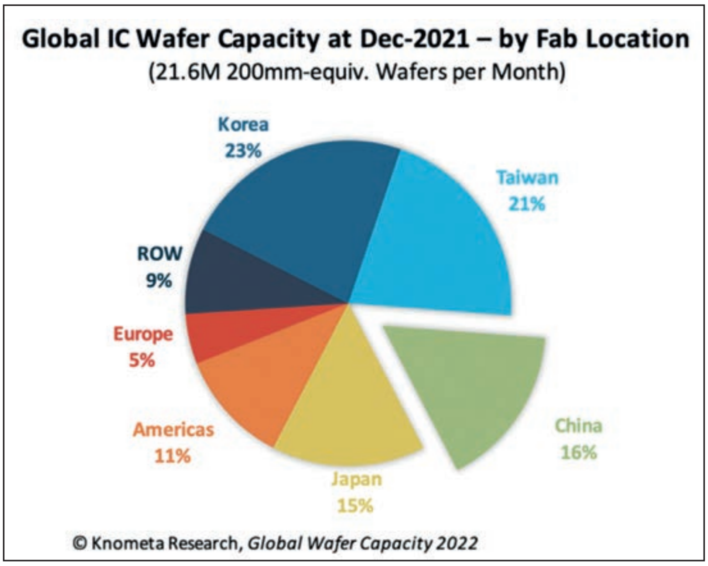
The new 2022 edition of Global Wafer Capacity from Knometa Research shows that China's share of the world's capacity for fabricating IC wafers continued to grow in 2021. The country ended the year having 16 % of global capacity, based on normalized installed monthly capacity amounts.

Worldwide IC wafer capacity at the end of 2021 was 21.6 million 200 mm-equivalent wafers per month, with fabs in China having the capacity to process 3.5 million. China's share of capacity has increased one percentage point in each of the last two years and a total of seven points since 2011, when the country accounted for just 9 % of all IC wafer capacity.

A report published by the SIA and Boston Consulting Group in 2021 showed that the cost of building and operating a fab in China is lower than in any other nation . As a result, fab capacity is expanding faster in China than anywhere else. Roughly half of all IC wafer capacity in China is controlled by foreign companies. In fact, some of the largest fabs in the country are owned by SK Hynix, Samsung, TSMC, and UMC. SK Hynix alone controls 17 % of China's capacity, and that does not count Intel's NAND flash fab in Dalian that SK Hynix is in the process of acquiring. Ownership of the fab was transferred to SK Hynix in December 2021, but Intel will continue to run it until March 2025.

As projected in Global Wafer Capacity 2022, China's share of global IC wafer capacity is expected to reach nearly 19 % by 2024. While SK Hynix, TSMC, and UMC are expanding their existing fabs in China, most of the new fabs under construction in the country are owned by domestic entities.

https://knometa.com



Chinese GaN Company Enters Europe and USA

After chargers for handhelds Notebook manufacturers are also interested in using GaN power devices, making the GaN power market the fastest rising category in the third-generation semiconductor industry. Trenforce estimates that revenue will reach $83 million in 2021, with an annual growth rate of up 73 %. The Chinese manufacturer Innoscience has risen to 20 % market share in 2021, jumping to the third place mainly due to the substantial increase in high and low voltage GaN product shipments.

Founded in December 2015, Innoscience is an Integrated Device Manufacture (IDM) that is focused on GaN technology. The company has two wafer fabs including dedicated 8-inch GaN-on-Si site, featuring the latest high-throughput manufacturing equipment. Currently the company has a capacity of 10,000 8-inch wafers per month which will ramp up to 14,000 8-inch wafers per month later this year and 70,000 8-inch wafers per month by 2025. The company has a wide portfolio of devices from 30 V to 650 V and has shipped more than 35 million parts for use in applications including USB PD chargers/adapters, data centers, mobile phones and LED drivers.

In February the company announced the opening of subsidaries in Leuven/Belgium and the US Bay area (see PEE 1-2022, page 9) and also the INN40W08, a 40 V bi-directional GaN-on-Si e-mode HEMT for mobile devices, including laptops and cellular phones. Featuring a bi-directional blocking capability, the new INN40W08 GaN HEMTs have a ultra-low on resistance of just 7.8 mΩ. This is achieved by the company's advanced

InnoGaN patented strain enhancement layer technology which reduces sheet resistance by 66%. Gate charge (QG) is typically 12.7nC. The 5x5 grid wafer level chip scale package (WLCSP) measures just 2x2 mm. In March they announced a new ultra-high-density 140 W power supply demo that uses the company's high- and low-voltage GaN HEMT devices to achieve efficiencies of over 95 % (230VAC; 5 V/28 A). Measuring just 60x60x22 mm (2.4x2.4x0.9 in) the PSU has a power density of 1.76 W/cm^3 (29 W/in^3). The 140 W 300 kHz AC/DC adapter uses a CRM Totem Pole PFC + AHB topology. It features INN650DA140A, a 650 V/140mΩ GaN HEMT in the 5x6 mm DFN package, for switches S1 and S2, the 650 V/240 mΩ, 8x8 mm DFN-packaged INN650D240A for S3, and the INN650DA240A, a 5x6 mm DFN 650 V/240mΩ device for S4. S5 and S6 are delivered by the INN150LA070A, a 150 V/7mΩ, 2.2x3.2 mm LGA part within Innoscience's low-voltage GaN HEMT range.

Commented Dr. Denis Marcon, General Manager of Innoscience Europe and Marketing Manager for the USA and Europe: "GaN technology has been adopted by manufacturers of mobile phone chargers over the last couple of years to deliver increased power and shrink device size. However, Innoscience's significant breakthrough now makes it possible to introduce GaN HEMTs into mobile phone handsets as well, increasing efficiency and performance. With Innoscience's huge available capacity, we provide the secure supply chain that customers nowadays expect."

Goal to rank number one by controlling own fabs

Thus PEE took the opportunity to ask Denis Marcon about the company's GaN strategy and manufacuring capability as well as future applications.

PEE: GaN on Silicon has been in mass production for almost 12 years with vendors such as EPC, Infineon/Panasonic, GaN Systems, Navitas, Nexperia, PI, STM, TI, or Transphorm. Some of them manufacture GaN power devices in-house, other uses the foundry-model. What differentiates Innoscience from these companies and in particular from world-leading foundries such as TSMC serving many of the mentioned vendors?

DM: I think the big difference is the fact that we own and control our own fabs, and this means we don't have to fight for capacity. In simple terms, if you don't fight for capacity, you then have stability of supply. We are much, much bigger in terms of capacity– around three times bigger - than the closest player that is a foundry who is serving several fabless players. Furthermore, contrary to everybody else, we produce on eight-inch wafers versus six-inch. This means almost 2x more devices/wafer and thus greater capacity, and lowest price as a result. And that goes hand in hand with the economy of scale.

PEE: Innoscience uses 8-inch wafers so far. What is the effect of the company's stress enhancement layer regarding (dynamic) on-resistance and how does it differentiate from other devices?

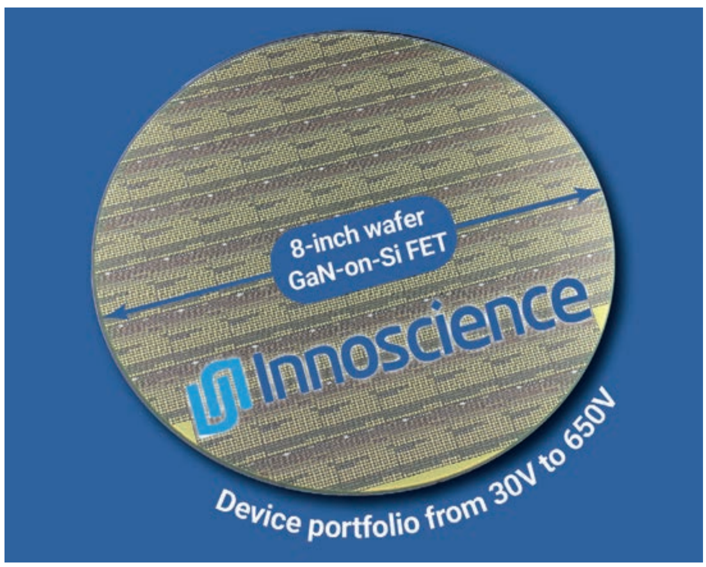
DM: We do indeed use eight-inch wafers. But actually, the stress enhancement layer has no relation to the wafer size. The stress enhancement layer is proprietary to Innoscience and enables our devices to have a very low dynamic on-resistance measure. The strain enhancement layer technology consists of the deposition of a specific layer after the gate stack definition. The stress modulation created by the strain enhancement layer induces additional piezoelectric polarizations; this causes the 2DEG density to increase and thus the sheet resistance to decrease by 66 % compared with a device without strain layer. Since the strain enhancement layer is deposited after the gate formation, it only affects the resistance in the access region and it does not impact other device parameters such as threshold, leakage etc. The bottom line is that our devices today have very, very low dynamic on-resistance over the full temperature and voltage range of a given device.

PEE: Since 2019 there is a shortage in 8-inch wafer production capacity. Is Innoscience affected by this trend and if yes, how to overcome this shortage? Possibly moving towards 12-inch?

DM: It's important to differentiate between the Silicon <100> that is used by the CMOS industry, and the silicon <111> that is used by the GaN industry. So, that's the first differentiator. We have agreement in place with our suppliers so we are not affected by this. We have also bought our stock to assure the supply, so we're good. Regarding an eventual move to 12-inch, that is of course something that we think about. We could produce more wafers, and we could also use 12-inch tools in the future. Let's say we remain open-minded about that possibility.

PEE: According to the website "Innoscience is the largest IDM that is fully focused on GaN technology. This means that Innoscience will fully support you by listening to your needs, providing Innoscience's samples and devices, developing specific devices for you and, in case of need, we can also support you to develop your system based on Innoscience's GaN devices." So, do customers have to follow certain design rules? Do you offer them company-specific devices or even GaN ICs at which quantity?

DM: First of all, it's important to remember we are not a foundry. We don't provide customers with rigid design rules for them to design with our



technology. We are an IDM. However, we are different to other IDMs in that we can provide customers with a customized design and supply wafers. We can design devices according to the needs of our customers. We listen to what the customers tell us, and we design the devices for them, and we can then supply the wafers. And we can also agree to supply devices only to an individual customer – as long as there is enough volume to warrant it.

PEE: GaN is used so far mostly in chargers and adapters for smart phones and coming notebooks, also LiDAR or other automotive applications are envisioned. What is missing are powertrain applications due to GaN voltage limitations. Do you expect to increase GaN BV levels in the near future in order to compete with SiC? And has Innoscience any activity to offer bulk GaN-on GaN in the future?

DM: For automotive EVs, GaN is already in the laser driver for LiDAR sensor and low voltage DC/DC converter. We also expected GaN to penetrate the large onboard charger (OBC) market. That is something for which GaN is already suitable; we have a 650 volt device, and we feel that this is going to be the next GaN automotive application. Then, with regards to the power train beat, GaN is not there yet. Normally you need 1200 volt device to address such an application. You therefore have two solutions. The first one is to develop a multilevel converter; in that case, you need a low voltage GaN to achieve that. The second option is to really develop 1200 volt GaN, to really position GaN to compete with silicon carbide. My previous employer, IMEC (Belgian research institute) has shown that it's possible to make 1200 volt lateral GaN devices on QST substrate. This is an interesting path that Innoscience will take a closer look at and compare it with a possible GaN-on-Si solution for 1200 volt. Regarding GaN on GaN bulking, that is also certainly interesting, technology-wise. The big limitation is the wafer size. The GaN wafers are limited to four-inch, that's not compatible with our current manufacturing capabilities. The second point is the price of those bulk GaN wafers, which can be incredibly expensive. But that is also something we are open-minded about and we will keep monitor the market evolution of GaN bulk substrate.

PEE: Aside from market research figures what is your expectation in the GaN market for the coming 5 years in order to justify huge investments in wafer processing equipment and packaging? At what ranking would you see Innoscience in this time frame, in 2021 its market share was estimated around 20 %?

DM: Well, nobody has a crystal ball that's for sure. But we think the GaN market will be booming – especially through greater penetration of the mobile phone market. This is one area we think will contribute to grow the overall volume of GaN dramatically. We also think GaN will penetrate elsewhere in the industry, in several consumer-type products, and eventually in the automotive sector too. We aim to produce 70,000 wafers per month, and that might not be even enough for the whole market. It's fair to say that today many companies understood the benefit of GaN devices and we expect a big, big increase. We want to support the development of GaN technology and its wider adoption; we want to play our part in the development of an ecosystem. And our goal is to rank number one. That's what we're aiming. **AS**

www.innoscience.com

SEMIKRON and Danfoss Silicon Power Join Power Module Forces

German-based SEMIKRON and Danfoss Silicon Power announced a merger to create a joint business specialized in Power Electronics focusing on power semiconductor modules and Silicon Cabide.

With an existing workforce of more than 3,500 dedicated power electronic specialists, the new SEMIKRON-Danfoss will provide world-class technology expertise as the leading partner in Power Electronics. The merger comes with a firm commitment to future investments, paving the way for green growth and a more sustainable, energy efficient and decarbonized future. Electrical power will be in the future the most important energy source. The power semiconductor module is at the heart of all power electronic solutions. With the rise of e-mobility, the demand for electric vehicles is expected to increase by 30 % each year over the next years. This speaks to the enormous growth potential of power modules as they are a key component for powering the electric motor and in vehicle chargers. Industrial motors are consuming 50 % of electrical energy in the world and only 20 % of these motors are equipped with variable speed motor controls, leaving a large untapped potential to improve energy efficiency and reduce carbon dioxide emissions. The power module is the key component in any variable speed control for electric motors. The ongoing global transition aiming at replacing fossil fuels by improving energy efficiency and ambitious use of renewables also increases the demand for power modules. The power module is critical in all solar installations and all wind turbines to enable the power conversion to grids and energy storage.

SEMIKRON-Danfoss will leverage its strong core business in industrial- and renewable power module applications and will utilize the partnership to target a leading position in Automotive power modules, and will set the trend and drive the technology shift into Silicon Carbide solutions in both industrial and automotive applications. The newly formed joint business will be owned by the current owner-families of SEMIKRON and the Danfoss Group, with Danfoss being the majority owner. The joint business will be operated in the accustomed manner, retaining existing production facilities in Germany, Nuremberg and Flensburg. The current factories and sales offices of Semikron and Danfoss Silicon Power will continue operations as usual. "With electrification driving the green transition, SEMIKRON-Danfoss aims to become the preferred decarbonizing partner for customers. We have the passion, competences and technologies to more than double our business in five years", said Danfoss President & CEO Kim Fausing. "With the emerging technology transition from Silicon to Silicon Carbide, we are set to become the strongest partner of our customers and will inspire the future", commented Claus A. Petersen, General Manager, Danfoss Silicon Power GmbH. "By combining our expertise as a pioneer for semiconductor technology with more than 70 years of experience in the development of top-class power modules and systems and the strength, innovativeness and fast-paced operations of Danfoss Silicon Power and the Danfoss Group we are positioned ideally to become one of the strongest players in power electronics", added Karl-Heinz Gaubatz, CEO of SEMIKRON.

www.semikron.com, www.danfoss.com

Management team of the new SEMIKRON-Danfoss (left to right): Claus A. Petersen, General Manager, Danfoss Silicon Power GmbH; Dominik Heilbronner, Shareholder, SEMIKRON International GmbH; Karl-Heinz Gaubatz, CEO/CTO, SEMIKRON International GmbH; Jorgen Mads Clausen, Shareholder, Former Chairman of Danfoss A/S; Bettina Martin, Shareholder, SEMIKRON International GmbH; Dr. Felix Hechtel, Head of Supervisory Board, SEMIKRON International GmbH; and Kim Fausing, President and CEO, Danfoss A/S **Photo: SEMIKRON-Danfoss**

pcim
EUROPE

Nuremberg, 10 – 12 May 2022

Exhibition & Conference Highlights

From 10 - 12 May 2022, the international power electronics industry will meet again live in Nuremberg after nearly two years of predominantly digital exchange.

As early as May 4, interested parties can look forward to so-called “Teaser Talks” from exhibiting companies and summaries of the conference highlights as part of the “digital warm-up”. This digital networking feature will be open from this point on. Subsequent to the on-site event, the “digital follow-up” will be opened on May 18 as a finale and to intensify the contacts made.

Special exhibition topics

The exhibitor list includes more than 300 companies, from start-ups to well-known industry leaders, of which more than half are international (53 %).

With the Batteries & More - Energy Storage Pavilion, a special exhibition area will be dedicated to the subject of Power Quality and Energy Storage, with companies specializing in this area of application. This topic will also be part of the lecture program of the specialist forum as well as the user-oriented conference.

