POWER ELECTRONICS EUROPE

ISSUE 4 – Oct/Nov 2021 www.power-mag.com

POWER SEMICONDUCTORS

A New Approach to Circuit Breaker Design Using Silicon Carbide Switches

THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

Also inside this issue

Editor Achim Scharf
Tel: +49 (0)892865 9794
Fax: +49 (0)892800 132
Email: PowerElectronicsEurope@t-online.de

Production Editor Chris Davis
Tel: +44 (0)1732 370340

Financial Manager Caren Brown
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034
Email: caren.brown@dfamedia.co.uk

Reader/Circulation Enquiries
Perception
Tel: +44 (0) 1825 701520
Email: dfamedia@dmags.co.uk

INTERNATIONAL SALES OFFICES
Mainland Europe:
Victoria Hufmann
Norbert Hufmann
Tel: +49 911 9397 643
Fax: +49 911 9397 6459
Email: pee@hufmann.info

Eastern US
Ian Atkinson
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034
Email: ian@dfamedia.co.uk

Western US and Canada
Ian Atkinson
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034
Email: ian@dfamedia.co.uk

Japan:
Yoshinori Ikeda,
Pacific Business Inc
Tel: 81-(0)3-3661-6138
Fax: 81-(0)3-3661-6139
Email: pbi2010@gol.com

Taiwan
Prisco Ind. Service Corp.
Tel: 886 2 2322 5266 Fax: 886 2 2322 2205

Publisher & UK Sales Ian Atkinson
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034
Email: ian@dfamedia.co.uk
www.power-mag.com

Circulation and subscription: **Power Electronics Europe** is available for the following subscription charges. **Power Electronics Europe**: annual charge UK/NI £95, overseas $160, EUR 150.
Contact: DFA Media, 192 The High Street, Tonbridge, Kent TN9 1BE Great Britain.
Tel: +44 (0)1732 370340.
Fax: +44 (0)1732 360034. Refunds on cancelled subscriptions will only be provided at the Publisher's discretion, unless specifically guaranteed within the terms of subscription offer.

Editorial information should be sent to The Editor, **Power Electronics Europe**, PO Box 340131, 80098 Munich, Germany.

Printed by: Warners.

ISSN 1748-3530

FEATURE STORY

A New Approach to Circuit Breaker Design Using Silicon Carbide Switches

Mechanical circuit breakers have been around for a long time and do the basic job very well – they are low loss when on and provide excellent isolation when off. They do have their downsides though, with slow make/break times and arcing across the contacts, degrading their operating lifetime, particularly with DC power lines. Complex arrangements have been devised to disconnect quickly but it might still take around 10 milliseconds, allowing significant and possibly damaging energy to pass after a short circuit is detected, for example. Similarly, DC arcs can be suppressed to an extent with labyrinth clearances, a magnetic bias field or even blasts of compressed air. However, there are new applications for high current DC circuit breakers where this complexity cannot be afforded such as in EVs, where cost, size and weight are major issues.
Solid-state circuit breakers (SSCBs), typically using IGBTs, can break power lines perhaps a thousand times faster than mechanical types with no arcing or aging problems, but they are imperfect switches. Wide band-gap semiconductors such as Silicon Carbide types (SiC) usually hit the headlines for their fast switching speed, but they also have inherently around 10x better on-resistance for a given die area and voltage rating than Silicon. This makes them potential candidates for small, efficient SSCB switches, and the high material operating temperature and better thermal conductivity are additional benefits for peak power dissipation considerations. This article discusses the issues and introduces a new Silicon Carbide semiconductor, the DG-FET as an enabler for better performance.

More details on page 23.

Cover image supplied by United SiC, USA

Automotive Relies Increasingly on Power Semis

With around $9.5 billion by 2026, the Silicon MOSFET market will grow at roughly 4 % between 2020 and 2026. Leading MOSFET manufacturers are based in Europe, United-States and Japan, whit a big push from China. The ranking of top players has not evolved significantly since 2019 as 2020 MOSFET market was affected by COVID-19 crisis. Main MOSFET players are also involved in other power electronics technologies, such as IGBT, GaN or SiC. Automotive, including EV, will boost the demand for Silicon power MOSFETs due to increasing adoption of auxiliary systems and electrification. Auxiliary motor drives boost low voltage MOSFETs, while electrification boosts high voltage MOSFETs that are included in DC/DC converter or on-board charger systems. The two segments together are today 21 % of the MOSFET market. They will increase to 32 % by 2026, according to market researcher Yole. In addition to performance improvements, Silicon MOSFET die costs will be further reduced thanks to a 12-inch (300 mm) Silicon wafer transition that will make their cost increasingly competitive. In this ecosystem, Infineon Technologies keeps its leading position thanks to its large MOSFET portfolio and its CoolMOS technology – along with its 300 mm wafer manufacturing capability. In the MOSFET ranking, onsemi reaches the 2nd position, with 13 % market share , with leadership in low-voltage automotive market segment.

Chinese companies are also gaining market share via acquisitions and are also investing in technology knowledge. Five years back, Chinese products were believed to be lower performance than Europe, Japan, or American manufacturers for high-end components like Superjunction MOSFETs. However, this is changing. Some Chinese companies can achieve similar performances to key MOSFET players. All in all, Chinese manufacturers are racing to capture a big portion of the MOSFET market.

With $8.4 billion by 2026, the IGBT market will get a 7.5% growth between 2020 and 2026. IGBT modules segment will represent 81 % of the total market in 2026 during the same period, boosted by EV/HEVs adoption, which represented a market of $500 million in 2020 and which will grow with an impressive 23 % CAGR between 2020 and 2026. "This is due to the transition from ICE vehicles to EV/HEVs, which is being strongly driven by governments' targets for CO_2 emissions reductions. This transition is further accelerating, due to President Biden's action plans for the USA as well as the recent EU climate initiative in which all new cars registered in Europe from 2035 will be zero-emission. Therefore, the EV/HEV segment share will more than double by 2026. Charging infrastructure is also impacted by government decisions as the deployment of chargers is crucial for the expansion of electric vehicle uptake. Although charging infrastructure is still a small market for IGBTs, it is expected to increase by more than 300 % in the coming five years. More than 80 % of the market will be focused on the 600-1200V nominal voltage ranges by 2026. IGBT main manufacturers are spread all over the world, but Yole sees also an important growth of Chinese IGBT manufacturers, both foundries and IDMs. The ranking of main IGBT suppliers remains almost unchanged. The top 3 are Infineon Technologies, Mitsubishi Electric and onsemi.

The adoption of Silicon Carbide-based power solutions is rapidly growing across the automotive market as the industry moves from internal combustion engines to electric vehicles, enabling greater system efficiencies that result in electric cars with longer range and faster charging, while reducing cost, lowering weight and conserving space. In the industrial market, silicon carbide solutions enable smaller, lighter and more cost-effective designs, converting energy more efficiently to unlock new clean energy applications. To better support these growing markets, device manufacturers are interested in securing access to high-quality Silicon Carbide substrates to support their customers. Recently STMicroelectronics Wolfspeed and STMicroelectronics expanded their 150 mm SiC wafer supply agreement, as well earlier Infineon. The Japanese-based semiconductor manufacturer ROHM, together with Chinese Geely Automobile Group, have also entered into a strategic partnership to develop advanced technologies in the automotive field. Geely is working to extend the cruising range of electric vehicles while reducing battery costs and shortening charge times by developing high efficiency traction inverters and onboard charging systems that adopt ROHM's SiC power devices.

Also Gallium Nitride power devices are on the move into automotive applications. Canadian GaN Systems announced the signing of a capacity agreement with the BMW Group for automotive-grade GaN power transistors, which increase the efficiency and power density of critical applications in electric vehicles. BMW's relationship with GaN Systems began more than four years ago when BMW's engineers found that small size, lightweight, low-cost onboard chargers, DC/DC converters, and traction inverters were enabled by GaN. As electric vehicles become more prominent, the demand for critical semiconductor components such as GaN is only going to increase, BMW expects.

Thus the automotive industry relies more and more on efficient power semiconductors and tries to secure their supply through such agreements, in case GaN Systems/BMW this is a multi-$100 million deal and in case ST Micro/Wolfspeed it is now worth more than $800 million – an example of their application is the drive inverter of Tesla's Model 3.

More on new developments in devices and applications are introduced in this issue. Enjoy reading!