Complementing the E-mobility Area, the E-mobility Forum offers specialist presentations by Hitachi Energy, Heraeus, EBV Elektronik and other well-known exhibitors.

At the Exhibitor Forum in Hall 7, interested parties can discover the latest product innovations by companies such as Semikron and Nexperia.

The Industry Forum is the platform for high-quality presentations and panel discussions on current research and development topics. The agenda includes, for instance, “Next Generation BESS Design - Future-Oriented Connection Technology for Enabling New Design Architecture” (Pheonix Contact), “Besides SiC Inverter Numerous Advantages what are its Impacts on E-Motor?” (Yole Developpement) and in addition, the forum will offer three lectures as part of the “Women in Engineering” initiative.

Over 300 conference presentations

As every year, the international conference will take place parallel to the exhibition. This format offers insights into the latest developments and research results from science and industry, for instance on SiC and GaN devices, new materials for high performance storage devices and photovoltaic power converters. Speakers will be providing specialist knowledge for example in the following sessions:

- Proven Power Cycling Reliability of Smart Cut SiC Substrate for Power Devices, Eric Guiot, SOITEC, France

- Trans-Inductor Voltage Regulator (TLVR): Circuit Operation, Power Magnetic Construction, Efficiency and Cost Trade-offs, David Wiest, Pulse Electronics, USA

- Reliability of Inverters in Photovoltaic Power Systems – A Detailed Field Data Analysis, Felix Kulenkampff, Fraunhofer Institute ISE, Germany

“On the one hand, this year’s conference will be offering outstanding presentations covering important future developmental directions in 107 oral and 194 poster presentations, these include new module interfacing materials for wide bandgap devices achieving dedicated lif etime, advanced power converter technologies for transportation systems and renewable energy technologies or driving and protection strategies for ultrafast switching transistors”, summarizes Professor Leo Lorenz, General Conference Director of PCIM Europe. “On the other hand, outstanding keynote presentations on ‘Hydrogen – Key Element to Achieve Net Zero CO^2’ and ‘Power Electronics for a Future Sustainable Society’ will trigger inspiring discussions and important future open innovations. Experts from industry and academia will benefit and be able to develop new future business models.” In addition, three special sessions will deal with the topics: “Cognitive Power Electronics”, “Advanced Measurement Technology in Power Electronics” and “Advanced GaN Power Electronics” (see our PCIM preview on keynotes and special sessions in PEE 1-2022 page 20-23).

A wide range of seminars and tutorials on the two days prior to the PCIM Europe provide additional knowledge transfer at the highest level. This year’s conference sponsors are Infineon, Mitsubishi Electric Europe and Semikron.

This year, the PCIM Europe will be held in a hybrid format, focusing on the on-site event, which will be accompanied by a digital platform. The latter can be used to make appointments for the event week, as well as to watch contributions of the forum and conference on-demand afterwards.

“This year’s conference will be offering outstanding presentations covering important future developmental directions in 107 oral and 194 poster presentations,” underlines PCIM Europe conference director Leo Lorenz

Are hybrid transducers the future for power converters with SiC MOSFETs?

Markets are expected to open up for sensors capable of delivering response times as low as 100 ns and unprecedented cut-off frequencies above 1MHz.

Much of what many operators in the industrial world are looking to achieve in terms of sustainability and productivity gains revolves around having the most efficient power converters. Suitable for working in the harshest of environments, including in a wide range of temperatures, the power converter of the future will need to be high-power yet lightweight, quiet and capable of high-frequency operation. Low power consumption will be essential.

The high-frequency requirement and the need to be as compact as possible mean that power converters must incorporate smaller passive components if benefits of reduced size and weight are to be realised. The trend to move away from pure silicon and increasingly make use of high-frequency SiC MOSFETs in high-voltage pulsed-power circuits has made it possible to cut space requirements, reduce costs, boost efficiency and enhance performance.

Because of their faster switching capabilities, SiC-based devices are able to operate at bandwidth frequencies that are greater than 100 kHz. This has led to them being used in such applications as uninterruptible power supplies (UPSs), solar inverters, AC variable speed and servo motor drives, power factor correction (PFC) and computer-controlled welding machines.

However, there has always been a trade-off between performance and response time and users in these various market sectors have been struggling for a solution that can satisfy their increasingly demanding requirements. While classic open loop transducers and closed loop versions are capable of frequency responses as high as 300kHz, in today's market these are still not sufficient for the high bandwidth sensing needs that have been driven by the adoption of SiC insulated-gate bipolar transistors (IGBTs).

Bandwidth above 1 MHz

LEM was approached by a customer in the welding sector, for whom existing response times and frequency responses on their power converters were proving to be inadequate. It was against this backdrop that LEM developed a hybrid transducer that more than trebled the performance levels of anything else on the market.

The hybrid is a mix of ASIC and DC-based transducer with a pure inductive coil to speed up the signal. Thanks to the pick-up coil on LEM's ASIC, the transducer is capable of reacting like a current transformer. While existing AC transducers based on a pure coil can achieve higher levels, there is no DC transducer featuring open loop technology and a pick-up coil that can perform at bandwidths above 1MHz – until now.

The LEM solution – the HOB family of around 20 low power consuming multi-range current sensors capable of measuring DC, AC or pulsed current up to 250A – was developed to meet high bandwidth sensing targets when using fast-switching SiC MOSFETs in high-voltage pulsed-power circuits where rapid and flexible high-voltage pulses are essential. The customer specifically wanted a top performance solution that delivered rapid response reaction times and expanded bandwidth, all in a smaller footprint.

Totally different semiconductor technology

While a closed loop sensor would ordinarily represent a high-cost option for any sector wanting to achieve these goals, LEM expects its hybrid transducer to become rapidly attractive to a range of markets that are looking to adopt any kind of switch-mode converters based on SiC and GaN WBG power modules. The growing trend to switch-mode converters is being driven by the need for devices and equipment to be as small as possible and to achieve superior power/weight ratios.

Thanks to what LEM calls "a totally different semiconductor technology", SiC or GaN very high-speed transistors not only ensure faster switching times but also offer higher frequency capabilities and higher voltage withstanding. The company expects that this transistor technology will become the norm in just five years.

Far more important than bandwidth frequency in the HOB family, however, is response time – the time between the primary current and the output on the transducer. This was a key factor for the customer who was aware that transistors that are switching faster and faster must have a current transducer able to follow the di/dt as closely as possible.

Response rate as little as 100 ns

Traditionally, while the di/dt could be as high as 500 A per microsecond (possibly even 1kA/µs) with this technology, the response

time on other transducers was around 1.5 microseconds. For its customer, LEM was committed to providing a guaranteed response rate as fast as 200 nanoseconds. Not only was this target met but it was exceeded, with the new HOB and its pick-up coil offering 150 ns response time. In some instances, the response rate was as little as 100 ns.

The models within the HOB family offer nominal currents of 50 A, 75 A, 100 A and 130 A, with currents at maximum power of 2.5 times those figures. The special (SP) models in the range are custom-designed to meet individual user specifications but all of them have a cut-off frequency (at -3dB) of above 1 MHz. The standard HOB family of transducers has a 5 V power supply (with voltage reference of 2.5) but other models have power supplies of 3.3 V, 3.4 V and 3.5 V. All are capable of operating in temperatures from -40°C to +105°C. Other features include galvanic separation between the primary and secondary circuit, an integrated busbar and an innovative design that enables space-saving THT (through hole technology) PCB mounting.

The future for hybrid technology

With a footprint the same as previous transducers on the market, the hybrid transducer is based on technology that LEM has provided successfully in the past for the automotive sector. However, thanks to its improved compactness and superior performance levels, LEM expects the technology to spread out into other domains as transistor production costs come down, automation increases and volumes rise.

The future for this new hybrid technology is expected to be assured when the market grows for very low cost, excellent performance, high response time applications. Some of the extremely demanding applications include hand-held plasma cutters, welders and DC/DC converters, as well as the previously mentioned UPS market, switched mode power supplies, AC variable speed and servo motor drives, and static converters for DC motor drives.

Already, LEM is receiving requests from customers for a PCB-mounted transducer offering nominal currents of 300 A, 600 A and more. While it is difficult to work out exactly how quickly demand will move, LEM has put itself in a position where it is now ready to provide a large number of markets with an open loop multi-range current sensor that combines unprecedented response times and frequency bandwidth with reliability, low power consumption, low noise and enhanced immunity to the dv/dt (acceleration) issues that SiC power modules can be prone to.

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GaN Assisted PFC and LLC for High-Efficiency Power Supplies

Power Integrations announced at APEC 2022 the HiperPFS™-5 family of power-factor-correction (PFC) ICs with an integrated 750 V PowiGaN™ gallium-nitride switch. With efficiency of up to 98.3 percent, the new ICs deliver up to 240 W without a heat sink and can achieve a power factor of better than 0.98. In combination with the off-line LLC switcher IC (HiperLCS-2) featuring integrated 600 V FREDFETs, synchronous rectification and FluxLink feedback high-power USB PD adapters, and power supplies for TVs, game consoles, all-in-one computers. appliances, and even e-bikes can be designed.

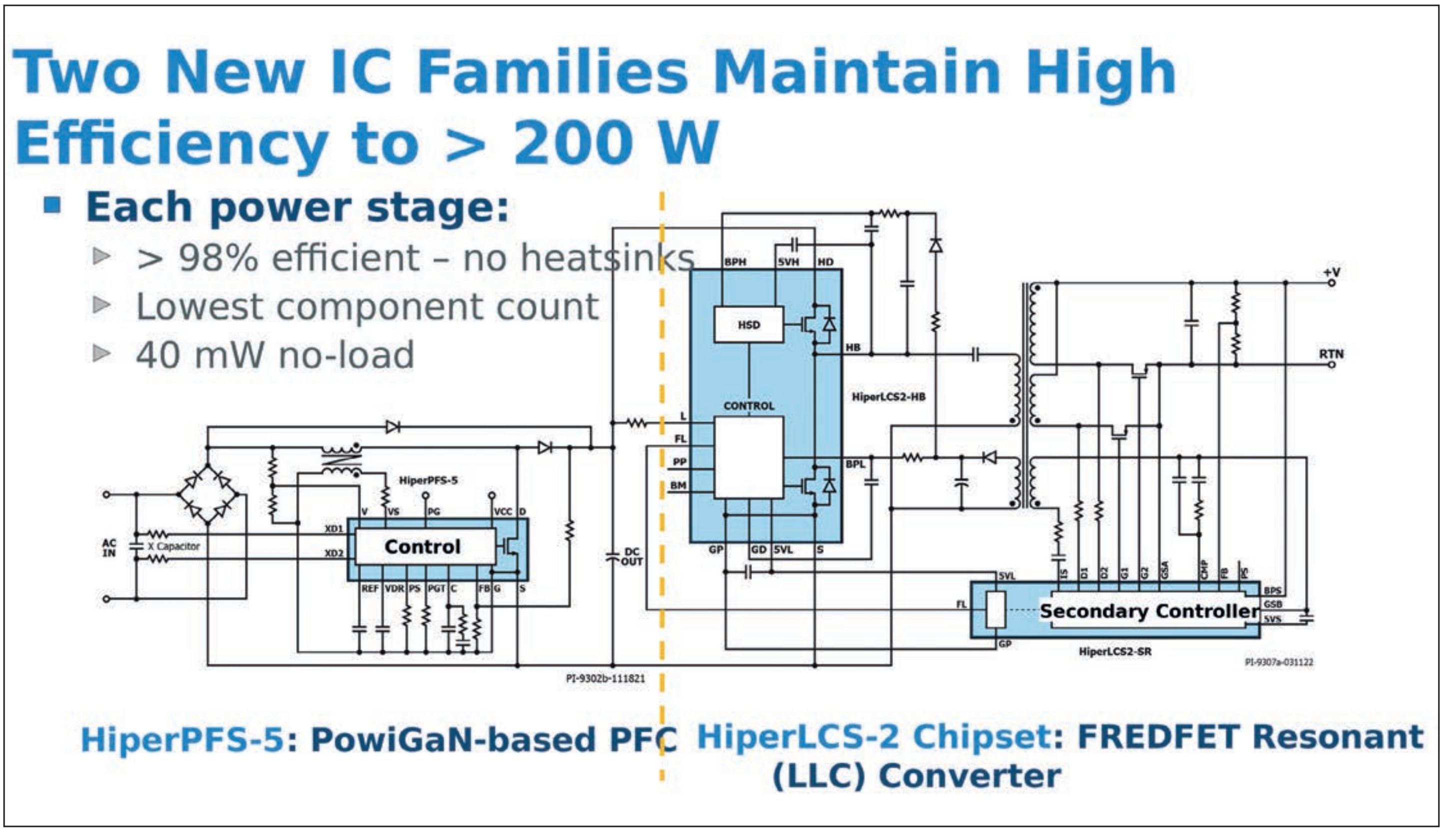
"We have combined our proprietary PowiGaN switch with a quasi-resonant, variable-frequency discontinuous mode boost PFC topology. By pairing HiperPFS-5 ICs with our new HiperLCS™2 chipset or our InnoSwitch™4-CZ active-clamp flyback ICs, designers can beat even the most aggressive efficiency regulations while cutting the bill of materials by half and achieving extremely attractive form factors for ultra-fast chargers," commented Andy Smith, Director of Training at PI/San Jose. "Many countries require power supplies over 75 W to adjust a phase change between current and voltage with so-called power factor correction, or PFC. While there are many PFC solutions available, HiperPFS-5 ICs with PowiGaN technology and a quasi-resonant (QR) control adjusts the switching frequency across output load, input line voltage and input line cycle. QR DCM control ensures low switching losses and permits the use of a low-cost boost diode. The variable frequency engine allows the reduction of boost inductor size by more than 50 percent compared to conventional critical-conduction-mode (CRM) boost PFC circuits. Low switching and conduction losses—which are further reinforced by the PowiGaN switch—together with lossless current sensing, mean that HiperPFS-5 ICs offer high efficiency across the entire load range, with efficiency rising as high as 98.3 percent. HiperPFS-5 ICs provide a PF higher than 0.98 at full load. At light loads an innovative power-factor-enhancement (PFE) feature compensates for input filter capacitance, maintaining a high PF of 0.96 even at 20 percent load. No-load power consumption is just 38 mW."

In many locations worldwide the mains power can be highly unstable, often leading to over-voltage failure of power supply components. HiperPFS-5 ICs maintain a high power factor up to 305 VAC and can operate continuously at up to 460 VAC during line swells. Additionally, X-capacitor discharge (CAPZero™) function works automatically, including the required redundant pins to meet safety regulations, and high-voltage self-start-up—all in a low-profile, InSOP™-T28F SMD power package. Exposed cooling pads are at source potential, providing effective cooling and simplifying EMI suppression. Digital line-peak-voltage detection ensures robust performance, even in the presence of distorted input from uninterruptable power supplies (UPS) or generators.

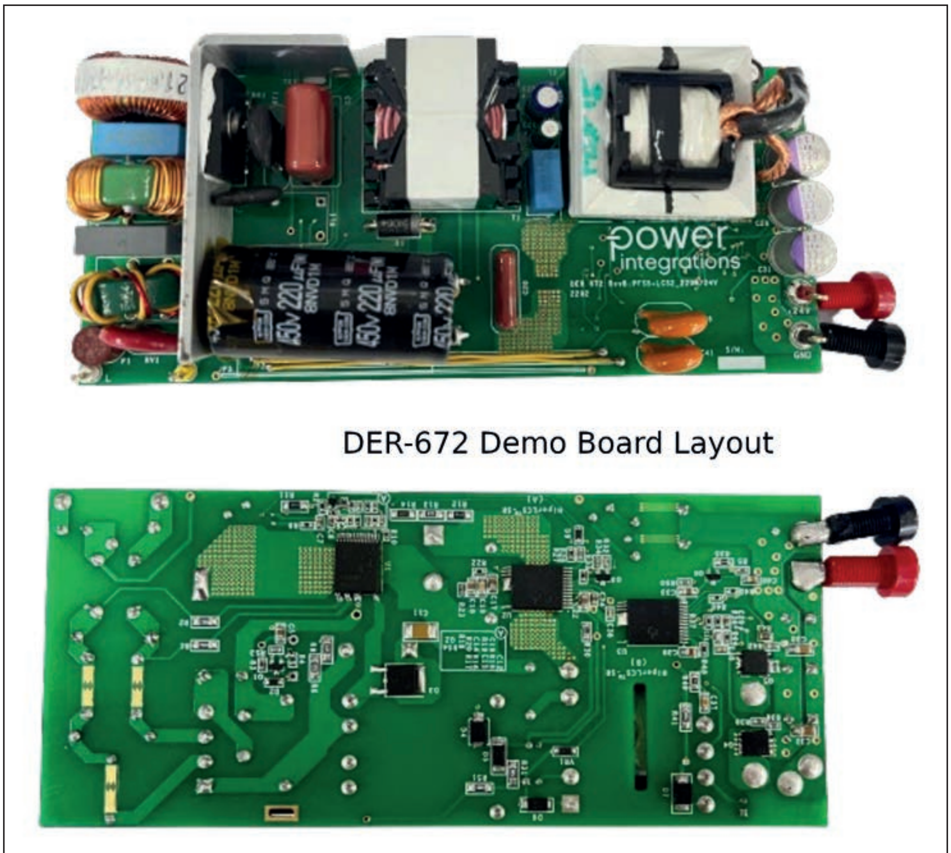
LLC controller

The HiperLCS-2 is designed for half bridge LLC converters, which are high-efficiency resonant ZVS, variable frequency converters. This IC chipset simplifies the design and manufacture of LLC resonant power converters. The LCS72xxC primary-side devices incorporate 600 V FREDFET in a half bridge

arrangement with control, level shifting, drive and self-powered start-up. The LSR2000C master controller device provides reinforced isolated feedback, output sensing and SR management. HiperLCS-2 family devices incorporate multiple protection features including: line over and undervoltage protection, output overvoltage and over-temperature shutdown. Device fault response options support common combinations



Two new power IC chipsets combine GaN assisted PFC and LLC for high-efficiency power supplies eliminating heatsinks



LEFT: DER-672 220 W reference design board layout

of latching and auto-restart behaviors required by applications such as chargers, adapters, consumer electronics and industrial systems.

HiperLCS-2 comes as a chip-set with two devices: the power-device, and the isolation device. The power-device (LCS726x), is on the primary side of the isolation barrier and includes an LLC controller with built-in high-side and low-drivers and half bridge power MOSFETs. The isolation-device (LSR2000), straddles the isolation barrier to facilitate communications to the power-device (primary device). The isolation-device also includes the secondary controller and SR-driver. The HiperLCS-2 is able to operate with nominal frequencies of up to 240 kHz. It offers extremely high conversion efficiency coupled with low-component count and rugged protection features.

The chipset complements the HiperPFS-5 ICs. The new dual-chip solution features an isolation device with a high-bandwidth LLC controller, synchronous rectification driver and FluxLink™ isolated control link, alongside a separate half-bridge power device utilizing 600 V FREDFETs with lossless current sensing and high- and low-side drivers. Both devices are housed in low-profile InSOP™-24 packages. This integrated, energy-efficient architecture eliminates heatsinks and reduces component count by up to 40 percent compared to discrete designs.

Power supply designs based on the new HiperLCS-2 can achieve no-load input power of less than 50 mW at 400 VDC input and provide a continuously regulated output, easily complying with the world's most stringent no-load and standby efficiency regulations. HiperLCS-2 devices operate at high efficiency across the load range with dissipation so low that direct heat transfer through the FR4 PCB is all that is required, eliminating heatsinks in adapter designs up to 220 W continuous output with up to 170 percent peak power capability. All HiperLCS-2 family members feature self-powered start-up and provide the start-up bias for a PFC stage using the company's ICs described above. Secondary-side sensing provides less than one percent regulation accuracy across line and load range and across production variations.

Devices are priced at $2.34 respective $3.20 in 10,000-unit quantities.

Design example

The DER-672 describes a 24 V, 220 W reference design power supply that can operate from 90 VAC to 265 VAC for TV and computer monitor applications. The power supply uses the mentioned CRM PFC front-end with a LLC DC-DC converter operating at 120 kHz for high efficiency power conversion.

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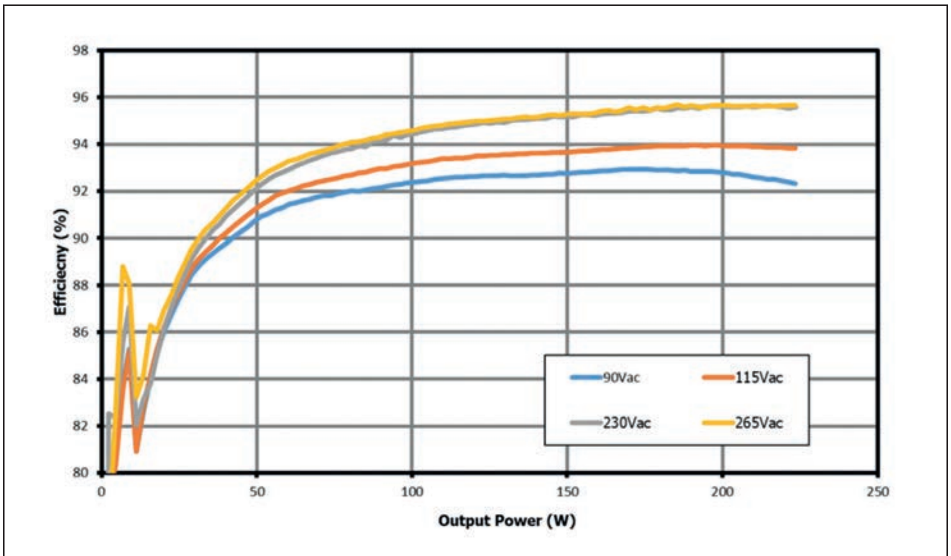

LEFT: DER-672 220 W reference design total efficiency with respect to output power and different line voltages

Enhancing Power Conversion from Watts to Megawatts with 1700 V SiC MOSFETs

In the world of power electronics, bigger is never better. This holds particularly true for high-voltage power systems, where designers are clamoring for better semiconductor technology to meet customer demand for converters that are smaller, lighter, more reliable and efficient, and less expensive. With Silicon MOSFETs and IGBTs, compromises must be made; for example, one must select either the most reliable design or the most efficient design, but not both. High-voltage Silicon carbide (SiC) MOSFETs are the key that designers need to unlock themselves from Silicon's handcuffs. In this article, the benefits offered by 1700V SiC MOSFETs over the incumbent silicon solutions across a wide range of power levels—from watts to megawatts—are discussed in detail. **Kevin Speer, Sr. Manager SiC Solutions, and Xuning Zhang, Sr. Tech Staff Engineer, Microchip Technology, USA**

For nearly two decades, SiC power devices rated from 650 to 1200 V have permeated the marketplace, at last allowing designers to make disruptive advancements to technologies and end equipment – simultaneously improving performance, reliability, size, weight, and even cost. The recent release of a 1700V SiC product family extends SiC's myriad benefits up the power food chain to help shift the power conversion paradigm into new end segments, such as electrified commercial and heavy-duty vehicles, light rail traction and auxiliary power, renewable energy, and industrial drives (Figure 1).

Tens to hundreds of watts

At such a low power level, what cause

Figure 1: **Examples of electrified vehicles which will reap the benefits of high-voltage SiC MOSFETs**

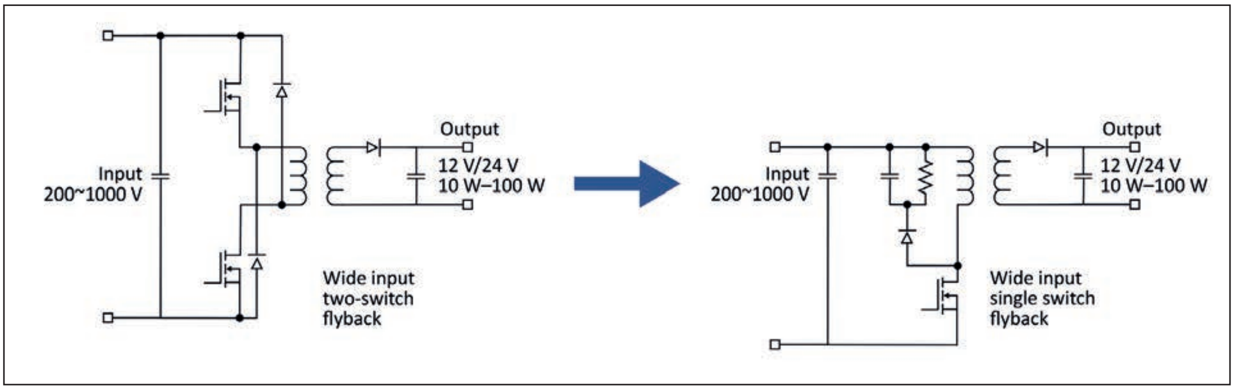

Figure 2: The two-switch topology (left) using Silicon transistors can be replaced with the much simpler single-switch flyback (right) using better-performing and lower-priced 1700V SiC MOSFETs

might there be for a 1700V transistor? Though there is just one, it is ubiquitous: Found in every power electronics system, the auxiliary power supply (AuxPS) is essential to the routine operation of industrial motor drives, electric vehicles, data center and backup power, solar inverters, charging infrastructure, and more. The AuxPS is system critical because it provides power to gate drivers, sensing and control circuits, and cooling fans; consequently, the AuxPS must not fail, and any associated risks should be mitigated.

Because these low-power, isolated, switch-mode power supplies are used in diverse applications, they must accept a wide-ranging, high-voltage dc input (300 to 1000 V) and output a low-voltage (5 to 48 V) source. Perhaps the most powerful method of failure mitigation is a simplified circuit design. As shown in Figure 2, the most reliable circuit design is the single-switch flyback topology (Figure 2, right), which offers simplicity and reduced component count – the latter adding a benefit of lower overall cost.

The introduction of 1700 V SiC MOSFETs provides an ideal solution for the AuxPS. Combining a high breakdown voltage, lower specific on-resistance, and fast switching speed, these devices are well-suited for the single-switch flyback topology. In contrast, Silicon-based solutions either have too low voltage rating, which necessitates a two-switch architecture (shown in Figure 2, left) and doubles the possibility of failure; or they have an adequate voltage rating but poor performance, few suppliers, and compared to SiC, a higher price.

Beyond the improved reliability, simpler control scheme, reduced component count, and lower cost, an AuxPS utilizing 1700 V SiC MOSFETs can also be smaller. The area-normalized on-state resistance, also called specific on-resistance ($R_{on,sp}$), of SiC MOSFETs is a fraction of that for Silicon MOSFETs. This means smaller packages may be used for the smaller die, and conduction losses are reduced which can ultimately result in smaller (or completely removed) heat sinks. Furthermore, SiC MOSFETs have lower switching losses, providing a pathway to shrink transformer size, weight, and cost by increasing the switching frequency.

Tens to hundreds of kilowatts

Moving up the power range, 1700V SiC MOSFETs also provide many advantages over Silicon MOSFETs and IGBTs in applications ranging from tens to hundreds of kilowatts. Examples include string and central solar inverters, auxiliary power units (APUs) in commercial transportation vehicles, induction heating and welding machines, industrial drives, wind converters, and more.

As the processed power increases, so does the impact of SiC's faster, more efficient switching.

Compared to the Silicon IGBT, SiC MOSFETs reduce switching losses by an average of 80 %, allowing converters to increase switching frequency and shrink the size, weight, and cost of bulky, expensive transformers. And though the conduction losses of SiC MOSFETs and Silicon IGBTs are similar under heavy loads, many applications spend most of their service lifetimes operating under so-

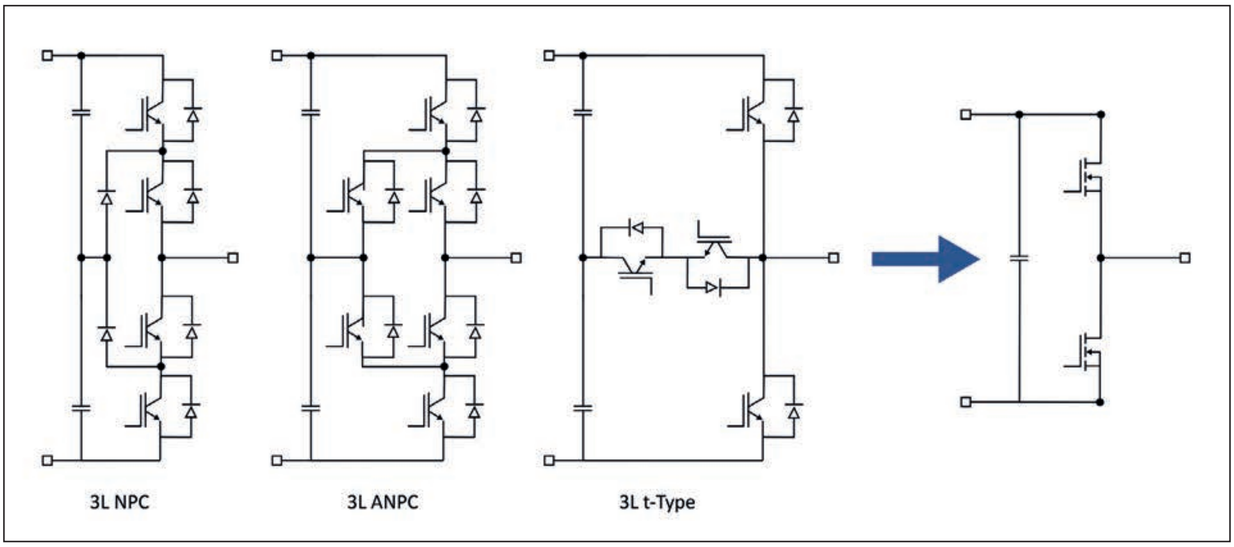

Figure 3: The complicated three-level circuit topologies (left) using Silicon IGBTs can be simplified to the more elegant and reliable two-level topology (right) using half (or fewer) 1700 V SiC MOSFET power modules

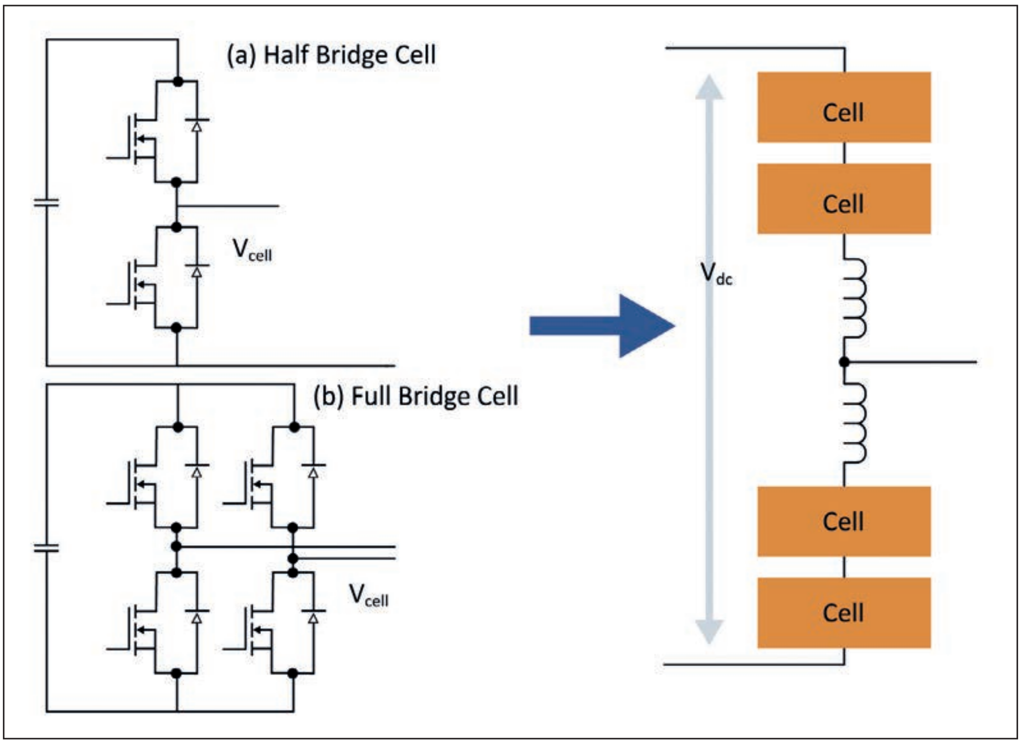

Figure 4: Modular multilevel converter (left) with multiple cells to achieve required power rating and (right) two examples of how a simple, two-level unit cell configuration may be used with 1700V SiC MOSFETs

called "light load conditions". Consider a few examples: solar inverters operating on cloudy days or under shade; wind turbine converters on still days; or train doors (opened/closed by transportation APUs) that are closed nearly all the time. Under these highly common light load conditions, SiC MOSFETs offer lower conduction losses to complement its reduced switching losses, making possible the reduction of heat sinking or other thermal management measures.