Achim Scharf
PEE Editor

China Race to Enlarge MOSFET Market Shares

With around $9.5 billion by 2026, the MOSFET market will grow at roughly 4 % CAGR between 2020 and 2026. Leading MOSFET manufacturers are based in Europe, United-States and Japan, whit a big push from China. The ranking of top players has not evolved significantly since 2019 as 2020 MOSFET market was affected by COVID-19 crisis. Main MOSFET players are also involved in other power electronics technologies, such as IGBT, GaN or SiC.

"Silicon MOSFETs are key components in a very wide range of low and mid-power applications", asserts Ana Villamor, Market Analyst at Yole Développement. "In 2020, the MOSFET market was worth $7.5 billion. We expect a 3.8% CAGR from 2020-2026, with most revenue coming from consumer and automotive markets." In general, 2021 has been an impressive year for MOSFETs with a huge recovery from COVID-19 thanks to the high demand for computing and consumer electronics. Today the consumer market contributes 37 % of MOSFET revenues, making it the largest sector. Yole's analysts are expecting this to fall in coming years due to lower end system demand after COVID-19 lockdowns, which have been very good for computing and consumer electronics, resulting in a $2.8 billion market by 2020.

Automotive, including EV, will boost the demand for Silicon power MOSFETs due to increasing adoption of auxiliary systems and electrification. Auxiliary motor drives boost low voltage MOSFETs, while electrification boosts high voltage MOSFETs that are included in DC/DC converter or on-board charger systems. The two segments together are today 21 % of the MOSFET market. They will increase to 32 % by 2026. "Indeed, new environmental regulations targeting carbon neutrality by 2050 by some governments play in favor of faster vehicle electrification", adds Amine Allouche, Technology Analyst at System Plus Consulting. "And power electronics is a key technology for this transition. Silicon MOSFETs benefit from mature infrastructure and processes. Meanwhile, new device generations are coming to the market. In addition to performance improvements, Silicon MOSFET die costs will be further reduced thanks to a 12-inch Silicon wafer transition that will make their cost increasingly competitive." In this ecosystem, Infineon Technologies keeps its leading position thanks to its large MOSFET portfolio and its well-known CoolMOS technology – along with its 12-inch (300 mm) wafer manufacturing capability. In the MOSFET ranking, onsemi reaches the 2nd position, with 13 % market share , with leadership in low-voltage automotive market segment.

And what about the Chinese players? "Indeed, they are not very visible in the MOSFET market, since it is highly technologically driven. However, we start to see players such as Jilin Sino Microelectronics, Silan Microelectronics or CRMicro with quite a few MOSFET products in their portfolio. As detailed in Yole's Silicon MOSFET report, China accounts for 38 % of MOSFET sales. As well as growing demand for MOSFETs for different applications, the Chinese government is pushing for domestic manufacturing. It is therefore not surprising that Chinese players are investing in manufacturing capabilities," asserts Milan Rosina, Analyst, Power Electronics. "Foundries like HHGrace and CanSemi have invested in 300 mm facilities to cope with higher production of MOSFETs and other power components and have started production in them.

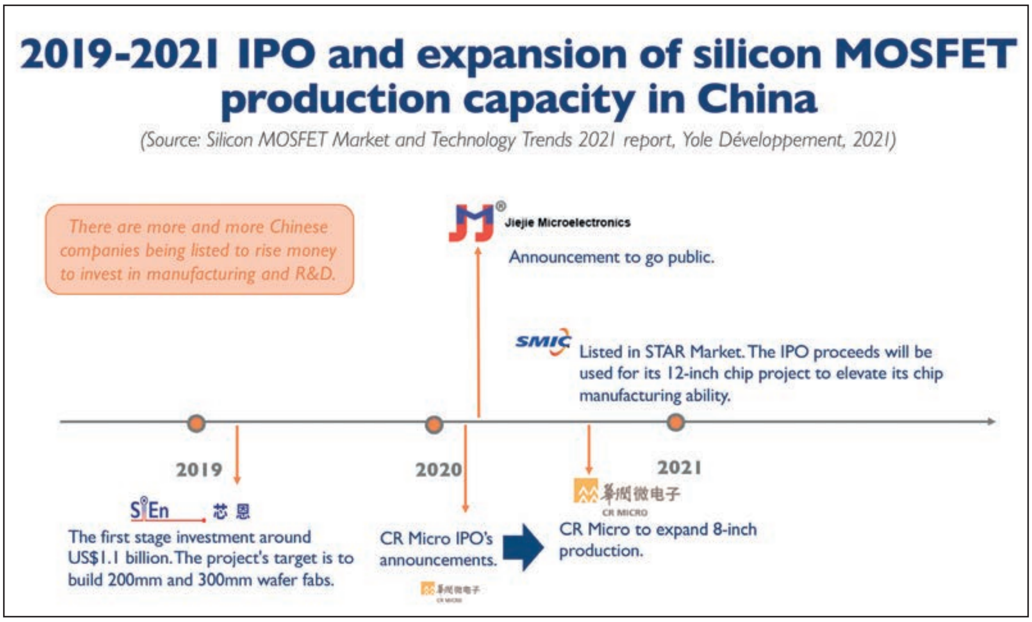
However, this is not the end of Chinese push for 300 mm. SiEn is building a 300 mm fab, as well as CRMicro and Nexperia. In fact, CRMicro recently raised money through an IPO , and has already expanded its 200mm line. Other companies like Jiejie Microelectronics and SMIC are following the same pattern. All of them want to invest the money raised into manufacturing capacity."

Chinese companies are also gaining market share via acquisitions. Deals by Chinese-owned companies are not straightforward since the China-US trade war started. See for example the Nexperia–Newport, UK, Wafer Fab or Magnachip-Wise Road Capital acquisitions. Chinese manufacturers are also investing in technology knowledge. Five years back, Chinese products were believed to be lower performance than Europe, Japan, or American manufacturers for high-end components like Superjunction MOSFETs. However, this is changing. Some Chinese companies can achieve similar performances to key MOSFET players. All in all, Chinese manufacturers are racing to capture a big portion of the MOSFET market.

IGBT market driven by automotive

With $8.4 billion by 2026, the IGBT market will get a 7.5% growth between 2020 and 2026. IGBT modules segment will represent 81 % of the total market in 2026 during the same period, boosted by EV/HEVs adoption. More than 80 % of the market will be focused on the 600-1200V nominal voltage ranges by 2026. IGBT main manufacturers are spread all over the world, but Yole sees also an important growth of Chinese IGBT manufacturers, both foundries and IDMs. The ranking of main IGBT suppliers remains almost unchanged. The top 3 are Infineon Technologies, Mitsubishi Electric and onsemi.

In 2020, the largest IGBT market segments were industrial applications and home appliances. They were closely followed by EV/HEVs, which represented a market of $500 million in 2020 and which will grow with an impressive 23 % CAGR between 2020 and 2026. "This is due to the transition from ICE vehicles to EV/HEVs, which is being strongly driven by governments' targets for CO2 emissions reductions. This transition is further accelerating, due to President Biden's action plans for the USA as well as the recent EU climate initiative in which all new cars registered in Europe from 2035 will be zero-emission. Therefore, the EV/HEV segment share will more than double by 2026. Charging infrastructure is also impacted by government decisions as the deployment of chargers is crucial for the expansion of electric vehicle uptake," said Abdoulaye Ly, Technology Analyst. "Although charging infrastructure is still a small market for IGBTs, it is expected to increase by more than 300 % in the coming five years."



www.yole.fr

Introducing a New Generation of AVR® Devices

AVR-DA Flexibility in Design

Functional Safety Ready

The Functional Safety Ready AVR-DA family is the new generation of AVR microcontrollers running up to 24 MHz across the full supply voltage range 1.8V to 5.5V featuring intelligent analog and core independent peripherals.

The AVR-DA family uses the latest Core Independent Peripherals and low-power capability to handle real-time control functions in industrial control, home appliance, automotive and Internet of Things (IoT) applications. The Event System and Configurable Custom Logic (CCL) peripherals offer near-zero latency for time-critical functions. Intelligent Analog peripherals like 12-bit differential Analog-to-Digital Converter (ADC), Zero-Cross Detect (ZCD), 10-bit Digital-to-Analog Converter (DAC) and the latest-generation Peripheral Touch Controller (PTC) put the AVR-DA family in the center of sensor interface, system monitoring and human interface applications. 5V operation for increased noise immunity and low-power features ease power supply concerns.