From a reliability standpoint, SiC MOSFETs empower designers with the ability to simplify the circuit topology and control scheme, as well as reduce component count – associated, of course, with a lower cost. Due to the higher-power delivery needs of these medium-power converters, a higher DC bus voltage is used – typically between 1000 and 1300 V. When selecting Silicon transistors for use at these high DC link voltages, efficiency requirements dictate that designers must choose among a few complex, three-level circuit architectures. Shown in Figure 3, these include the diode neutral point clamped (NPC) circuit, the active NPC circuit, or T-type circuit. In contrast, the use of 1700 V SiC MOSFETs allows designers to break free of these constraints and return to the more elegant two-level circuit shown in the right side of Figure 3, slashing device count in half and streamlining control.

The importance of power packaging and proper gate driving of SiC MOSFETs is worth mentioning. Because SiC can switch high levels of power at very high speeds, care must be taken to avoid voltage overshoot and reduce noise emissions. Medium-power converters in these applications routinely turn off hundreds of amperes across a 1000-1300 V bus in under a microsecond, necessitating the lowest possible package inductance, intelligent and fast-acting gate drivers, and optimal system layout. Combining Microchip's SP6LI power package with the AgileSwitch® family of digital gate drivers (see also the sidebar article) provides designers with ready-made solutions to get the maximum benefit out of 1700 V SiC MOSFETs without facing these common challenges.

Megawatts

In the multi-megawatt power range, key design factors include ease of scalability and minimal maintenance, prompting the use of modular solutions based on a basic unit cell. As shown in Figure 4, the unit cells, sometimes referred to as power electronic building blocks or sub-modules, are configured as cascade H-bridge converters or modular multi-level converters (MMCs). Megawatt-scale applications include solid-state transformers (SSTs), medium-voltage DC distribution systems, traction power units (TPUs) in commercial and heavy-duty vehicles, central solar inverters and offshore wind converters, and shipboard power conversion systems.

Traditionally, the power semiconductor devices used in the unit cells have been 1200 to 1700 V Silicon IGBTs. Much like the lower power applications, the deployment of 1700 V SiC MOSFETs at the unit cell level extends their power handling capability and electrical performance. As mentioned previously, 1700 V SiC MOSFETs have much lower switching losses, making it possible to increase switching frequency and drastically reduce the size of each unit cell. Moreover, the high blocking voltage of 1700 V reduces the number of unit cells required for the same DC link voltage, which ultimately heightens system reliability while slashing cost.

Summary

The arrival of 1700V SiC MOSFETs benefits a variety of applications and end equipment by offering higher reliability at reduced cost – both possible even while simultaneously making converters smaller, lighter, and more efficient. From watts to megawatts, high-voltage SiC MOSFETs are allowing designers to move beyond Silicon's compromises and make disruptive improvements to power conversion systems. Alongside the industry's most rugged SiC power devices, advanced power packaging with ultra-low parasitic inductance and digital gate drivers are helping designers to get the most value out of SiC and accelerate time to market.

Digital Gate Drivers Enable Next Step in Optimizing SiC Power Management in Electrified Heavy Transport Vehicles

SiC-based power-management solutions are proving their superior efficiency as compared to silicon especially in applications including electric buses, trains, trams, and other heavy transport vehicles. The same is true for higher-voltage solar inverters, rapid electric vehicle (EV) chargers, energy storage systems and aircraft flight actuators. Complicating SiC adoption, however, are the secondary effects produced by its faster switching speeds, including noise and electromagnetic interference (EMI), limited short circuit withstand time, overvoltage due to parasitic inductance and overheating that cannot be sufficiently managed using traditional analog gate drivers. **Nitesh Satheesh, Tomas Krecek and Perry Schugart, Microchip Technology**

To solve this problem, developers are turning to configurable digital gate driver technology to help them achieve new levels of SiC power density in these transportation and other industrial systems. The technology reduces switching losses and unlocking the full capability of SiCs by making all secondary-effect mitigation configurable. There are multiple ways to optimize the success of today's digital gate-driver solutions so that designers can fine-tune configurations on the fly to reduce system cost and size by using lower-voltage parts and smaller heat sinks. These solutions also transform the design experience by substituting computer keystrokes for the many hours previously spent with a soldering iron and bins of gate resistors.

Move to digital gate drivers

Because SiC devices run faster than Silicon, designers have had only one choice: slow down the SiC device to avoid the secondary effects of faster switching, but this was at the expense of SiC technology's fullest possible return on investment. While designers have used traditional analog gate driver techniques with Silicon-based designs to try and reduce a system's EMI noise, catch short circuit conditions before they became a hazard, cut down thermal losses, and control voltage overshoots and ringing, these techniques are not adequate for SiC MOSFETs.

Even with modifications, standard analog gate drivers are simply not designed from the ground up to address the special needs of SiC technology. Moving to digital gate drivers and combining them with SiC devices squeezes significantly more productivity from less energy. Plus, configurability enables designers to experiment with and then save configurations for a variety of gate driver parameters including gate switching profiles, system critical monitors and controller interface settings, cutting development time by months. The result is a gate driver that is tailored to its applications without having to change hardware, which helps to speed

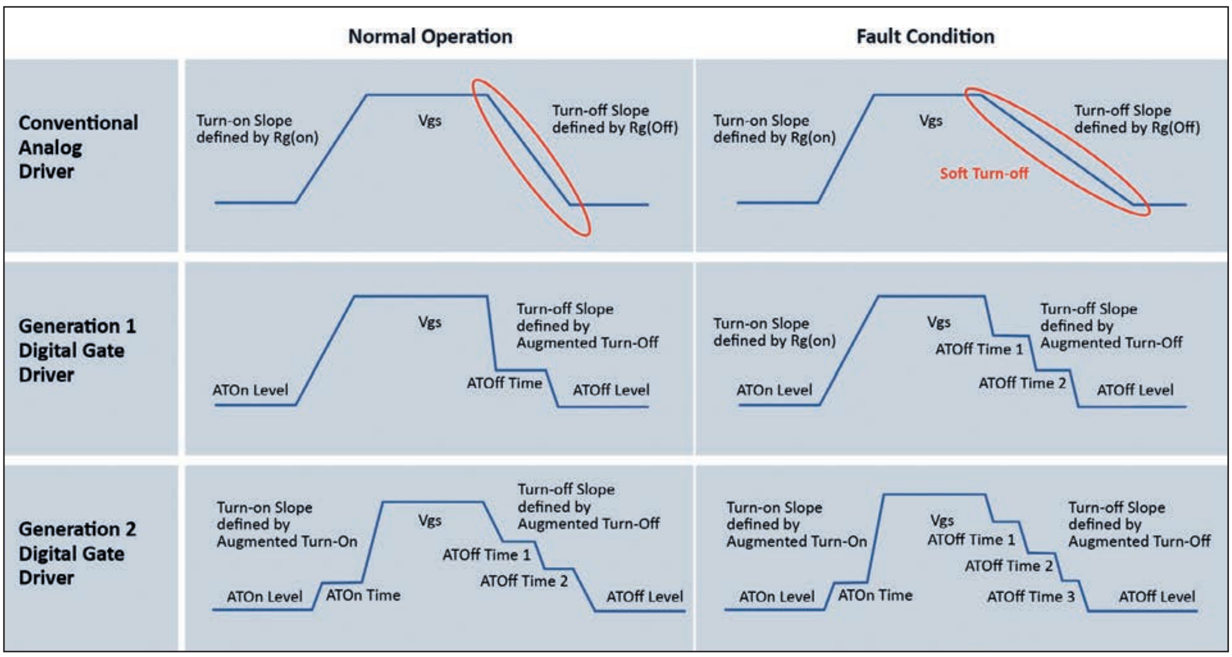

Figure 1: A conventional analog gate driver compared to the first and second generations of digital gate driver

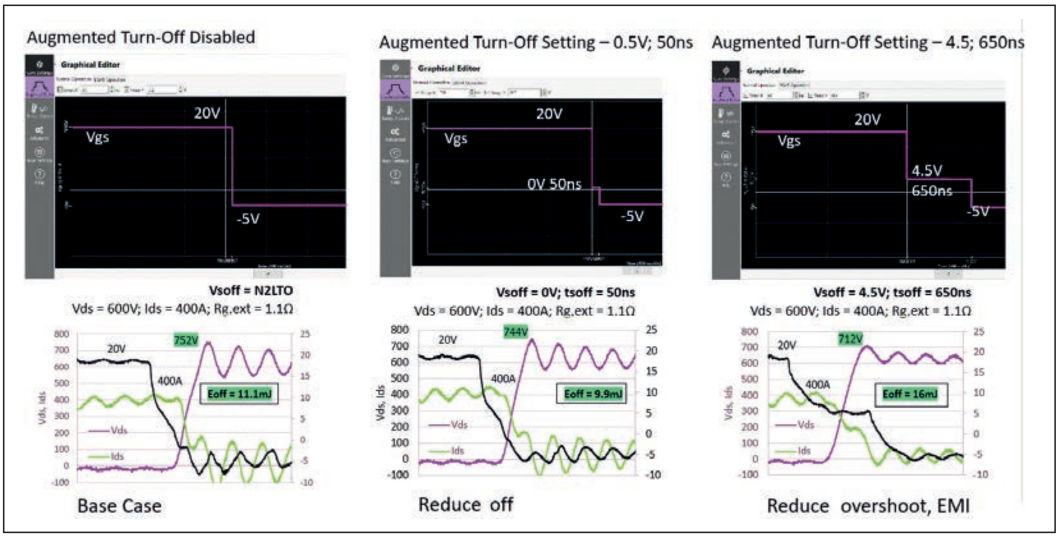

Figure 2: Benefits that the latest, more granular augmented switching solutions have on overshoot, ringing and turn-off energy, among other variables

development time from evaluation through production while enabling designers to change their control parameters throughout the design process.

New set of best practices

To ensure reliable, safe operation of SiC MOSFET-based power systems, digital gate drivers provide multiple levels of control and a higher level of protection than is possible with analog solutions. The drivers can dampen drain-source voltage (V_{ds}) overshoots by up to 80 % compared to their analog counterparts while cutting switching losses by as much as 50 %. They can also source/sink up to 20 A of peak current and include an isolated DC/DC converter with low capacitance isolation barrier for pulse width modulation signals and fault feedback.

Digital gate drivers can be used to augment switching capabilities in several ways, including providing independent short-circuit response along with robust fault monitoring and detection. Unlike traditional analog gate drivers that control turn-off slope through gate resistors for normal and short-circuit situations, the latest digital gate drivers enable designers to much more precisely control MOSFET turn-on and turn-off, as shown in Figure 1.

Furthermore, the second generation takes augmented switching even further to provide up to two steps of control at turn-on compared to the single step of traditional analog drivers, and up to three levels of control at turn-off. This ensures a “soft landing” during turn-off that is analogous to tapping a foot on the brakes of an antilock system. Four levels of short-circuit settings enable digital gate drivers to deliver similar advantages for controlling this secondary effect of SiC switching speeds.

Figure 2 shows the benefits that the latest, more granular augmented switching solutions have on overshoot, ringing and turn-off energy, among other variables. It illustrates how the increasing demands of SiC require not only faster switching but also more precise, and dynamic, multi-step turn-on and turn-off. In each of these three examples, the graphical editor toolbar is shown on the top and an associated scope image is shown on the bottom. The scope image on the far left shows a base case with augmented turn-off disabled, while the others depict two turn-off configurations. The one in the center example shows the configuration’s impact on Turn-Off Energy Loss (E_{off}) and the one on the right shows how augmented switching settings control both voltage overshoot and EMI.

Configurable augmented turn-on capabilities are particularly important in applications involving motors, which are highly susceptible to the rate of change of voltage (dV/dt). A dV/dt that is too high deteriorates the motor’s lifetime, increasing warranty costs. Manufacturers are working on higher-frequency motors but, until then, the only way to reduce dV/dt with analog gate drivers is to compromise efficiency by reducing SiC speed. Tuning this to speedily find the most appropriate compromise is only possible with digital gate drivers.

Maturing SiC ecosystem

Digital gate drivers are tightly integrated digital hybrid mixed-signal ICs that reduce end-product costs through a combination of processing horsepower and low component count. They are entering the market as production-qualified, fully configurable devices that are just one element of a total system solution for implementing SiC MOSFET-based designs. These solutions include the gate driver core, module adapter boards, a SP6LI low-inductance power module, mounting hardware, connectors to the thermistor and DC voltage, and a programming kit for the configurable software. Together, these elements provide a direct path from evaluation to production.

Adapter boards are pivotal to maximizing flexibility, enabling designers to configure a gate driver’s turn-on/turn-off voltage and then use it across many different suppliers of SiC MOSFETs with different positive or negative voltage ranges. These SiC devices can be used without any redesign, even if they previously were used with an analog gate driver – the digital gate driver is simply reconfigured. Once a module has been chosen and the digital gate driver circuitry has been completed, the solution can immediately move into production. Because the core driver board will work across multiple adapter boards, designers can continue mixing and matching gate driver cores and adapter boards with a similarly fast path to production. Figure 3 illustrates how today’s maturing SiC ecosystem is transforming the design experience while accelerating time to market.

Increasing a designer’s module options has important benefits. Some SiC MOSFETs have more robust intrinsic body diodes, and designers should select those that show no perceptible shift in tests of pre- to post-stress ON-state drain–source resistance (R_{DSon}). They do not degrade after many hours of constant forward current stress when conducting reverse current and commutating whatever energy remains after a switching cycle. Other MOSFET options show some level of degradation, and some actually become unstable, so reviewing SiC MOSFET test results is critical. Choosing correctly enables designers to eliminate the die cost and power module real estate that comes with adding an external antiparallel diode to solve the degradation problem. These savings, however, also come at the cost of potentially choppy body diode performance (some more choppy than

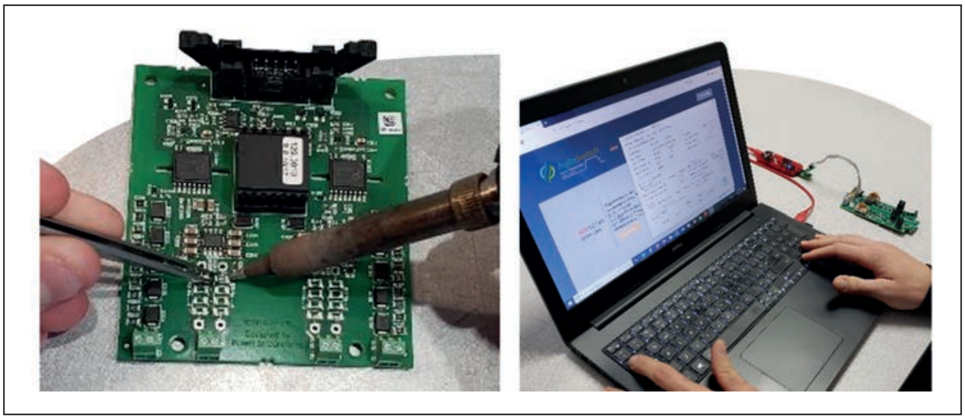

Figure 3: The digital gate driver design example on the right shows an SP6LI low-inductance power module with connections to a laptop computer and a phase leg. Testing can begin immediately, without the laborious process of soldering gate resistors onto a board, shown on the left

others), which can be eliminated by using digital gate drivers to adjust the MOSFET's turn-on parameters.

Utilizing 1200V MSCSM120AM042CD3AG SiC MOSFET and AgileSwitch® 2ASC-12A1HP digital gate driver, a jointly with French Mersen designed high-performance stack reference design allows to rapidly develop high-voltage systems using kits predesigned for typical and individual applications, reducing time to market by up to six months. This reference design provides 16 kilowatts per liter (kW/l) of power density, up to 130°C Tj and peak efficiency at 98 % with up to 20 kHz switching frequency.

Looking to the future

The ability to configure a digital gate driver creates new opportunities to change switching profiles in the field as MOSFETs degrade. This can already be done on a periodic basis – such as after a month or year of deployment. But there is no reason why it could not also be done dynamically, in real time, by sending a command to a controller that instructs the gate driver to change its settings.

In the meantime, combining SiC power modules with digital gate drivers is enabling designers to quickly and easily influence critical dynamic issues including voltage overshoot, switching losses and EMI. The most granular turn-on/turn-off configuration options reduce or even eliminate the secondary effects of operating SiC switches. Packaged into total system solutions, these digital gate drivers are paving the way for significantly smaller auxiliary power units in metro, subway, and other heavy transportation vehicles that make room for more paying passengers. They also greatly accelerate time to market by eliminating months of system development time, transforming the design experience from soldering resistors onto a board to simply entering keystrokes to change gate driver behavioral parameters.

Microchip Enters 3.3 kV SiC Power Market

3.3 kV SiC MOSFETs and Schottky Barrier Diodes (SBDs) extend designers' options for high-voltage power electronics in transportation, energy and industrial systems

Microchip's new 3.3 kV SiC power devices, lauched at APEC 2022, include MOSFETs with lowest on-resistance of 25 mΩ and Schottky Barrier Diodes (SBDs) with high current rating of 90 A. Both MOSFETs and SBDs are available in die or package form. Many Silicon-based designs have reached their limits in efficiency improvements, system cost reduction and application innovation. While high-voltage SiC provides a proven alternative to achieve these results, until now, the availability of 3.3 kV SiC power devices was limited. Microchip's 3.3 kV MOSFETs and SBDs join the company's comprehensive portfolio of SiC solutions that include 700 V, 1200 V and 1700 V die, discretes, modules and digital gate drivers. Customers can combine Microchip SiC products with the company's other devices including 8-, 16- and 32-bit microcontrollers (MCUs), power management devices, analog sensors, touch and gesture controllers and wireless connectivity solutions to create complete system solutions at a lower overall system cost.

To the question, if an internal body diode is suitable for replacing an external diode and save space in a power module, SiC manager Rob Weber commented: "In general, yes, because of the reliable body diode of our devices, you may not need to use an external Schottky diode. However, it depends on details of the design. The Schottky diode has a lower forward voltage in most conditions and lower reverse recovery, resulting in overall lower losses. If there is enough margin in the thermal design then the body diode may be sufficient."

Adding an SBD in parallel with the MOSFET reduces power dissipation in most cases due to the lower forward voltage (V_f) of the Schottky. The positive temperature coefficient of the SBD at higher current (increasing V_f with temperature) and the negative temperature coefficient of the MOSFET's body diode means that at high temperature and high current, the body diode and SBD will share current. Therefore the first order improvement in power dissipation may not be realized due to this current sharing and higher V_f of the SBD at high temperature. The MOSFET gate turn-off voltage is recommended to be -5 V to prevent the MOSFET's channel from partially turning on during reverse current flow. A lower negative turn-off voltage would lead to increases current sharing between the SBD and MOSFET and negate the benefit of the Schottky diode. A 1:1 ratio of MOSFET to SBD is usually not required. In most cases, we use a 2:1 ratio of MOSFET to SBD, which saves on cost and area.

The expanded SiC portfolio is supported by a range of SiC SPICE models compatible with Microchip's MPLAB® Mindi™ analog simulator modules and driver board reference designs. The Intelligent Configuration Tool (ICT) enables designers to model efficient SiC gate driver settings for Microchip's AgileSwitch® family of configurable digital gate drivers.

Range Extension Promise of SiC in Traction Inverters

There are two major disruptions currently affecting the future of vehicular transport and semiconductor technology. We are embracing a new and exciting means to propel our vehicles cleanly with electrical power, while simultaneously re-engineering the semiconductor materials that underpin electric vehicle (EV) subsystems to maximize power efficiency and, in turn, EV driving range. **Timothé Rossignol, Marketing Manager, Analog Devices, France**

Government regulators continue to mandate that automotive OEMs reduce the overall CO_2 emissions of their vehicle fleets, with stringent penalties for noncompliance, and EV charging infrastructure is beginning to proliferate alongside our roadways and parking areas. For all these advancements, however, mainstream consumer adoption of electric vehicles remains stunted by lingering concerns over EV range limitations.

Complicating matters, the larger EV battery sizes that could extend EV range and neutralize consumers' range anxiety threaten to simultaneously increase EV prices—the battery accounts for more than 25 % of the final vehicle cost.

Fortunately, the semiconductor revolution occurring in parallel has yielded besides others new wide band gap (WBG) devices such as silicon carbide (SiC) MOSFET power switches that can help shrink the gap between consumers' EV range expectations and OEMs' ability to satisfy them at competitive cost structures. Figure 1 shows the power conversion elements in EVs. The traction inverter converts the HV battery's DC voltage into AC waveforms to drive the motor, which in turn propels the car. The battery to motor signal chain is depicted in Figure 2. To deliver on the range extension, each block should be designed for the highest efficiency level.

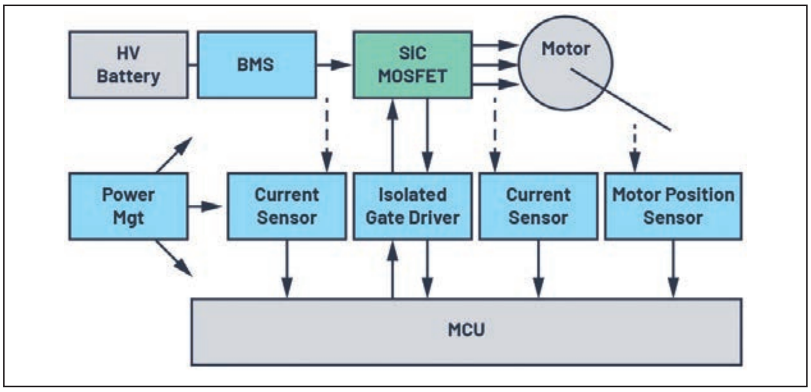

Figure 2: **The battery to motor signal chain. To deliver on the range extension, each block should be designed for the highest efficiency level**

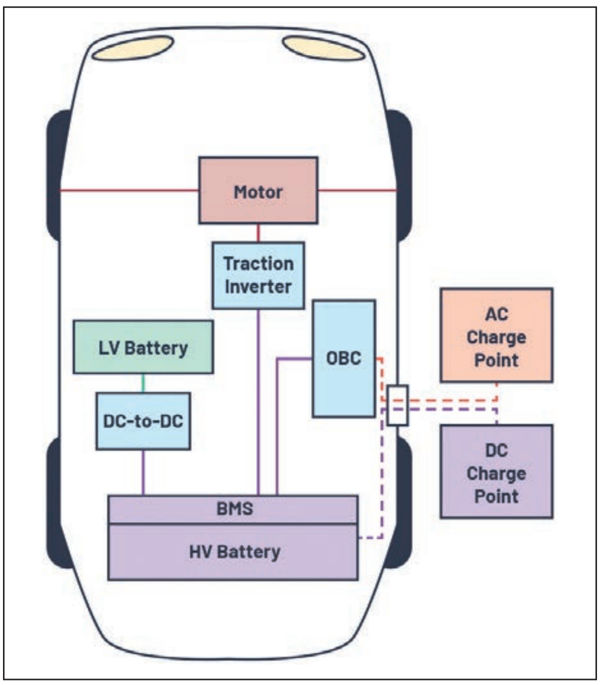

Figure 1: **Power conversion elements in EVs. The traction inverter converts the HV battery's DC voltage into AC waveforms to drive the motor, which in turn propels the car**

Reduced inverter size and cost

The inherent benefits of SiC-based power switches with regard to power density and efficiency are well understood, with key implications for system cooling and size. The evolution to SiC promises 3× smaller inverters at 800 V/250 kW, with additional significant size and cost savings on companion DC link film capacitors. Compared to conventional Silicon, SiC power switches can enable better range and/or a reduced battery pack, giving the switches a favorable cost comparison from the device level to the system level.

At the intersection of these range and cost considerations, the traction inverter remains the epicenter for innovations aimed at unlocking further EV efficiency and range gains. And as the most expensive and functionally important element of the traction inverter, SiC power switches need to be controlled very accurately to realize the full benefit of the extra switch cost. Figure 3 shows voltage and current waveforms at turn-on (left) and turn-off (right). In SiC environments, dv/dt will exceed 10 V/ns, which means no more than 80 ns to switch an 800 V DC voltage. In a similar way, a 10 A/ns,

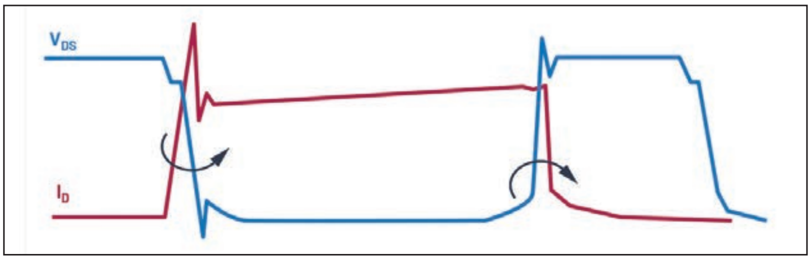

Figure 3: Voltage and current waveforms at turn-on (left) and turn-off (right)

meaning 800 A in 80 ns, type of di/dt can be observed.

Indeed, all the intrinsic advantages of the SiC switch would be negated by common-mode noise perturbations, as well as extremely high and destructive voltage overshoot due to ultrafast voltage and current transients (dv/dt and di/dt) generated in a poorly managed power switches environment. Broadly speaking, the SiC switch has a relatively simple function despite the underlying technology—it's only a 3-terminal device—but it must be carefully interfaced to the systems.

Driving SiC devices efficiently

The isolated gate driver bridges the signal world (control unit) and the power world (SiC switch), se Figure 4. Other than isolation and signal buffering, the driver performs telemetry, protection, and diagnostic functions, making it the key element of the signal chain.

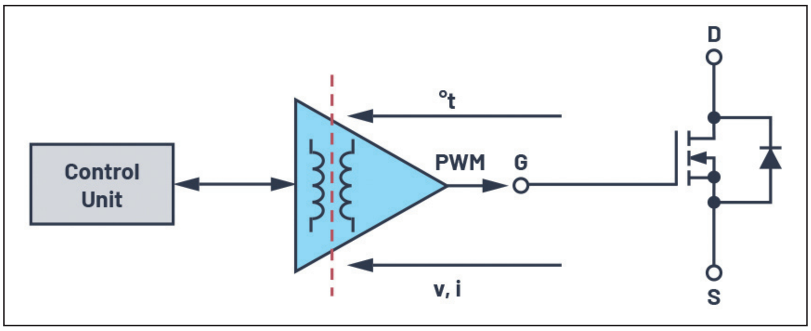

Figure 4: The isolated gate driver bridges the signal world (control unit) and the power world (SiC switch)

The isolated gate driver will take care of setting the best switching sweet spot, ensuring short and accurate propagation delay through the isolation barrier, while providing system and safety isolation, controlling power switch overheating, detecting and protecting against short circuits, and facilitating the insertion of the sub-block drive/switch function in an ASIL D system.

The high slew rate transients introduced by the SiC switch can corrupt data transmission across the isolation barrier, however, so measuring and understanding the susceptibility to these transients is critical. iCoupler® ADI proprietary technology has shown leading common-mode transient immunity (CMTI) with measured performances up to 200 V/ns and beyond. This unlocks the full potential of SiC switching time under safe operation. ADI has advanced digital isolation technology for over 20 years with iCoupler digital isolation ICs. The technology is comprised of a transformer with thick polyimide insulation (see Figure 5). Digital isolators use foundry CMOS processes. Transformers are differential and provide excellent common-mode transient immunity.

High performance gate drivers have proven their value in real-world testing with leading SiC MOSFET power switch providers like Wolfspeed. Across key parameters, including short-circuit detection time and total fault clearance time, performance can be achieved down to 300 ns and 800 ns, respectively. For additional safety and protection, test results have demonstrated the adjustable soft shutdown capabilities essential for smooth system operations.

Switching energy and electromagnetic compatibility (EMC) can likewise be maximized for improved power performance and EV range. Higher drive capability allows users to have faster edge rates and therefore reduces switching losses. This not only helps with efficiency but also enables board space and cost savings by eliminating the need for external buffers allocated per gate driver. Conversely, under certain conditions, the system may need to switch more slowly to achieve optimal efficiency, or even in stages, which studies have shown can increase efficiency further. An adjustable slew rate is provided to allow users to do this, and the removal of external buffers eliminates further obstacles.

Elements in a system

It's important to note that the combined value and performance of the gate driver and SiC switch solution can be completely negated by compromises and/or inefficiencies in the surrounding components.

A holistic view of the EV reveals additional opportunities for optimizing drive train power efficiencies, which are critical for exploiting the maximum usable battery capacity while ensuring safe and reliable operations. The quality of the BMS directly impacts the miles per charge an EV can deliver, maximizes the battery's overall

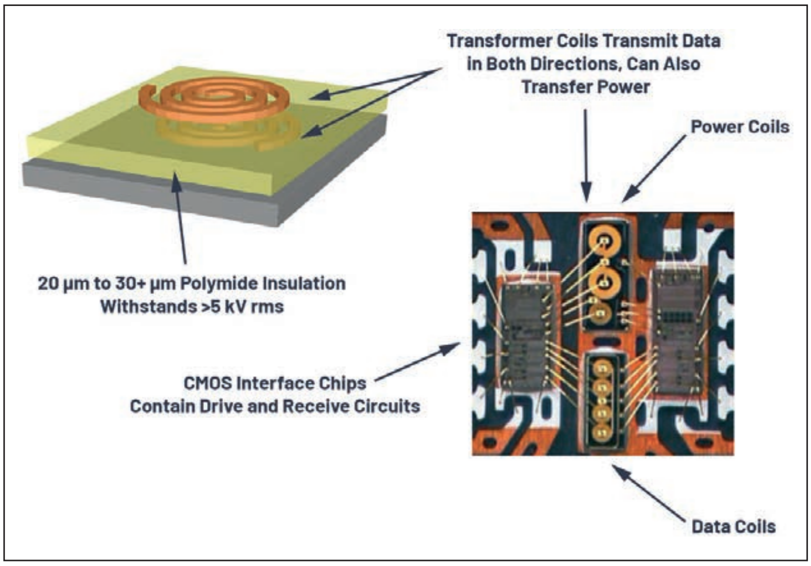

Figure 5: ADI has pioneered advances in digital isolation technology for over 20 years with iCoupler digital isolation ICs

lifetime, and, as a result, lowers the total cost of ownership (TCO).

In terms of power management, the ability to overcome complex electromagnetic interference (EMI) challenges—without compromising BOM costs or PCB footprint—becomes paramount. Power efficiency, thermal performance, and packaging remain critical considerations at the power supply layer, regardless of whether the layer is for an isolated gate driver power supply circuit or auxiliary high voltage-to-low voltage DC-to-DC circuit. In all cases, the ability to neutralize EMI issues takes on greater importance for EV designers. EMC is a critical pain point when it comes to switching for multiple power supplies, and superior EMC can go a long way toward shortening testing cycles and reducing design complexities, thereby accelerating time to market.

Deeper into the ecosystem of supporting componentry, advancements in magnetics sensing have yielded a new generation of contactless current sensors delivering no power loss with high bandwidth and accuracy, as well as accurate and robust position sensors for end-of-shaft and off-shaft configurations. There are between 15 and 30 current sensors targeted for deployment in a typical plug-in hybrid EV [1], with rotation and position sensors monitoring traction motor functions. Sensing accuracy and robustness to the stray field are critical attributes for measuring and maintaining efficiencies across EV power subsystems.

End-to-end efficiency

Looking holistically at all elements in the EV power train—from the battery to the traction inverter to the supporting components and beyond—ADI sees myriad opportunities to improve EV in a manner that enhances overall power efficiency and extends EV driving range. Digital isolation is one of the many important parts of the equation as SiC power switching technology penetrates the EV traction inverter.

Likewise, automotive OEMs can leverage a multidisciplined approach to EV optimization to help ensure that all available power monitoring and control devices are working in close concert for maximum performance and efficiency. In turn they can help to overcome the last remaining barriers to mainstream consumer EV adoption—vehicle driving range and cost—while helping to ensure a greener future for all. The author can be reached at timothe.rossignol@analog.com

Literature

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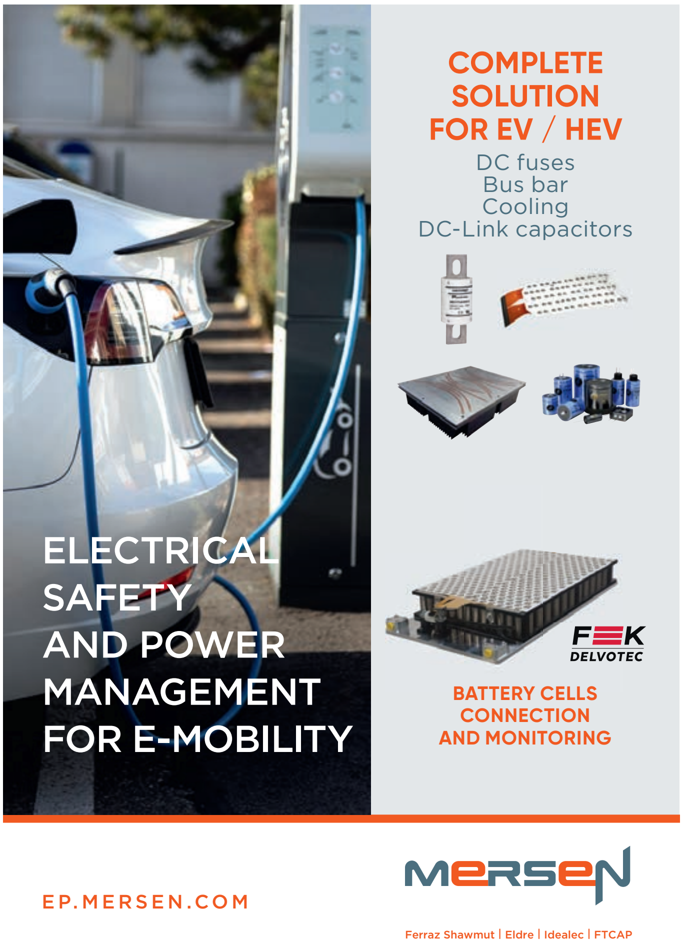


Edge Computing Leverages Modular Power in Scalable Micro Data Centres

Edge computing is essential to realizing the full potential of artificial intelligence (AI), machine learning and internet of things (IoT). These technologies are being infused into every corner of our lives—autonomous driving, smart buildings, robotics, supply chain management and healthcare. To deliver on the promise of these smart technologies, faster computation and data transfer speeds are needed closer to smart devices, closer to "the edge." HIRO, a Dutch entrepreneurial technology company, leverages modular power in scalable micro data centres for low latency applications, powered by DCM power modules from Vicor.