- Product certifications made easier with Functional Safety supporting documentation and development tools.
- Add IoT and connectivity to your application, thanks to the high memory densities and SRAM-to-Flash ratio.
- Design robust and noise-immune applications with built-in safety features and 5V supply.
- Create state-of-the-art capacitive touch interfaces using the latest-generation PTC.

www.microchip.com/avr-da

MICROCHIP

Nexperia Acquires Newport Wafer Fab

Nexperia has completed the transaction to acquire Newport Wafer Fab (NWF), contributing to the company's investments to boost global production capacity. With the acquisition, Nexperia obtains 100 % ownership of the Welsh semiconductor production facility. Nexperia Newport will continue to have a strong position in the Welsh ecosystem and technology development and will secure the current jobs at the Newport site and others across the region.

Nexperia is a customer of the foundry services offered by Newport Wafer Fab and became its second largest shareholder in 2019. The Newport site complements Nexperia's other European manufacturing operations in Manchester and Hamburg, which have also seen significant recent investments. The Newport semiconductor production site was first established in 1982 and was originally named INMOS. Current capacity is over 35,000 200 mm wafer starts per month covering a wide range of semiconductor technologies ranging from MOSFETs and Trench IGBTs using wafer thinning methods to CMOS, analogue and compound semiconductors. It will support Nexperia's strategic $10 bln growth ambition and enrich Nexperia's product lines in IGBT, Analog and compound semiconductors in parallel to the current 8-inch investments at the Manchester and Hamburg wafer fabs. This acquisition significantly enhances the automotive-qualified product supply capability and the market share. "Nexperia has ambitious growth plans and adding Newport supports the growing global demand for semiconductors. The Newport facility has a very skilled operational team and has a crucial role to play to ensure continuity of operations. We look forward to building a future together", commented Achim Kempe, Nexperia's Chief Operations Officer. "The acquisition is great news for the staff here in Newport and the wider business community in the region as Nexperia is providing much-needed investment and stability for the future. We are looking forward to becoming part of the global Nexperia team and are keen to keep the current workforce. Additional local resources may be required too. We are also pleased that we will be able continue to contribute to the local ecosystem", added Paul James, Operations Director at the Newport site.

ww.nexperia.com/about

Renesas Acquires Dialog Semiconductor

Iapanese Renesas Electronics Corporation announced on August 31 the successful completion of Renesas' acquisition of the entire issued and to be issued share capital of UK-based Dialog Semiconductor. Renesas will fund the cash consideration payable to Dialog shareholders of approximately EUR 4.8 billion (approximately 624.0 billion yen at an exchange rate of 130 yen to the Euro) through a combination of debt, cash on hand and the proceeds of an equity offering of approximately 222.6 billion yen. The closing of the acquisition of Dialog, following the acquisitions of Intersil and IDT, reinforces

Renesas as a premier embedded solution provider. Renesas will expand its market presence with an even broader range of product portfolio by combining Dialog's low-power mixed signal products, low-power Wi-Fi and Bluetooth® connectivity expertise, flash memory, battery and power management as well as its long-standing experience and in-depth knowledge in providing configurable mixed-signal (CMIC) solutions and more.

Renesas anticipates incremental revenue growth of approximately $200 million from cross-selling and offering winning combinations. The combined company also expects cost savings from operational efficiencies to result in a financial impact of approximately $125 million. With the transaction now closed, Dialog became a wholly owned subsidiary of Renesas. About 2,300 Dialog employees have joined Renesas Group, and the two companies will work together to integrate both businesses. "Today represents an important milestone for Renesas. This transaction builds on our long-term strategy to offer a complete set of solutions with more leading-edge analog and mixed signal products that deliver value and innovation to the customers," said Hidetoshi Shibata, President & CEO of Renesas.

www.renesas.com

Wolfspeed and STMicroelectronics Expand 150 mm SiC Wafer Supply Agreement

This amended agreement, which calls for Cree to supply ST with 150 mm SiC bare and epitaxial wafers over the next several years, is now worth more than $800 million.

"This latest expansion to our long-term wafer supply agreement with Cree will continue to contribute to the flexibility of our global silicon carbide substrate supply., complementing the other external capacity we have secured and the internal capacity we are ramping. The agreement will help meet the high volumes required by our product manufacturing operations in the next years, with a large number of automotive and industrial customer programs in high volumes or ramping up," said Jean-Marc Chery, President and CEO of STMicroelectronics. The adoption of Silicon Carbide-based power solutions is rapidly growing across the automotive market as the industry moves from internal combustion engines to electric vehicles, enabling greater system efficiencies that result in electric cars with longer range and faster charging, while reducing cost, lowering weight and conserving space. In the industrial market, silicon carbide solutions enable smaller, lighter and more cost-effective designs, converting energy more efficiently to unlock new clean energy applications. To better support these growing markets, device manufacturers are interested in securing access to high-quality silicon carbide substrates to support their customers. "We are very pleased that STMicroelectronics will continue to leverage Wolfspeed silicon carbide materials as part of their supply strategy for the next several years," said Cree CEO Gregg Lowe. "Our long-term wafer supply agreements with device manufacturers now total more than $1.3 billion and help support our efforts to drive the industry transition from Silicon to Silicon Carbide. Our partnerships and significant investments in increased production capacity ensure we are well positioned to capitalize on what we believe to be is a multi-decade growth opportunity for Silicon Carbide-based applications."

www.st.com, www.cree.com

ROHM and Geely Focus on SiC Automotive Applications

The Japanese-based semiconductor manufacturer ROHM, together with Chinese Geely Automobile Group, have entered into a strategic partnership to develop advanced technologies in the automotive field. Both companies have been collaborating on a variety of automotive applications since 2018, when they first agreed to carry out technical exchange. This partnership is expected to further promote cooperation and accelerate innovation for automotive applications.

Geely is working to extend the cruising range of electric vehicles while reducing battery costs and shortening charge times by developing high efficiency traction inverters and onboard charging systems that adopt ROHM's SiC power devices. At the same time, Geely is committed to improving user experience through the development of high performance ADAS and intelligent cockpit systems using a wide range of products and solutions, including communication ICs and discrete devices. As a first step, traction inverters equipped with ROHM's SiC power devices are being integrated in electric vehicle platforms currently being developed by Geely.

www.rohm.com/eu

GaN Systems Signs Semiconductor Capacity Agreement with BMW

GaN Systems announced the signing of a capacity agreement with BMW Group for GaN Systems' automotive-grade GaN power transistors, which increase the efficiency and power density of critical applications in electric vehicles.

GaN power semiconductors are a key ingredient to achieve the small size, lightweight, and high efficiency required in the next generation of high-performance inverters of electric vehicles. Under the terms of the agreement, GaN Systems will provide capacity for multiple applications in series production. The guaranteed volumes by GaN Systems are a key building block for reliability in the supply chain for automotive players like BMW. "Electric vehicles represent the future of transportation, and we are delighted to continue to support BMW with our design and production capacity," stated Jim Witham, CEO of GaN Systems. "This multi-$100 million agreement demonstrates BMW's commitment to innovation and sustainability."

BMW's relationship with GaN Systems began more than four years ago when BMW's engineers found that small size, lightweight, low-cost onboard chargers, DC/DC converters, and traction inverters were enabled by GaN. This led to investment from BMW's venture capital firm, BMW I Ventures, to support and accelerate the automotive qualification of the GaN technology. "The close collaboration among GaN Systems and BMW's engineers has helped to solidify the technology for automotive series production, resulting in the most advanced GaN power transistors in the marketplace today," said Kasper Sage, managing partner BMW i Ventures. "As electric vehicles become more prominent, the demand for critical semiconductor components is only going to increase, thereby making strategic partnerships with suppliers like GaN Systems even more important."

www.gansystems.com

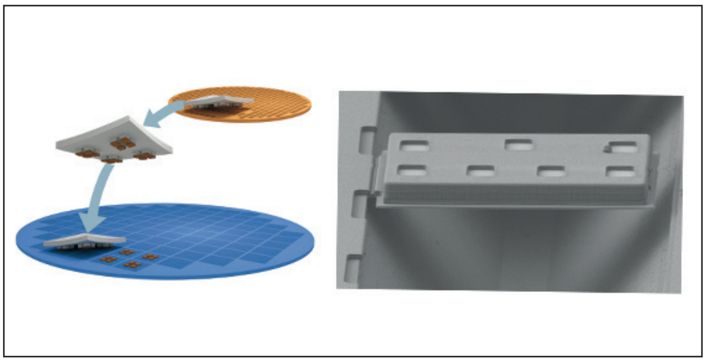
X-FAB Becomes First Foundry to Offer High-Volume Micro-Transfer Printing

X-FAB Silicon Foundries is now able to support volume heterogeneous integration via Micro-Transfer Printing (MTP), thanks to a licensing agreement that has just been secured with X-Celeprint.

This means that a diverse range of semiconductor technologies may be combined together, each being optimized for particular functional requirements. These will include SOI, GaN, GaAs and InP, as well as MEMS. X-Celeprint's proprietary massively-parallel pick-and-place MTP technology stacks and fans-out ultra-thin dies based on different process nodes, technologies, and wafer sizes. It results in the formation of virtually monolithic 3D stacked ICs, which have enhanced performance, greater power efficiency, and take up less space. Furthermore, all this can be achieved at an accelerated rate, thereby significantly shortening time-to-market.

In order to become the first foundry to provide customers with MTP-based heterogeneous integration, X-FAB has made substantial investments over the last two years. It has also established new optimized workflows and cleanroom protocols. This will allow customers to work with the foundry on heterogeneous design projects - benefitting from a scalable business model that offers a clear migration to volume production. "By licensing X-Celeprint's MTP technology, we are uniquely positioned in our ability to facilitate the incorporation of numerous different semiconductor technologies. Our customers will be able to utilize a technology that no other foundry is offering, and existing X-Celeprint customers may now tap into capacity levels that will easily meet their future demands," Volker Herbig, VP of X-FAB's MEMS business unit, explains. "As a result, we can assist customers looking to implement complete multifunctional subsystems at the wafer level, even when there are high degrees of complexity involved. Signal conditioning, power, RF, MEMS, and CMOS sensors, optoelectronic devices, optical filters, and countless other possibilities will all be covered."

www.xfab.com



Solid-State Battery Market Will Grow to $8 Billion by 2031

The rapid growth of the electric vehicle market has driven the development, manufacture, and sales of batteries, especially lithium-ion batteries. In the meantime, interests in solid-state batteries have attracted the attention of material providers, battery vendors, component suppliers, automotive OEMs, and investors.

The popular discussions on solid-state batteries have brought development both in academia and industry. With an increasing number of players working in this field and some milestones being achieved, the solid-state battery market is expected to grow to $8 billion by 2031, according to IDTechEx's new report "Solid-State and Polymer Batteries 2021-2031: Technology, Forecasts, Players". In 2015, Volkswagen got a 5 % stake in QuantumScape, Dyson acquired Sakti3, Bosch acquired SEEO, and Johnson Battery Technologies sold its solid-state batteries to BP. Although in 2017, Bosch gave up SEEO and was selling the company, and Dyson abandoned the technologies of Sakti3, the interest in solid-state batteries never vanished. Ford, Samsung, and Hyundai invested in Solid Power. The latter also partnered with BMW. Renault, Mitsubishi, and Nissan invested in Ionic Materials. In 2020 there were the newly developed solid-state batteries based on argyrodite electrolyte by Samsung and a further $200 million investment by Volkswagen on QuantumScape. As well as the companies just mentioned, Honda, Fisker, Panasonic, CATL also got involved in this game.

Flammable liquid electrolytes in most commercial li-ion batteries are considered a threat to safety as they can easily shrink under high temperatures, lead to short circuits and then catch fire. Replacing organic liquid electrolytes with solid-state counterparts, solid-state batteries enable safer, long-lasting batteries. Better safety means less safety monitoring electronics in the battery modules/packs. Therefore, even the initial generations of solid-state batteries may have similar, or even less energy density than conventional lithium-ion batteries, the energy available in the battery pack can be comparable or even higher than the latter. With the larger electrochemical window that the solid electrolytes can provide, high voltage cathode materials can be used. In addition, high-energy-density lithium metal anode can further push the energy density beyond 1,000 Wh/l. These features can further make the solid-state battery a game-changer.

Lithium-ion battery manufacturing has been dominated by East Asia, with Japan, China, and South Korea playing a significant role. US and European countries are competing in the race, shifting the added values away from East Asia and building battery manufacturing close to the application market. New material selection and change of manufacturing procedures show an indication of a reshuffle of the battery supply chain. From both technology and business point of view, the development of solid-state batteries has become part of the next-generation battery strategy. It has become a global game with regional interests and governmental supports. Opportunities will be available with new materials, components, systems, manufacturing methods, and know-how.

With most companies' mass production plans, like Japan ~2025-2030, Europe ~2025-2026, mainland China & Taiwan ~2022-1023, the solid-state battery will likely take off after 2025, although small-scale production may happen even earlier. The car plug-in market will take the largest share (66 %) in 2031, followed by smartphone applications.

www.IDTechEx.com/

Infineon Opens 300-Millimeter Power Semi Wafer Fab

On September 17 Infineon Technologies officially opened its high-tech chip factory for power electronics on 300-millimeter wafers at its Villach site in Austria under the motto “Ready for Mission Future.” At 1.6 billion Euros, this investment represents one of the largest projects in the microelectronics sector in Europe.

The Villach site is one of the world’s most modern fabs and was opened by Infineon’s CEO Reinhard Ploss, Infineon’s Austria CEO Sabine Herlitschka along with EU Commissioner Thierry Breton and Austrian Chancellor Sebastian Kurz.

Infineon set the stage for long-term, profitable growth based on energy efficiency and CO2 reduction at an early stage and announced the construction of the chip factory for power electronics in 2018. “The new fab is a milestone for Infineon, and its opening is very good news for our customers,” Ploss said. “The timing to create new capacity in Europe could not be better, given the growing global demand for power semiconductors. The last few months have clearly shown how essential microelectronics are in virtually every area of life. Given the accelerated pace of digitalization and electrification, we expect demand for power semiconductors to continue to grow in the coming years. The additional capacities opens up an additional revenue potential of around two billion Euros annually and will help us serve our customers worldwide better.”

After three years of preparation and construction, the factory was commissioned at the beginning of August, three months ahead of schedule. In the first stage of expansion, the chips will primarily be used to meet demand from the automotive industry, data centers and renewable energy generation of solar and wind power. The annual capacity planned for industrial semiconductors is sufficient to equip solar systems producing a total of around 1,500 TWh of electricity – roughly three times the annual power consumption in Germany.

During the construction of the factory, attention was paid to further improve its energy balance sheet: 80 percent of the site’s heating requirements will be covered by intelligently recycling the waste heat of the cooling systems, thus around 20,000 tons of CO2 can be avoided each year. The extensive use of exhaust air purification systems will cut direct emissions to virtually zero. Another milestone in terms of sustainable production and circular economy is the production and recycling of green hydrogen. The hydrogen required as a process gas in production will be produced directly on site in Villach from renewable energy sources starting at the beginning of 2022. This green hydrogen will be recycled after use in chip production and used to fuel public transportation buses. This project of dual use of green hydrogen is unique in Europe. With the help of these and other measures, the site take a huge stride forward in its effort to become carbon neutral by 2030.

The new chip factory has about 60,000 m? of gross floor space. Production will be gradually ramped up over the next four to five years. More than two-thirds of the 400 additional highly qualified specialists needed to operate the factory have already been hired. The chip factory is one of the most modern in the world and relies on full automation and digitization. As a “learning factory,” artificial intelligence solutions will be used primarily in the area of predictive maintenance. Networked plants will know at an early stage when they need maintenance thanks to a multitude of data and simulations.

The Villach-site is also part of a so-called virtual fab. “Infineon now has two large power semiconductor manufacturing sites for 300-millimeter thin wafers, one in Dresden and this in Villach. Both sites are based on the same standardized production and digitization concepts. This allows us to control the manufacturing operations at the two sites as if they were one factory. We increase productivity and create additional flexibility. This is because we can quickly move production volumes for different products between the sites and thus respond even faster to customer needs. This makes further increases in resource and energy efficiency possible, as well as optimization of the environmental footprint,” underlined COO Jochen Hanebeck. “The chips are manufactured on thin wafers, which at 40 micrometers are thinner than a human hair. Villach is the Group’s center of expertise for power semiconductors and has long been an important innovation site in Infineon’s manufacturing network. It was here that the production of power semiconductors on 300-millimeter wafers was developed about ten years ago. This was then expanded to fully automated volume production at the Dresden site in recent years. The use of this technology brings significant productivity advantages due to the larger wafer diameter and reduces capital expenditure”.