Lev Slutskiy, Vicor EMEA Business Development Manager HPC, UK

Edge computing is the invisible driver to this smart world, designed to make our lives easier and better in ways we never imagined. But what does it look like, and what's driving it? Just as importantly, how do you reliably and efficiently power the edge?

HIRO, a Dutch entrepreneurial technology company, develops innovative high-performance, reliable edge infrastructures (hardware and software) that can deliver intelligent edge as a service for industrial and other end users. They have seen steadily-increasing demand for intelligent edge services that can run autonomously and support analysis of large data streams in real time for multiple tenants (groups of users sharing access to a software instance), while safely sharing the analysis results across multiple locations.

Why edge computing?

Edge computing serves as a faster (middle layer) relay for data to enable mission critical, real time responses in devices. Edge computing can dramatically boost services and applications by supporting AI natively, instead of relying on AI in the cloud. Edge computing technologies integrate the limited memory, storage and computation of nodes that are closer to where data are generated into the cloud architecture. They facilitate intelligent decisions on when to move computation from the edge to the cloud, while allowing for the network capabilities as well as the security and sensitivity of data.

This industry-preferred approach enables long-awaited developments, including Factory 4.0 and smart manufacturing, 5G, internet of things (IoT), self-driving vehicles, smart cities, smart hospitals, robotics, machine vision and others.

The success of edge computing depends on the availability of suitable hardware; systems that can economically provide the necessary processing speed and power, while being able to survive in the less-regulated and more unpredictable environments encountered away from the conventional data centre.

The edge computing hardware must comprise compact, energy-efficient solutions that can be widely deployed, even in space-constrained and harsh environments, to locate computing closer to sensors and other data sources. The hardware includes the power delivery networks and conventional bulky low-voltage power solutions are not able to support the increasing power density and small form factors at the edge and are a major bottleneck for edge computing innovation.

An efficient and scalable solution

HIRO makes Edge Micro Data Centre (EMDC) – a highly scalable, compact, edge computing resource that can thrive outside in harsh environments. It can

Figure 1: Micro Data Centre examples EMDC8 (1.5 kW), EMDC16 (3 kW), and EMDC24 (4.5 kW)

Figure 2: Intra-operative functional Ultrasound improves surgical effectiveness and patient safety while expanding a surgeon's view by directly visualizing neural structures and supporting the surgical procedure

integrate any type and quantity of CPUs, GPUs, FPGAs and NVMe® (Non-Volatile Memory Express) media into platforms from 1.5 kW shoeboxes to 500 kW containerized edge installations. Fully solid-state and modular, these platforms require little maintenance and no energy for cooling. Heat can be dissipated via a fan-supported dry-cooler (see Figure 1) or a completely passive dry-cooler making the EMDC passive. The high-bandwidth, dual-switching fabric (PCIe, Ethernet) and scalable design gives customers complete freedom to compose the EMDC with any combination or quantity of CPUs, accelerators, and flash storage.

Real applications with community impact

HIRO has a special commitment to building an edge infrastructure distributed across academic hospitals in Europe to support lareg data set and even real time procedures. Hospitals rely on large data sets that go beyond their own data sets to train AI models that can help detect and cure cardiovascular diseases, cancer, tumours, and other complex disorders. Additionally some hospitals are leveraging edge computing in the operating rooms. Intra-operative functional Ultrasound (IOfUS) has the potential of improving surgical effectiveness and patient safety while expanding the surgeon's view by directly visualizing neural structures and supporting the surgical procedure (see Figure 2). IOfUS is the most affordable and least invasive modality for intra-operative imaging of the brain. Ultrasound is portable, flexible and provides real time intra-operative imaging whenever needed during the procedure. The progress of surgery can therefore be closely monitored without major delays or interruptions in the workflow by employing edge micro data centres.

HIRO is also working on the €16 million BRAINE project, which received €8.5 million EU's ECSEL Joint Undertaking funding. Four test-bed locations across the EU – two in the Netherlands, one in Italy, and one development platform in Hungary – will serve several test applications addressing Smart City, Smart Hospital, Smart Manufacturing and Robotics, and Smart Supply Chain.

High power density leads to cost efficiency

HIRO is able to build highly compact EMDCs and solve the technical bottlenecks of signal integrity over shorter electrical traces, highly compact and efficient power conversion and energy efficient cooling and engineering. In addition to being device-agnostic, flexible and scalable, the EMDC is high-performing and saves at least 40 % on energy consumption compared to legacy systems. Its solid-state design (no moving parts) improves availability and reduces callout incidence – particularly valuable for edge installations in remote or unattended locations.

Highly compact and efficient power conversion is achieved by designing hardware running from 48 VDC power distribution, instead of 12 VDC (see Figure 3). The higher voltage reduces I?R losses across the power delivery network (PDN). While 48 VDC distribution is common in telecoms and industry, it is only now beginning to find acceptance in data centre and associated edge environments.

Vicor high-density, high-efficiency power modules contribute to HIRO's solid-state, thermally adept, compact, energy-efficient EMDC designs. Legacy solutions using standard COM Express modules (computer-on-module), for example, draw 150 W per card. This equates to approximately 3 kW within one 3U chassis. The ability to handle this high-density power conversion is unique to Vicor in the market.

HIRO has been using Vicor DCM modules for 48-to-12 V conversion. In their view, the Vicor power modules, with their flexible cooling options, offer world-leading volumetric power density. The flexibility lends itself to renewable energy opportunities. The HIRO EMDCs will eventually be able to be positioned by a solar farm or wind farm and connect safely and reliably into the renewable energy supply.

The first step for HIRO is to enable 48 V systems, while providing infrastructure for legacy 12 V designs. Next will come support for chips like PGAs, converting down from 48 V to around 1V at the point-of-load.

In the HIRO system, Vicor owns the DC power conversion from the chip level all the way up to edge data centre level. This

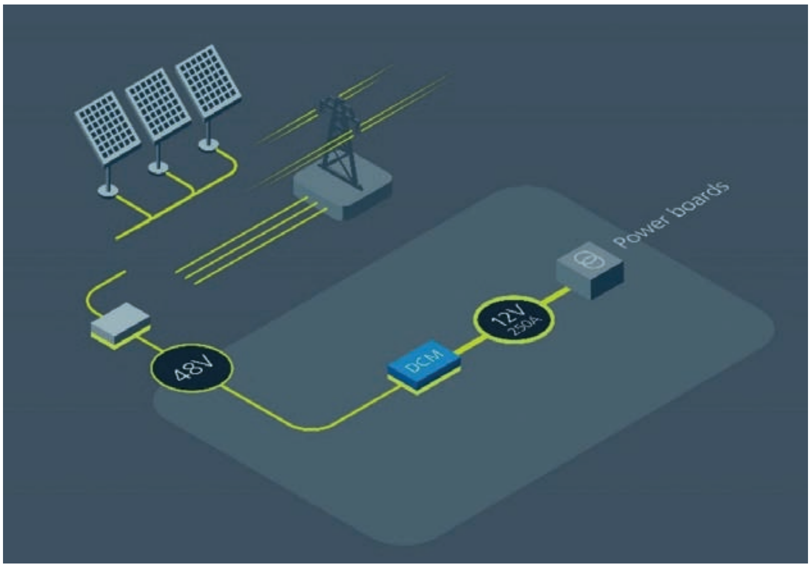


Figure 3: Vicor DCM 48 VDC – 12 VDC power modules: contributing to HIRO energy-efficient EMDC designs

is allows HIRO to apply a unified approach from data centre power distribution to ~ 1 V point-of-load power supplies on PCBs, while accommodating both new 48 VDC designs and legacy 12 VDC systems. Innovation in packaging, topologies and architectures enables the ever-increasing density and power efficiency essential to data centres.

Conventional alternatives such as custom discrete solutions or off-the-shelf power supplies were unable to meet the design requirements including form factor, scalability, flexibility and high efficiency. Discrete solutions require considerable power system design effort while off-the-shelf designs are bulky and lack the flexibility needed to adapt to different environments.

Vicor modules offer reliability, high power density, flexible cooling, high conversion efficiency and a wide choice of products for different DC voltages and power requirements. These products assist HIRO in designing compact, efficient, solid state EMDCs that can survive outside a conventional, environmentally managed data centre building.

Bringing Europe closer to the edge

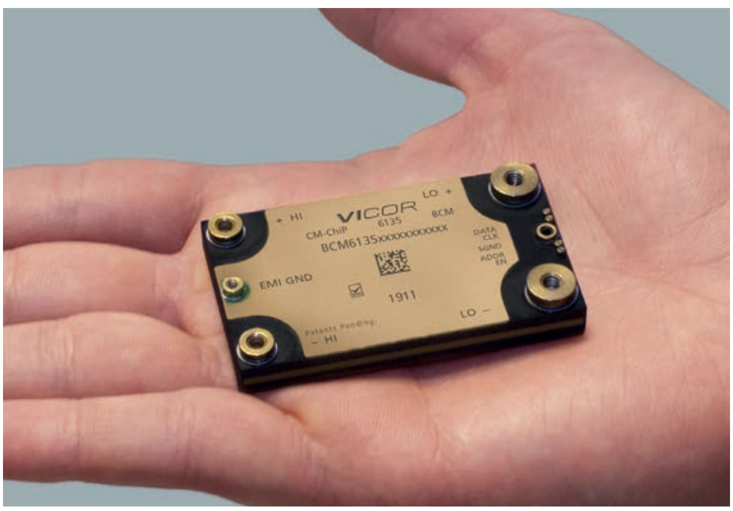
The continued mobilization of our smart, connected world is an enormous undertaking. Edge computing is the critical bridge to enable faster computing and realizing what new ideas are possible. HIRO, Vicor and PCB Design Ltd. are three important drivers of this movement, working together to push the technological boundaries. Today their partnership will lead to impactful enhancements in the areas of Smart City, Smart Hospital, Smart Manufacturing and Robotics, and Smart Supply Chain. Tomorrow they will power the newest world-changing ideas.

Automotive Applications Demand Highest Power Density

Vicor will unveil three new approaches for powering xEVs at the premiere global automotive engineering event, World Congress Experience in Detroit on April 5-7. Proven Vicor solutions using high density power modules and new power delivery architectures, deliver up to a 50 % reduction in power losses.

The three topics are: Eliminating the 12V Lead Acid Battery: An inventive power architecture that replaces the 12V battery with a "virtual battery," saving space and weight, and replacing legacy technology; DC Charging Station Compatibility: Higher-voltage primary batteries (800 V) create a 400 V charging station incompatibility that can be solved with onboard charging using compact, efficient and bidirectional power modules; and the Impact of Miniaturized Power Modules on Electrification: Power-dense modules combined with innovative power architectures deliver unprecedented design flexibility, scalability and space-savings for xEV development.

As the automotive industry aggressively moves toward full electric vehicles, power system design engineers are grappling with how to design significantly higher power delivery networks. EV's require up to 20x more electrical power than a traditional internal combustion engine vehicle which requires proportional size and weight increase for the power electronics. To meet those challenges, Vicor emphasizes the need for lightweight, compact systems offering flexibility so power components can easily scale and be reused across fleets. "Innovation is needed in the form of new architectures and topologies that provide maximum performance today and can also be reused and reconfigured for the future, "Integration is important. If you look at one of our modules that has 200 individual components inside, it's a lot easier to qualify one module than it is 200 components. And so integration has a lot of merits," said Patrick Wadden, VP of Vicor's Automotive Business Development unit. "Our power modules such as the BCM6135 which handles 2.5 kW of power help engineers to create high density power delivery networks for EV, PHEV, HEV and BEVs that are lightweight, efficient and offer an easily scalable platform."



Optimizing the Switching Stage in Wind Power Applications

Efficient power conversion is an important part of maximizing the cost-effectiveness of the switching stage in a wind-powered generator. Much effort has been expended in maximizing switching efficiency with excellent results. In this article, we will look at optimizing the utilization of the switches to increase the amount of power that can be processed by a given system. This, in addition to the benefits obtained by optimized switch driving, can show an increase in power throughput for a given system by >20 %.

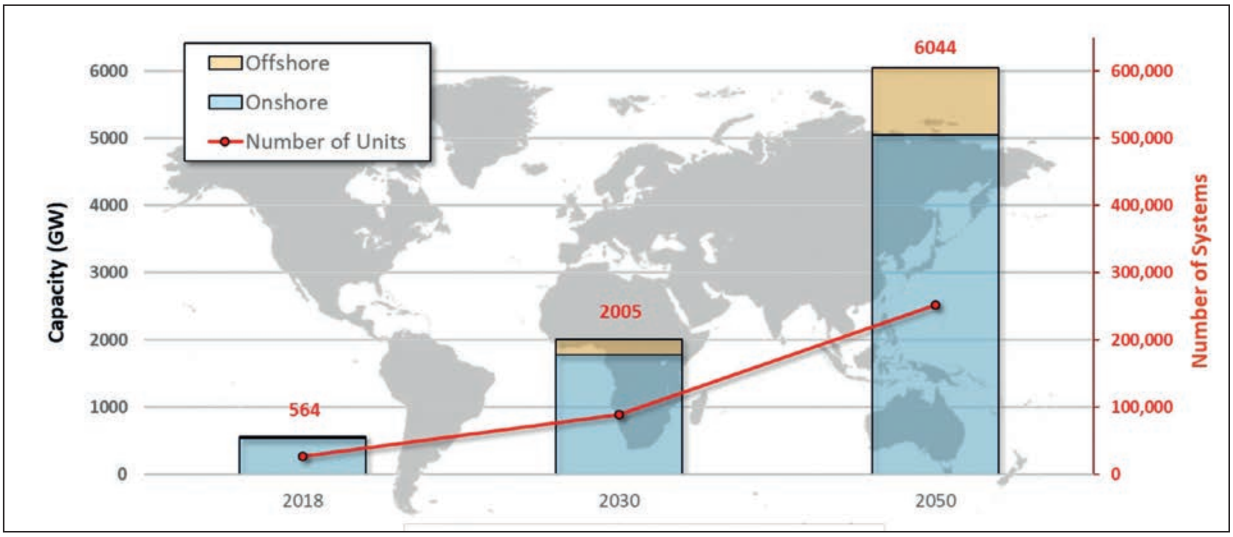
Thorsten Schmidt, Product Marketing Engineer, Power Integrations, Ense, Germany

A rapid expansion in wind-powered energy generation has already begun (Figure 1). A typical 10 MW windmill will require up to 40 dual IGBT drivers in the two inverter stages alone.

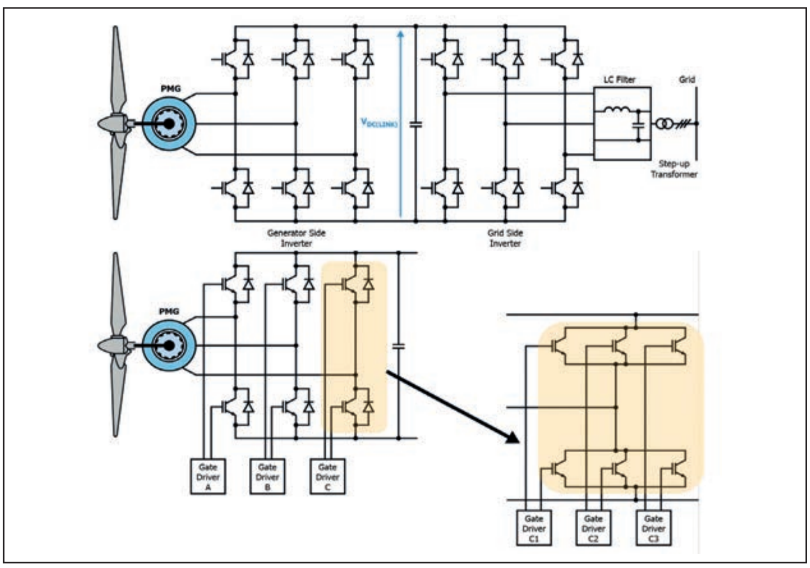
Maximizing DC rail voltage (DC-link) in an inverter

Typical wind-power inverter stages employ multiple groups of parallel-mounted IGBT modules (Figure 2), which offer more cost-effective and space-efficient implementation than single, large IGBT units. The factor that controls the maximum DC-link voltage (and therefore power) that can be processed by a given inverter stage is the maximum operating voltage that can be tolerated by each IGBT. The DC-link voltage must be set below the maximum rated IGBT blocking voltage to account for voltage overshoot during shutdown. By more accurately controlling the amount of voltage overshoot, it is possible to reduce the required voltage margin, raise the nominal DC-link voltage and process more power from each IGBT module.

Controlled turn-off of the gate driver –



ABOVE Figure 1: Anticipated worldwide growth in wind power suggests a >10X expansion of wind power use by 2050 (IRENA 2019d)



RIGHT Figure 2: Simplified view of a four-quadrant wind inverter showing multiple parallel switches and their associated gate drivers. Each dual IGBT module processes the same DC-link voltage and (ideally) equally shares current with the other parallel modules

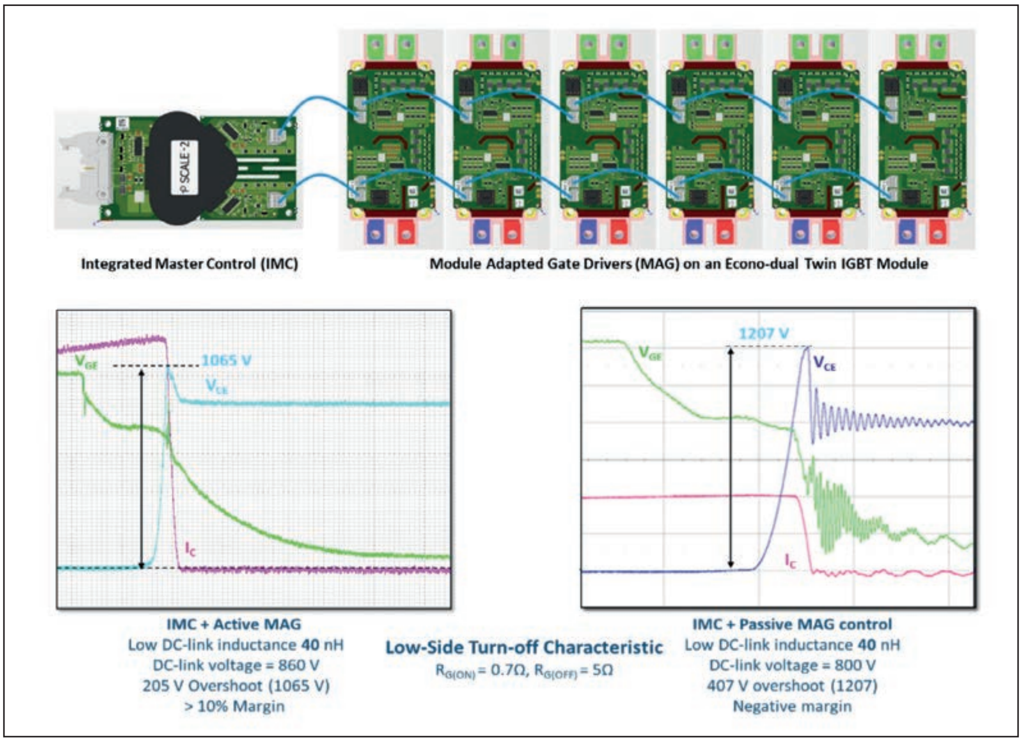


Figure 3: Controlled turn-off of the gate driver - IMC and MAG – SCALE-iFLex™ LT combines an MC module with active MAG drivers mounted on EconoDUAL 3 IGBT modules (a, top); and maximum voltage seen during short-circuit shutdown with a conventional passive gate drive circuit compared to a combination of IMC and MAG modules for low DC-link inductance (b, bottom)

Active Clamping (AC) and Advanced AC (AAC) – is most effective when active monitoring and shutdown circuitry is located near the switch as shown in Figure 3a. Figure 3b compares the clamping performance that can be obtained using a conventional passive detection architecture relying on a Master Control (MC) unit, and that which is obtained using an Integrated Master Control (IMC) that provides isolation and timing signals and Module Adaptive Gate drivers (MAG) with active drive circuitry mounted directly onto each gate driver to minimize the impact of parasitic circuit inductances and propagation delay.

In AAC control, the VCE voltage is monitored as the IGBT is turned off. Active drive via a control ASIC is used to modulate the gate drive to limit current slew rate, which in turn prevents the DC-link voltage from rising to excessive levels. Reducing the value of RG(OFF) in the discrete solution would improve clamp control, but it would reduce switching efficiency. The clamping voltage that can be obtained using the fast response of the MAG-based control can be shown to provide 10 % safety margin for an 860 VDC link voltage. By using the appropriate active clamping approach and positioning the detection and protection circuitry on the switch module, a higher nominal DC-link voltage can be selected which delivers >9 % more power in a given system.

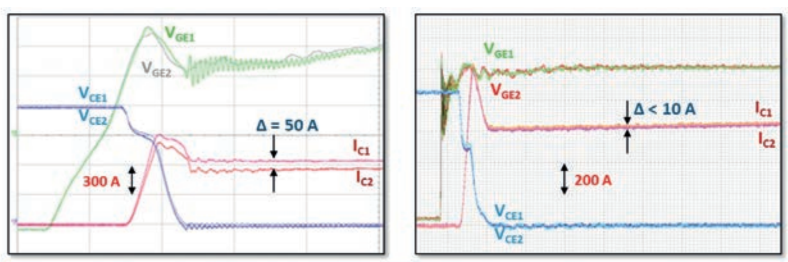
Current sharing

As shown in Figure 2, many wind turbine systems employ multiple IGBT dual modules in parallel. In a perfect system, the gate drives for each module would be identical and the IGBTs themselves would present similar impedance during conduction, resulting in equal current sharing. Total system current could be set at the maximum current per module multiplied by the number of systems in parallel.

Any imbalance in actual operation would lead to some modules working harder – creating increased heating in those modules. To prevent damaging overworked modules, the nominal current for each module would need to be reduced. So, using similar reasoning as was applied to the voltage calculation, by ensuring accurate current sharing, the power through each module may be higher, allowing more system power to be provided from a given IGBT arrangement.

Switch timing and gate-bias must be precisely matched between each switch module. Again, the provision of local drivers and control of gate voltage allows for close matching. Figure 4a shows the difference in performance between matched gate drives (timing match shown in Figure 4b) and a gate driver configuration that employs passive modular drives. Unbalanced impedance between the drive feeds to each module causes timing mismatches and reducing sharing accuracy.

If the current delivered to each module



Input	Command	$T_{D(A)}$ (µs)	$T_{D(B1)}$ (µs)	$T_{D(B2)}$ (µs)	$T_{D(B3)}$ (µs)	$T_{D(B4)}$ (µs)
INA	Turn-on	2.04	2.05	2.06	2.06	2.06
INB	Turn-on	2.06	2.08	2.08	2.08	2.09
INA	Turn-off	1.39	1.40	1.41	1.41	1.41
INB	Turn-off	1.41	1.43	1.43	1.44	1.44

Figure 4: Switch timing and gate-bias must be precisely matched between each switch module - comparison of current sharing between adjacent IGBT modules using passive MAGs (left) and actively driven MAGs with bias control (right). Nominal current is 600 A per module (a, top); and timing match for an actively driven MAG (SCALE-iFlex LT) showing timing mismatch across four modules of less than 20 ns. $T_{D(A)}$ shows the time delay for the switching signal induced by crossing the isolation barrier of the IMC (b, bottom)

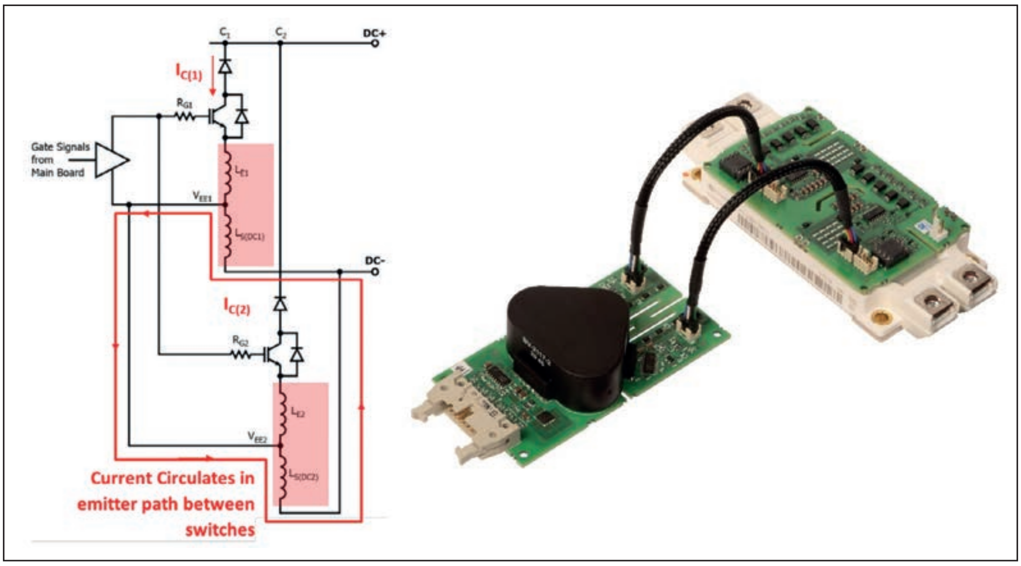


Figure 5: Large loop areas between the IMC and passively-driven gate drive modules create large parasitic inductance that can cause circulating common mode currents which limit switching frequency and can cause significant timing mismatch – often sufficient to cause jitter between modules

is close (within approximately 5-10 %), the module will naturally compensate and balance the collector currents due to the heating effect on RCE(ON), which has a positive temperature coefficient. Under these circumstances, current sharing will be very good once thermal equilibrium is reached in the system.

To reduce common mode currents flowing between modules (Figure 5), it is important to reduce the loop area (and therefore parasitic inductance) as much as possible. The propagation delay associated with large emitter loops can be in the order of 800 ns with mismatch of as much as 80 ns between modules. Active gate drivers located on the IGBT module (MAGs), which reduce the loop area and common mode chokes, are effective in reducing common mode currents. As well as reducing current sharing, gate drive can be challenging, being susceptible to EMI which can cause false triggering – a phenomenon only partially addressed by passive filtering.

Current imbalance between adjacent modules of an inverter phase means that an active MAG approach can increase output power by as much as 15 % compared to that achieved with a passive module drive stage with less accurate current sharing.

Optimizing gate drive for highest switching efficiency

The role of gate resistance in controlling the switching loss (especially turn-on loss) in an IGBT is well known. An actively driven gate signal located on the local MAG is able to support a low impedance gate drive for turn-on and turn-off. Turn-off losses are relatively constant compared to gate resistance, but the low gate impedance is important in preventing voltage overshoot during shutdown. The turn-on resistance of the gate-driver stage strongly influences switching loss, and there are important efficiency benefits associated with having a driver stage that can support a low on-resistance (0.7 Ω is shown in Figure 6) from a relatively high current drive stage. SCALE-iFlex LT can deliver up to 20 A of gate drive current per MAG channel due to the active drive-stage booster in the ASIC for each channel. Typical values for a discrete driver with remote driver stage will be in the order of 2-3 Ω.

With discrete local gate driver stages, it is often necessary to increase gate driver resistance on individual modules to achieve better load balancing between switch modules and, in discrete circuits to increase the effectiveness of the Active Clamp circuit. Optimizing drive to enable low gate resistance and better switching performance can increase overall switch efficiency by up to 3 %.

Conclusion

Combining the system utilization benefits of higher DC-link voltage and better current sharing with the efficiency that can be gained from localized gate drive, we can substantially increase system utilization efficiency. There is some crossover in parameter effect, so a straight addition of the benefits is difficult, but improvements in driver utilization of more than 20% are certainly possible. This suggests that with careful design and the utilization of active MAGs supporting the IMC, it is possible to remove one in five of the IGBT modules employed in a typical wind turbine inverter application – a very significant saving in space and material.

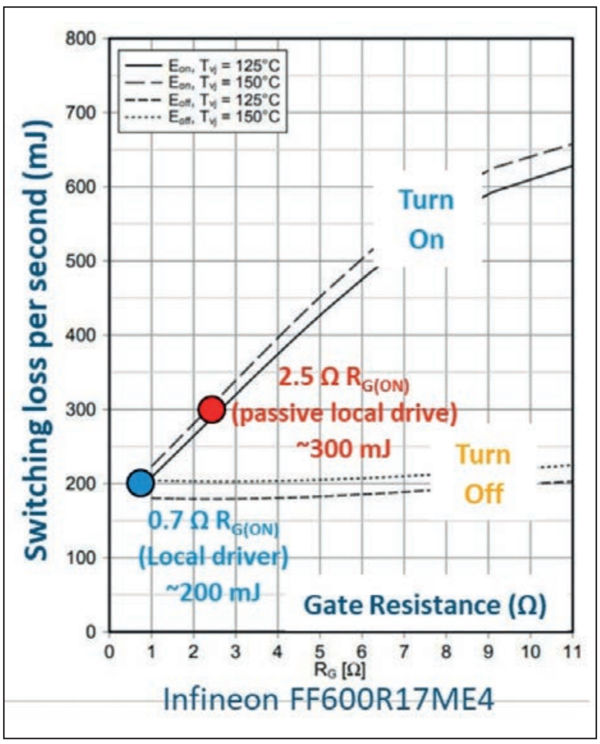


Figure 6: A localized active gate driver (MAG) is able to support a low gate drive resistance due to the buffered drive stage capable of delivering >1 A. This reduces turn-on losses by up to 50 % compared to the higher resistance typically needed to balance a passive gate driver stage

New Plug-and-Play Gate Driver Improves IGBT Module Performance by 20 %

Power Integrations announced its new plug-and-play SCALE-iFlex™ LT dual gate-drivers. The new drivers improve the performance of multiple parallel EconoDUAL modules by 20 %, allowing users to eliminate one of every six modules from power inverters and converter stacks. In addition to saving the cost of the driver and module, this reduces control complexity and costs related to modules, wiring, hardware, and heatsinking. SCALE-iFlex LT targets multiple applications in renewable energy generation and storage, and is particularly applicable to offshore wind turbines in the 3 to 5 MW range. Up to six EconoDUAL 3, or equivalent, power modules can be paralleled from the same Isolated Master Control (IMC) unit which has a more compact outline than conventional products. The Module Adapted Gate drivers (MAGs), which fit the footprint of the EconoDUAL module, each featuring two SCALE-2 ASICs – one per channel – to optimize symmetrical paralleling, efficiency and protection.

New gate driver eliminates one in six modules

"Dynamic and static current sharing is critical for robust operation of modules arranged in parallel. For the same power output, systems using SCALE-iFlex LT require just five parallel modules whereas competitive approaches need six. This substantial saving of cost and complexity is achieved by guaranteeing less than 20 ns of variance in turn-on and turn-off commands between modules and less than 20 A of variance between modules when conducting the rated 600 A. This allows the modules to operate reliably without current derating, which is obligatory with less advanced driver solutions," commented Thorsten Schmidt, product marketing manager at Power Integrations.

The new SCALE-iFlex LT gate-driver modules reduce switching losses by three to five percent, due to the fast turn-on and turn-off of the SCALE-2 ASIC which features an integrated booster stage. Advanced Active Clamping (AAC) protection enables higher DC link voltages to be achieved. A suite of other protection features, including short-circuit, are provided. Drivers feature reinforced isolation to 1700 V and may be ordered naked or conformally coated. As well as renewable energy, other applications include power quality, commercial air-conditioning units and medium-voltage drives. The new SCALE-iFlex LT gate drivers are available now.