Various industry speakers addressed this opening as a milestone to reach their targets in developing new products. “We at Volkswagen are convinced that the future of automobiles are autonomous, climate-neutral, fully connected and electric. We have taken this path consistently, and on this way we need strong partners such as Infineon, in our ID family more than 50 Infineon components are installed. Such chips are the infrastructure of tomorrow’s mobility,” said Heiner Lanze, Business Manager Procurement. Alan Zeng, CEO of Chines Nio-XPT, expressed his hope to overcome the shortage in supply chains. “As far as we know this new fab has the capacity to supply around 25 million electric vehicles annually and to release pressure from the existing production of IGBTs and SiC devices. Thus this new fab increases the supply chain what is also beneficial for all customers. We all have suufered from the 2020/21 shortage and hope that this situation will improve soon!” And Günther F. Apfalter, President Magna Europe & Asia added: “Especially in the automotive industry the dependence on Asian semiconductor manufacturers hit us very hard in recent years. Many millions of vehicles can not be built this year, we also don’t know what the next year will look like. Thus I welcome this investment in Austria to reduce dependency here in the future!”

At the opening, Kurz underscored the new chip factory’s significance, including to his own country. “The Infineon site in Villach is an absolute success story,” he said. “The new chip factory is an economic and technological lighthouse project for all of Austria. I would like to thank all of those responsible for their commitment to our country, which will create additional 400 jobs. The investment of 1.6 billion euros shows that Austria, as a business and technology location, offers excellent framework conditions and the employee know-how that is needed to make them happen. We in the federal government want to continue to invest massively in digitization in order to position ourselves in the best possible way in global competition.” Sabine Herlitschka, the CEO of Infineon Technologies Austria AG, said: “With this investment, Infineon has demonstrated that it is also possible to build attractive production sites in Europe in the highly competitive semiconductor sector. We are setting new standards with this investment. The energy-saving chips from Villach will become important core elements for the energy transition. We are thus making a relevant contribution to the European Green Deal and beyond. We are ‘Ready for Mission Future’.”

www.infineon.com

Infineon Austria CEO Sabine Herlitschka (left), CEO Reinhard Ploss and and COO Jochen Hanebeck officially opened on September 17 its new 300-mm power semi fab in Villach/Austria

Obtaining Highest Efficiency in DC/DC Converter Applications

While improvements in Silicon power devices have been incremental, the introduction of wide-bandgap devices, such as Silicon Carbide (SiC), allow a jump in performance to be attained. Thanks to reference designs, such as Toshiba's bidirectional DC/DC power supply, design engineers can significantly speed-up evaluation of suitable design approaches and topologies and get up to speed on the intricacies of using SiC MOSFETs. **Dr. Matthias Ortmann, Chief Engineer, Application Support,Toshiba Electronics Europe**

As the world weans itself from its dependency on fossil fuels, there has been a focus on innovative electronic systems to deliver clean, efficient electrical power. Government initiatives to reduce vehicle emissions have seen the automotive industry move to electric drivetrains. This requires a charging infrastructure that is efficient and robust to keep this method of mobility on the move. Electricity generation has also moved to renewable sources of energy, such as solar and wind. Unlike fossil fuel and nuclear alternatives, such power generation is dependent on the weather and time of day. Since these do not always match with grid demand, storage of energy such sources in batteries helps to improve its effectiveness in the energy supply mix.

Over the years, Silicon devices have advanced enormously, demonstrating continuous improvement in their capabilities. Microcontrollers offer clever pulse-width modulated (PWM) timers coupled with synchronous analogue to provide engineers with highly customizable platforms that can be programmed to meet exacting power conversion needs. Simultaneously, Silicon power devices have been optimized in terms of on-resistance and their parasitics to minimize their losses.

A jump in performance

SiC MOSFETs offer significant improvements in switching losses when compared to silicon IGBTs. Thanks to the high drain-source voltage supported, they are increasingly displacing IGBTs in power factor correction and other high-voltage power conversion stages. The SiC-based integrated diode incorporated into these devices is also support high surge currents, making them a robust component in the design.

Perhaps the most desirable characteristic is their high switching speed compared to IGBTs. Not only does this significantly reduce turn-on and turn-off losses, it allows higher switching frequencies to be used. In turn, this leads to a reduction in size of inductors, resulting in compacter designs when targeting the same output power compared to IGBT-based converters. Under the same conditions, the Toshiba TW070J120B SiC MOSFET has a turn-on loss of just 0.6 mJ compared to a similarly specified IGBT, which required 2.5 mJ (Figure 1).

Bidirectional DC/DC converters

Bidirectional DC/DC converters enable power stored in batteries to be used for other purposes once charging is complete. For EVs, there is interest in providing Vehicle-to-Grid (V2G) capability, allowing vehicles to provide power during outages or even to stabilize the grid locally when required. Renewable energy plants also make use of this capability, storing energy generated during optimal weather conditions and delivering back to the grid when it is required. As a result, fossil-fuel power sources, such as diesel generators, are required less often or not at all.

Efficiency is essential in such designs. One approach to construct two separate converters, each dedicated to the needs of the application, but this results in a bulky solution with a high component count. To achieve higher power density, designers turn to the Dual Active Bridge (DAB) topology (Figure 2). This allows the use of soft-switching, a lower device count, attain high efficiencies, while also providing galvanic isolation – often a critical design requirement – at a more attractive total system cost.

The DAB topology consists of two full-bridges connected by an inductor and a high-frequency transformer (Figure 3). The transformer's primary and secondary windings set the conversion ratio between

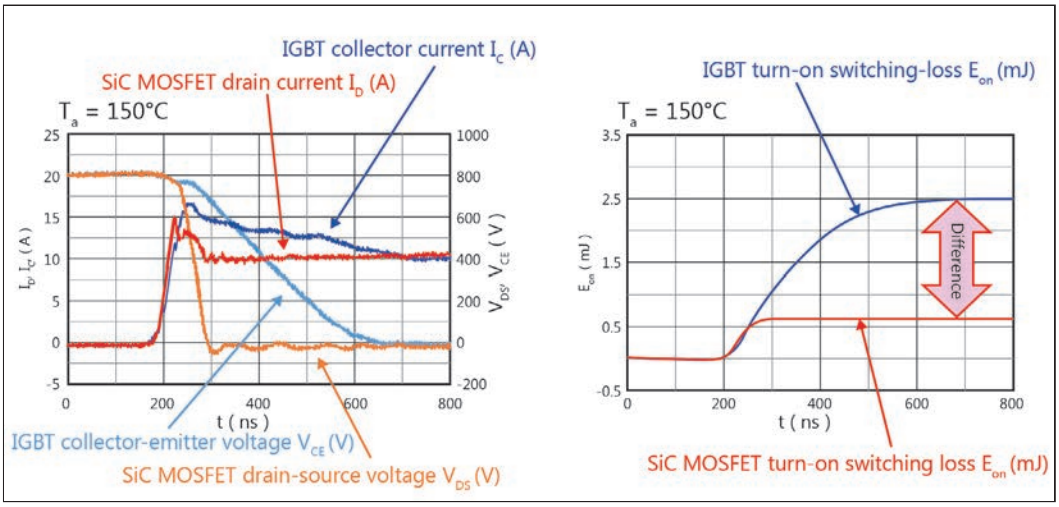


Figure 1: Compared to latest-generation IGBTs, the TW070J120B SiC MOSFET shows considerably faster switching speeds that deliver higher efficiencies in power converters

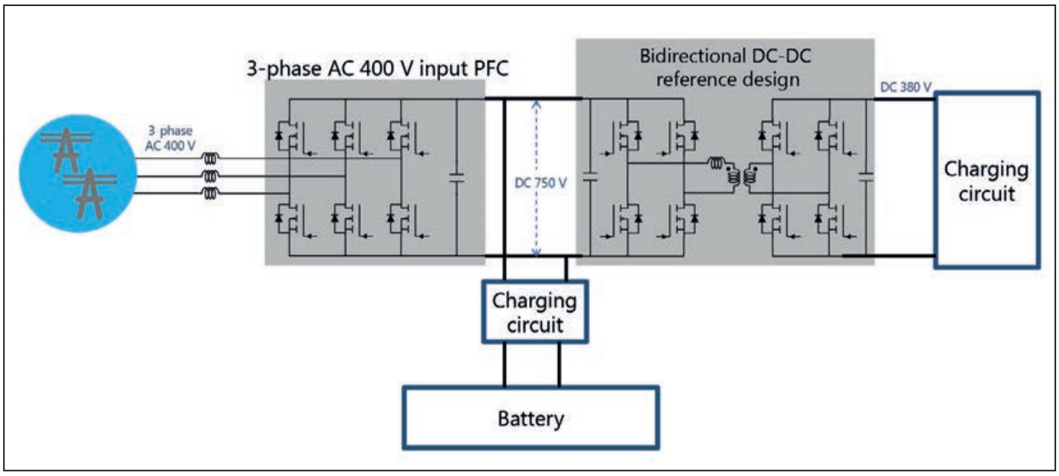


Figure 2: Role of bidirectional DC/DC converters in photovoltaic (left) and electric vehicle charging (right) applications