Single gate drivers for "New Dual" modules

Single gate-drivers for the popular "New Dual" 100 mm x 140 mm IGBT modules are alo available. The compact new drivers support modules up to 3.3 kV and are suited for light-rail, renewable energy generation and other high-reliability applications that demand compact, rugged driver solutions. "SCALE-iFlex Single gate-drivers fit the outline of the latest standard IGBT power modules including the Mitsubishi LV100/HV100, Infineon xHP2 and xHP3, ABB LinPak, Hitachi nHPD² and other similar products, " Schmidt added.

DC/DC Converter Design Basics

Most electronic equipment incorporates DC/DC conversion in some form. The switched-mode technique is an efficient solution which enables step up and step down in voltage as well as isolation, with small magnetics. This article gives a broad review of the technology and some commercial implementations.

Ann-Marie Bayliss, Senior Product Marketing Manager, and John Quinlan, Strategic Technical Marketing Manager, both Murata Power Solutions, USA

DC to DC conversion has been a challenge to system and product designers, starting in a major way when Edison lost out to Westinghouse in the 'War of the currents DC versus AC' in the late 19th century. Distributing AC at increasing power required ever-higher voltages to keep currents low and cables of reasonable size, but this could easily be achieved with transformers. DC could only be stepped up at the time with unwieldy motor-generator sets so the rest is history, Westinghouse won and AC distribution became the standard for the 20th century.

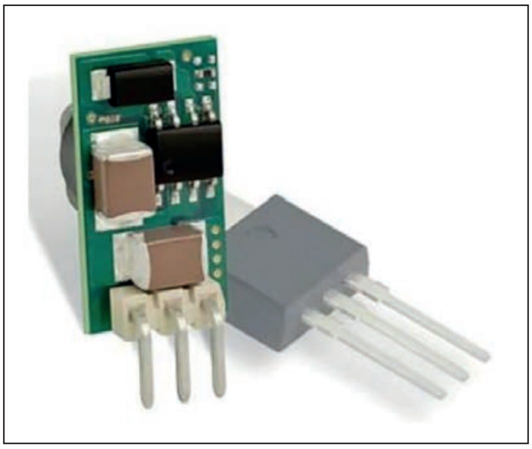
The last century was also the beginning of the age of electronics, which overwhelmingly requires DC for its components, so conversion from the AC distribution voltage to DC became necessary. But what DC? Circuitry can require anything from sub 1 V for a processor to several kilovolts for the magnetron in a microwave oven, sometimes together. If the rails required need to be accurate with changes in load and AC line, active regulation circuitry is also needed. Early equipment used 50/60 Hz transformers to drop the AC to lower voltages, which could then be rectified, smoothed to DC and regulated down to a lower voltage by a 'linear' series transistor, but when load, line and tolerances are taken into account, the power taken from the AC line is around twice the load power, worst case. The transformer is also large, heavy and expensive so the arrangement is far from ideal. If a system DC rail needs to be stepped up in voltage, there is no 'linear' way to achieve this.

Switched-mode conversion solves the problem

The practical solution to efficient DC down- and up-conversion is the 'switched-mode' technique. When isolation is not needed, 'buck' and 'boost' converters or derived variants are used. The buck (Figure 1, left) effectively 'chops' the input DC at high frequency so that its average is lower and then smooths the resulting waveform with an LC filter. The 'chopping' transistor is either fully on or off, in both cases dissipating little power and the output voltage is set by the transistor switching duty cycle. The boost converter (Figure 1, right) operates a little differently – the chopping alternately stores energy in the inductor magnetic field, then releases it. Energy can be released at any chosen voltage, higher than the input. Other circuit arrangements such as the simple buck-boost and ?uk can produce voltage inversion, while the SEPIC, ZETA and others can produce positive output voltages lower or higher than the input.

An example of Murata's 78SR series [1] buck is shown in Figure 2. The module has an input range of 7.5 V to 36 V for an output of 3.3 V at 0.5 A. At full load and 12 V input it achieves 83 % efficiency, dissipating about 0.7 W. It is pin compatible with the popular '78xx' series linear regulators which would dissipate a stressful 4.35 W under the same conditions requiring substantial heatsinking.

While this through-hole part can change out an existing linear regulator for a boost in efficiency, better performance still is achieved by surface mount 'Point-of-Load' DC/DC modules with land-grid array footprints.



LEFT Figure 2: 78SR series buck converter rated at 0.5A

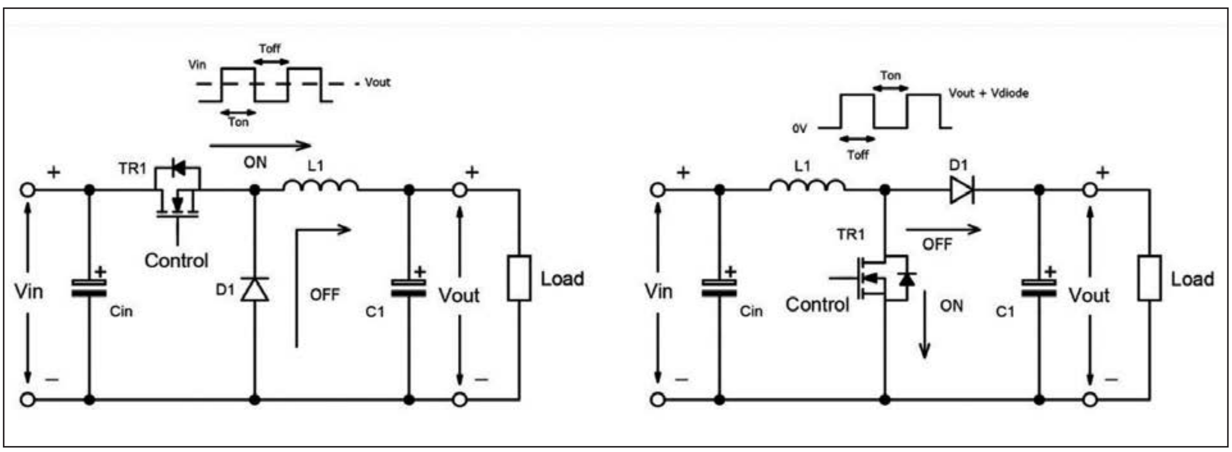


Figure 1: The buck and boost DC-DC converter outlines

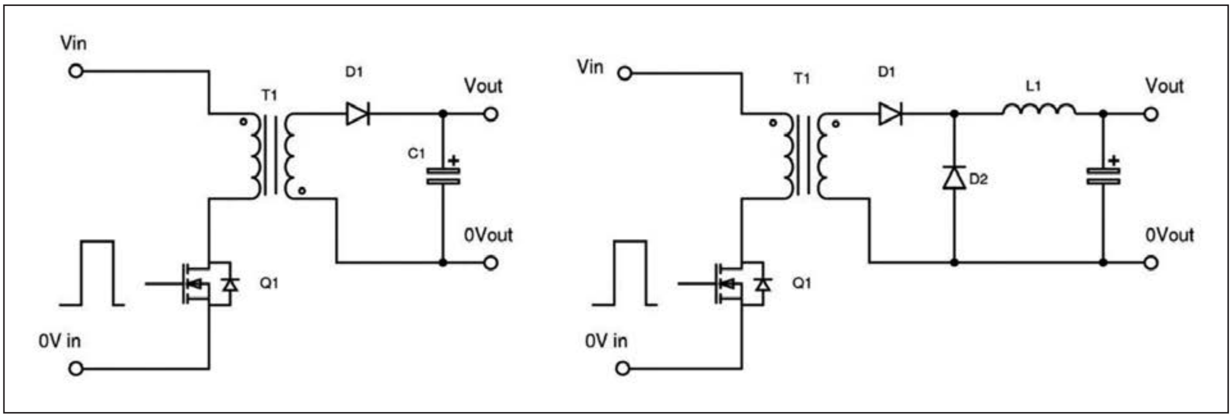


Figure 3: Flyback (left) and forward (right) converter outlines

The MYMGA series [2] for example, achieves 94 % efficiency at its full load current of 4 A (5 V version). This is all in a package 9 mm x 10.5 mm x 5.5 mm high.

At high power, 'multiphase' bucks spread the component stresses across duplicated switches and inductors, driven in two or more phases with common input and output capacitors. For best efficiency, bucks also use 'synchronous rectification' where the rectifier diode with its fixed voltage drop is replaced by a low on-resistance MOSFET.

Isolation is often required

Simple buck and boost converters do not provide galvanic isolation – their input and output grounds are connected. Often, that link needs to be broken to allow the output to 'float'. This could be because the input is referenced to an unsafe voltage, to prevent circulating ground currents, or simply so that the output can be configured as a negative voltage by grounding the positive. The equivalent isolated topologies to buck and boost are forward and flyback converters (Figure 3), which can be viewed as converting the inductor in each case into a transformer so an isolated winding can provide the DC output. Note the specific phasing of the transformer windings.

Isolated DC/DC converters are more difficult to fully regulate as the output voltage has to be sensed and an error signal passed back across the isolation barrier to the primary to control duty cycle. Sometimes regulation is not necessary however; if the input DC is constant, only load variations affect the output, which might only change by a few percent, which is often acceptable. One of the largest applications for small isolated DC/DC converters is to provide power for isolated data interfaces where regulation is not critical. When the input DC varies, 'semi' regulation can be used, sensing a primary winding on the transformer as an analog of the output, but for best accuracy, the output voltage is sensed directly and an error signal passed to the primary, typically through an optocoupler.

When isolation is required for safety reasons, the spacings and insulation arrangements are complex. Creepage, clearance and distance through solid insulation necessary depends on the level of protection required (basic, double or reinforced, for example) and other parameters such as environmental pollution degree, over-voltage category of the input and even altitude. The application sets the standards applied, with patient-connect medical for example, requiring larger separation distances than industrial.

There can be confusion about stated isolation rating; parts are often promoted with say, 3 kVDC test in production, which might seem adequate for isolation of 230 VAC. However, this is only a one-off test voltage and does not guarantee that the part continuously withstands a high voltage. Users should look for an actual safety agency certification, the level tested to and the 'system voltage' it refers to. A DC/DC converter isolating a 230 VAC mains referenced circuit from connections a user can touch in a home/office environment for example, might show 'reinforced isolation/250 VAC, maximum altitude 5000 m' according to EN 62368-1, the relevant safety standard in Europe.

Figure 4 is an example of NXJ series of an unregulated buck-derived (actually push-pull) DC/DC converter which simply converts 5 V to 5 V with agency-rated isolation for medical applications. The product features a novel method of em bedding the transformer core within the PCB stack, with the winding formed by PCB tracking and vias across many layers.

Resonant converters are more efficient

The forward converter appears in many varieties with different pros and cons, often dictated by the application trade-offs of efficiency, cost and size for given power and voltage conversion ratings. For optimum efficiency, 'resonant' converters are often used, which 'soft switch', that is, change switch state while current or voltage is zero.

This avoids the momentary spike in power dissipation if high voltage and high current occur together. There are many resonant topologies but a current favored one for low to medium power is the 'LLC'. The circuit applies pulses to an LC 'tank', typically just above its resonant frequency, with the pulses then passed as sine waves to a secondary load winding on the tank inductor, by transformer action. Regulation is achieved by varying the pulse frequency, which passes more or less energy through the transformer as a result of the increasing inductive impedance of the LC circuit with frequency, above

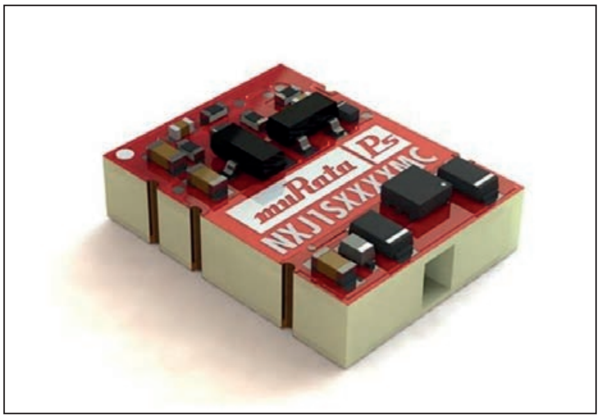


Figure 4: NXJ series of surface mount DC/DC converter with agency-rated isolation

resonance.

At high power, the stress on the LLC switching transistors becomes impractically high and then typically a 'phase-shift full bridge' topology is used. This is another resonant circuit in a four-switch bridge arrangement but operates at fixed frequency, with regulation achieved by varying the relative phase of the drive waveforms to each leg of the bridge. This technology is utilized in Intermediate Bus Converters such as the DRQ series [5].

Switched-capacitor converters need no magnetics

It is not necessary to use an inductor or transformer in a non-isolated DC/DC converter; switched capacitor arrangements can be used which charge capacitors in series or parallel then set them in parallel or series respectively to step down or up voltages respectively, in discrete multiples. Previously, switch and diode drops have limited the efficiency attainable but with modern MOSFETs and synchronous rectification, 96 %+ can be achieved at 72 W such as Psemi novel switched capacitor technology Figure 5 [3].

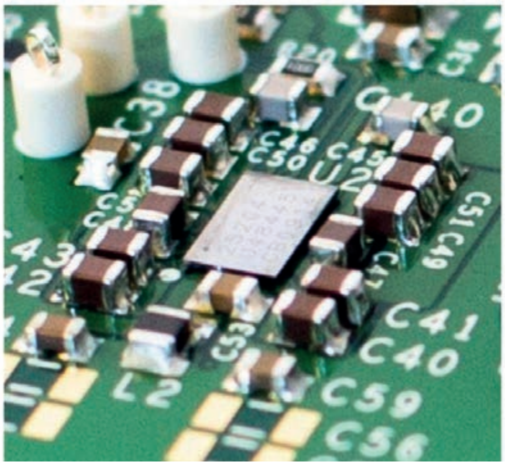


Figure 5: Psemi switched capacitor technology

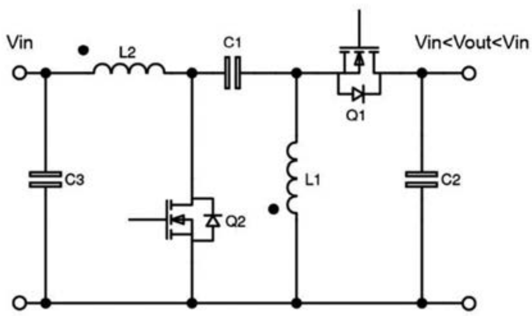


Figure 6: The SEPIC converter operates with input voltage above or below the output

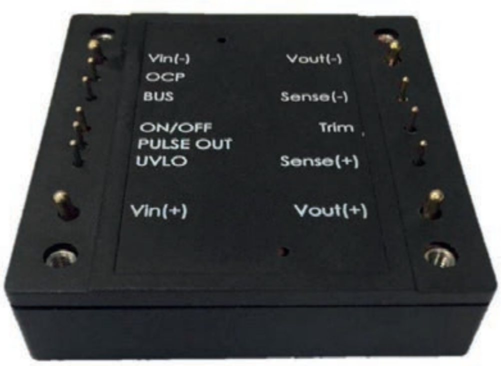


Figure 7: IRH250 ultra-wide DC input range converters

There is typically no active regulation and the step up or down is in a fixed ratio, 3 or 4 in [3] but the technique, without an inductor lends itself to modern fabrication methods and low-profile products.

Cell-phones require highest efficiency

Lower-power non-isolated DC/DC converters find a home in many commonplace electronic items such as cell-phones, where maintaining battery run-time is important and is facilitated by high efficiency of all power conversion stages. Converters that regulate an output with the input higher than, or lower than the output voltage are particularly valuable as a battery loses charge and its output voltage drops. Such converters are often classified as 'buck-boost', although strictly this gives a negative output which is not always useful. The SEPIC converter mentioned before (Figure 6), is a popular choice to provide a positive voltage with the input above or below the output. Q1 in the schematic operates as a synchronous rectifier. L1 and L2 can be separate inductors or wound on the same core.

Ultra-wide DC input range converters

Having a single DC/DC converter that can operate from a multitude of battery voltages, can simplify applications where the manufacturer of the equipment is uncertain which battery source will be used by the customer, for example in railway applications the battery can range from 24 V up to 110 V depending upon the manufacturer of the locomotive and the geographical region. Murata's IRH250 / IRQ150 satisfy this challenge with a DC voltage input range of 16 V – 160 V DC (Figure 7).

Automotive requirements are severe

Small DC-DC converters in automotive equipment can be subject to harsh environmental and electrical stress. The automotive AEC-Q qualification test requirements are not generally applicable to power converters so they are often classified as 'multi-chip modules' to AEC-Q104. The manufacturer of the device must also have certification to TS 16949 for their quality management system, above and beyond the familiar ISO 9001 standard. The NXJ series in Figure 4 is an example of an AEC-Q104 -qualified part.

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