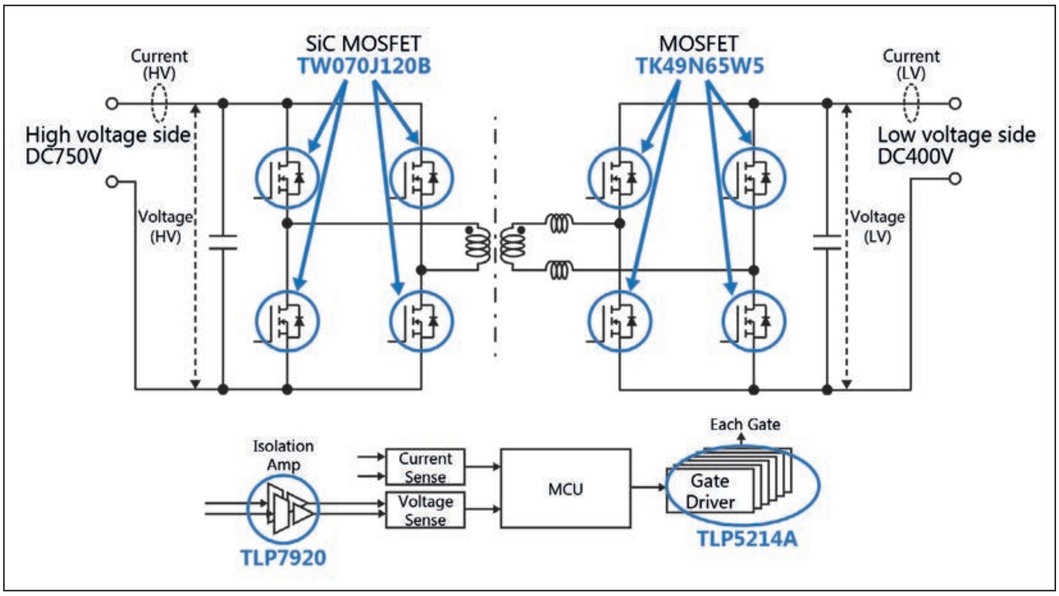


Figure 3: The DAB bidirectional DC-DC converters based upon the TW070J120B SiC MOSFET and TK49N65W5 silicon superjunction MOSFET

the two sides. The series inductor is not a requirement. In some cases the transformer can fulfill both roles, but this is typically at the expense of increase losses and a loss in efficiency. Both sides are controlled using complementary PWM control signals. Modification of the phase of the signal applied to the two sides defines the direction of energy transfer. The side connected to the high-voltage DC link is well suited to the capabilities of SiC MOSFETs. They support the high voltages being applied while supporting the high switching frequencies used. Thanks to the use of zero-voltage switching (ZVS), high-voltage Silicon MOSFETs are matched to the needs of the opposing side.

This is the approach taken in a new bidirectional DC/DC power supply reference design (RD167). Supporting high-side voltages of 750 V DC, and outputting 380 V DC, the supply can deliver 5 kW at a power efficiency of 97 % in either direction (100 % step-up load) using a 50 kHz switching frequency. The design uses the 1200 V TW070J120B SiC MOSFET rather than IGBTs to take advantage of the low switching losses, and the low 70 mΩ RDS(ON). The gate threshold (Vth) lies between 4.2 V and 5.8 V, which contributes to the robustness of the design by making it less prone to gate voltage fluctuations and noise.

On the low-voltage side, the design uses the 650 V TK49N65W5, a Silicon N-channel MOSFET, taking advantage of the performance improvements compared to IGBTs. Its high-speed parasitic diode, coupled with the DTMOS superjunction structure, contribute to the high efficiency thanks to the low switching losses and fast reverse recovery time (trr = 145 ns typical). With a low on-resistance of 0.051 Ω (typical), it can support drain DC currents (ID) of 49.2 A and drain pulse currents (IDP) of 192 A.

To provide optimal gate control to both the SiC and Silicon MOSFET, the TLP5214A gate drive is used. Its 4 A sink and source capability provide adequate drive and discharge currents at elevated voltages and the high switching frequencies used. It also provides a safeguard to the design thanks to its over-current protection and under-voltage lock-out function.

Conclusion

Continuous innovation in the domain of power devices is supporting power converter engineers to attain ever higher efficiencies with their products. It also helps ensure that the move from fossil-fuel to electric energy makes optimal use of our available resources. Whether targeting higher powers, or looking to move to greater power densities, IGBTs are increasingly being exchanged for alternatives. At high voltages (> 1000 V) SiC MOSFETs provide lower losses and, thanks to their support for higher switching frequencies, enable more efficient power conversion. Around 650 V, superjunction Silicon MOSFETs, with low reverse recovery times, low on-resistance, and support for higher switching frequencies, are also displacing IGBTs. Thanks to reference designs, such as Toshiba's bidirectional DC/DC power supply, design engineers can significantly speed-up evaluation of suitable design approaches and topologies and get up to speed on the intricacies of using SiC MOSFETs.

More Power Electronics for a Greener World

EPE ECCE 2021 from September 6 – 10 attracted some 500+ participants in a fully digital event. The more academic keynotes and the papers of this conference focused more on the system side of power electronics, particularly the grid and its subsystems, as well as e-mobility, rather than on the component side.

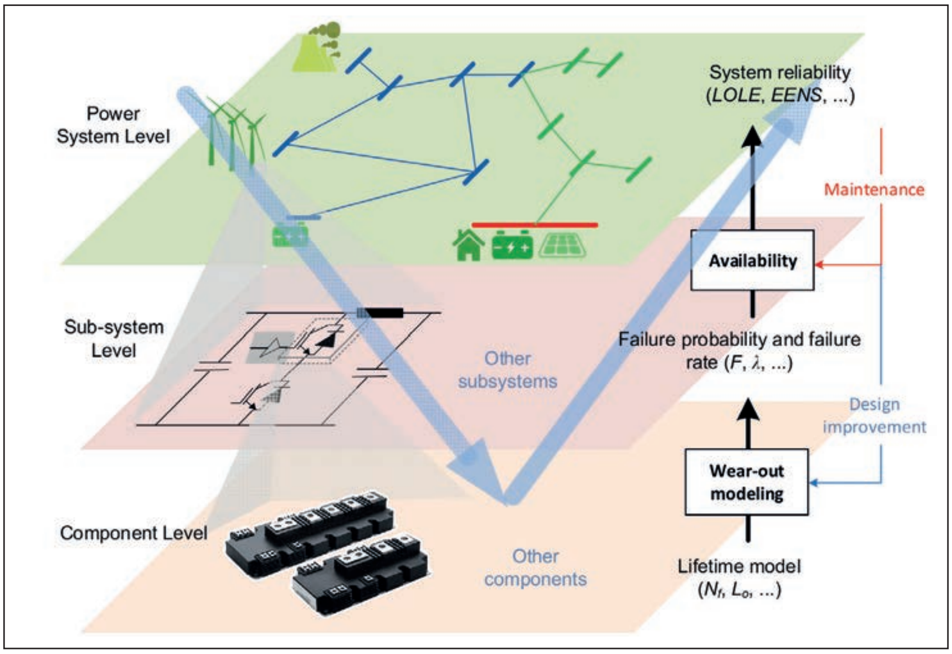
Electrification of mobile and non-mobile systems is progressing fast. Novel battery systems are being developed not only for drones, passenger cars and heavy-duty vehicle applications, but also for stationary storage applications. They need intelligent Battery Management Systems and control units as well as appropriate charging devices. For vehicle applications, high-power charging stations are being developed to reduce charging time. Bi-directional V2X charging systems allow for better grid management and, when combined with smart charging, for an increased share of renewables in the electricity mix. Power electronics interfaces, with their emerging wide bandgap (WBG) technologies (such as SiC and GaN), are a key element in these developments towards high energy-efficient systems. The reliability aspect is crucial in these and many other applications. Considering the reliability aspect in the design phase of battery systems, drivetrains, charging systems with both AC and DC networks, etc., will improve the lifespan of those systems and provide more robustness with less maintenance. These topics were discussed in various events at this year's EPE ECCE conference planned to be held in Ghent but due to the pandemic available digitally only.

Keynotes – from systems to components

The introduction of modular multilevel converters (MMCs) created a new momentum in the field of high voltage direct current (HVDC). HVDC is not anymore used only in point-to-point links embedded in AC systems or between asynchronous areas. It is now also used to transport power from offshore wind farms far from shore to land and multi-terminal direct current (MTDC) systems are becoming a reality. "With the expected massive development of renewable energy sources and the limited rights-of-way to create new overhead lines in many countries, the power system must evolve and HVDC technologies will have a major role to play", expects Dr. Florent Morel, Research group leader at French SuperGrid Institute **(https://www.supergrid-institute.com)** in his keynote.

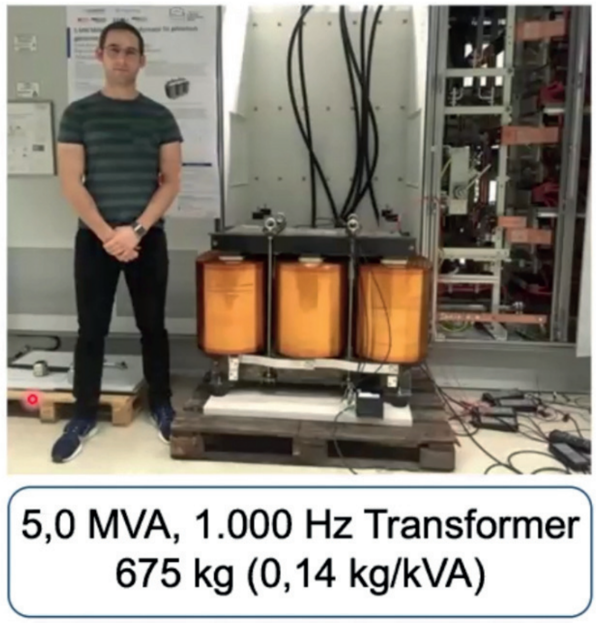
"What are the benefits and barriers for the e-mobility developments?", asked Prof. Dr. Ir. Joeri van Mierlo from Vrije Universiteit Brussel in his keynote. Driving range, charging infrastructure availability and especially cost are perceived as important barriers for the market take-up of electric vehicles. Driving range is defined by battery performance. The challenge of infrastructure lies in the return on investment (chicken and egg problem). And the cost will evolve by technological improvement, market take-up and in the mean time policy support. The purchase price of electric vehicles is currently higher than of conventional vehicles, however the driving cost is lower. Based on a Total Cost of ownership (TCO) different vehicle technologies can be compared. Especially when comparing the environmental performance of electric vehicle technologies, the emissions during production of the specific components and their appropriate end-of-life treatment processes should also be taken into account. Therefore, the complete life cycle (LCA) of the vehicle should be included in order to avoid problem shifting from one life stage to another.

"Hitachi's mission is to contribute to society through technology; not just by providing societal infrastructure and products such as energy equipment and rail but also through what we call Social Innovation Business where digital technology is leveraged to deliver new value," said Dr. Norihiro Suzuki, Chief Technology Officer at Hitachi Ltd. in his keynote. "Our approach is to work closely with the stakeholders in the ecosystem to drive innovation and co-create solutions that will raise quality-of-life. Social Innovation Business using "green solutions" in energy systems and transportation is focusing on carbon neutrality, as well as R&D activity in electrification and power electronics as examples, and the important role that we believe an industry-academia-government-ecosystem has in driving this innovation.



V-shape model-based reliability analysis in PEPS

DC-SST transformers not only reduce significantly the CO_2 footprint but also save steel and copper as the comparison of a 4.5 MVA 50 Hz transformer (left) with a newly 5.0 MVA 1000 Hz SST shows



Strict regulations and requirements are issued to cut emissions are accelerating investments in renewable hydrogen and electrofuels. "Accordingly, the marine industry is undergoing a rapid transition from fossil to alternative low-carbon fuels. This will introduce fuel cells as a credible alternative to internal combustion engines, and further increasing the share of electric power distribution semiconductor-based power conversion," stated Sami Kanerva, Global Product Manager Fuel Cells at ABB in his keynote. Meeting the International Maritime Organization's goal of halving greenhouse gas emissions from ships by 2050 is a critical step toward sustainability. It will require a comprehensive and proactive response from the maritime community. Shipping is well positioned to take concrete action by choosing to implement technologies that provide reduced fuel consumption and lower emissions.

The keynote paper "Reliability of Modern Power Electronic-based Power Systems" by Prof. Frede Blaabjerg from Aalborg University introduced a systematic approach based on the V- shaped model-based reliability analysis for design and planning of power electronic-based power systems (PEPS). According to this concept, the system performance is analyzed employing the physics of failure mechanisms in each components of different units in PEPS. "This will facilitate optimal and economic design of power converters as well as economic decision-making in planning of PEPS. Moreover, it helps to identify the weakest units and its components that can in turn help in reinforcement planning and spare unit optimization in PEPS", he underlined. The viability of the proposed approach was illustrated on a DC distribution network and numerical analyses showed how the proposed model-based reliability assessment approach can help to do optimal planning and design of future PEPS.

Model-based system engineering can be beneficial for power system planners to design PEPS and plan for maintenance of weakest units and plan for required spare units based on the identified fragile components in the system. The concept of model-based reliability assessment was illustrated by an example on a DC distribution system. The future research needs to focus on short-term performance of the system combined with long-term performance to guarantee both security and adequacy of the future power grids with more penetration of power electronics.

Awareness of global climate change due to the high consumption of fossil fuels has stimulated worldwide research and innovation towards a CO2-free energy supply. To realize this energy transformation innovation is required not only on the power generation, energy storage and the consumption side, but also, more importantly on the energy distribution infrastructure. In all these sectors, power electronic energy conversion systems are needed. The keynote "Power Electronics – A Key Enabling Technology to realize the Green Deal" by Prof. Dr. ir. Dr. h.c. Rik W. De Doncker from RWTH Aachen University focused on power electronic solutions for flexible electrical grid infrastructure, in particular on DC technologies such as DC transformers that better serve wind farms, PV systems, factories, building heating and cooling systems and fast charging infrastructure in the urban environment.

DC has proven advantageous compared to AC distribution networks. It allows the transfer of more power since the utilization of cables and lines is higher. Moreover, most renewable energy sources can be connected more efficiently to a DC system. Since these dc systems use power-electronic converters, power flows can be controlled actively to allow optimal utilization of lines and the limitation of fault currents. "Moreover, since these converters operate at relatively high frequencies, valuable materials like copper and steal, used for 50 Hz transformers, can be saved", he stated.

The following introduces a snapshot of some selected interesting technical papers out of the vast pool of informations.

Power devices for highly efficient power

Infineon **(www.infineon.com)** as a supplier of various power semiconductors has the expertise to jugde different technologies with the paper "600 V power device technologies for highly efficient power supplies".

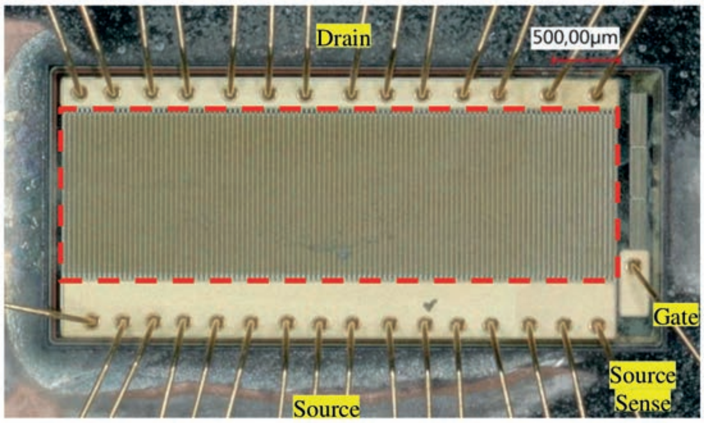
Switched mode power supplies (SMPS) for target applications covering a wide range from telecom rectifiers through servers to solar inverters or electric vehicle chargers share the need for high efficiencies in order to minimize the overall energy consumption and the total cost of ownership. With the appearance of wide bandgap (WBG) semiconductors, designers cannot only choose between different devices but also may benefit from using advanced topologies. Compared here are the properties of the latest generations of a CoolMOS Superjunction (SJ) device with integrated fast body diode, a CoolSiC SiC MOSFET and of a CoolGaN E-mode GaN power transistor in the 600 V class.

SJ devices will remain as the first choice for the PFC stage of a SMPS with an overall efficiency below 97 %. The devices are easy to drive, offer the most granular portfolio and offer a proven quality and reliability. Due to the higher output capacitance shape at $V_{DS} > 20$ V, WBG devices will not offer clear advantages in this topology. The SiC MOSFET offers the best solution for SMPS with standard form factor and an efficiency range of 97 % to 98 %. This better efficiency is linked to the move to the Totem Pole topology and eliminates the need for bridge rectifiers. Although C_{OSS}, Q_{OSS} and E_{OSS} are all higher than for the GaN transistor, the SiC device clearly benefits from a much lower increase of on-resistance over temperature. The SiC transistor is easy to drive, yet it is recommended to use a gate drive voltage of 18 V to benefit from the further lowered $R_{DS(on)}$. SiC MOSFET are especially beneficial for high power applications. Solutions using GaN devices are currently capable of delivering the highest efficiencies, exceeding 98 % in standard form factor. They are the first choice for high frequency applications where the form factor is the key requirement. However, GaN solutions use a dedicated gate drive concept that requires additional effort for its implementation.

Power Cycling of GaN Transistors

GaN power devices have a strong potential for the next generation of fast-switching, high efficiency power electronics, expressed the paper "Power Cycling Results of Discrete Gallium Nitride Gate Injection Transistors" by CHEMNITZ UNIVERSITY OF TECHNOLOGY **(www.tu-chemnitz.de/etit/le/).** The GIT (Gate Injection Technology) displays one very promising device concept for high voltage enhancement-mode GaN HEMTs. Beside semiconductor-level stress testing, power cycling is an important test procedure to assess the reliability of joining technologies under accelerated conditions not only for power modules but also discrete devices. Previous publications have shown that the power cycling capability of discrete GaN devices is limited by the degradation of the solder layer between housing and printed circuit board. In order to prevent PCB solder degradation during power cycling, GITs were prepared in a pressed configuration to decouple the electrical and thermal path. In this way, the focus was set on the package itself.

If the package-to-PCB solder is excluded as weak point, no end-of-life criterion was reached within a reasonable scope. This demonstrates a high reliability of discrete GaN devices with nailhead-bonding technology. In this long-term investigation, the accumulated stress at constant current at the gate up to 4000 hours is significantly above the typical 1000 hours in quality tests. Furthermore, the accumulated stress by current at a temperature close to maximum allowed junction temperature is significantly above the application conditions. Reasons for the high power cycling capability is on the one hand the high number of bond wires with small diameters. On the other hand, the temperature-stress condition of the bond wires is significantly reduced due to the location at the edge of the lateral GaN chip outside the active area. Furthermore, thermal imaging shows that the junction temperature measurement using the gate diode of p-GaN GIT as TSEP is very well applicable.



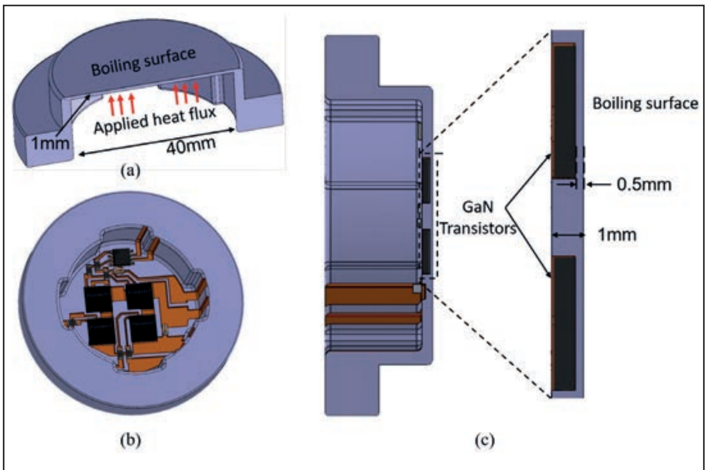
Microscope image of the chip top side after removal of the mold compound by chemical treatment; the dashed red line frames the active area

Polymer-based heat dissipator for GaN transistors

The paper "Investigation of 3D printed polymer-based heat dissipator for GaN transistors" presented by French Ampere Lab **(www.ampere-lab.fr)** introduced a polymer-based heat-pipe evaporator for GaN transistors using AM and plastronics.

GaN transistors are limited in their operational capabilities due to some limitations, of which the thermal management aspects. Until now, most of the existing heat-dissipator systems using additive manufacturing (AM) are based on a metallic finned heat sink, which is heavy and has a relatively high thermal resistance. Heat dissipation based on a phase change as operated inheat pipes is more efficient. Such heat sinks have been experimented with metals or ceramics and not by now with polymers. However, this may be of great interest. The use of polymer may enable reducing weight and cost of the thermal device. It may allow also improving the chemical compatibility of the heat pipe material and fluid, as this is often a severe issue. This paper presented a characterization of a 3D-printed polymer-based heat pipe evaporator intended for GaN transistors. The electronic copper circuit on the polymer surface is created using plastronics technology.

The use of polymer for heat pipes allows reducing the weight and cost of the assembly and improving their chemical compatibility with the cooling fluid. The copper circuit receiving the electronic components, is directly fabricated on the polymer surface. The copper thickness and the electrical resistivity provide a sufficient conductivity for the circuit operation. However, the electrical conductivity could be improved using electrolytic Cu plating to adapt to high current rating. A specific test bench was developed to characterize the effective heat transfer between the polymer wall and the heat pipe working fluid. Based on the observations of the two-phase flow, a fully developed boiling regime can be achieved on this particular type of material. This allows to improve the overall thermal performance of the evaporator.



Design structure details of the 3D printed and copper metallized evaporator- (a) isometric section view, (b) bottom view, (c) cross section view

Inverter design with different WBG devices

In the paper "Comparative Analysis of High Speed Drive Inverter Designs using different Wide-Band-Gap Power Devices" by Technische Universität Braunschweig **(www.tu-braunschweig.de/imab)**, a 15 kW drive inverter design with increased switching frequency demand for the high-speed drive of an automotive electrical turbo-compressor unit is described. After simulation-based evaluations eight inverter prototypes using different WBG power semiconductor devices are built and operated.

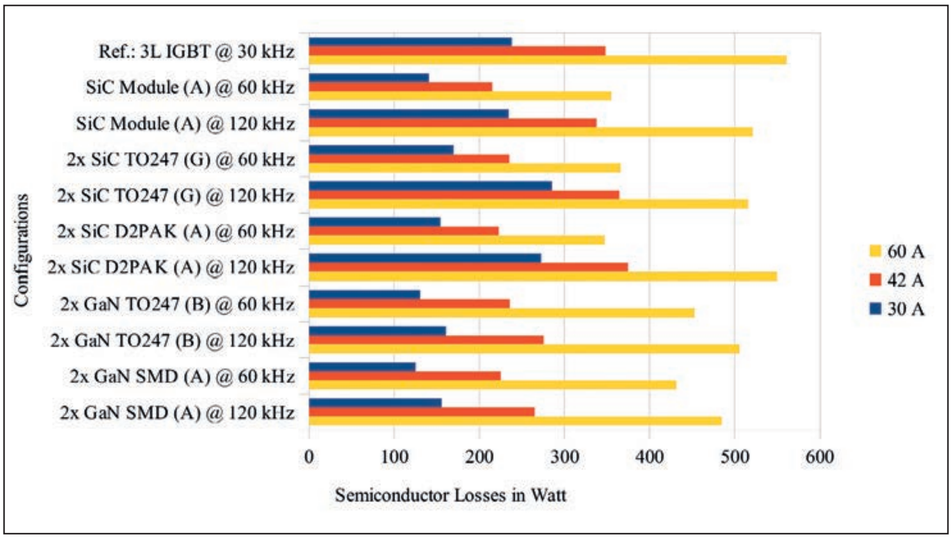
The selection of the most promising inverter designs and power semiconductor devices was performed using a detailed evaluation matrix with weighted criteria like estimated efficiency, estimated volume or power density, system complexity, qualification state of the devices and assembly aspects. A 3-level T-type inverter using Silicon IGBTs and diodes in a power module package is used as a reference design. Due to the prospective increase of power density, reduction of system complexity and the good availability of AEC-Q101 qualified devices the most selected 2-level WBG inverter designs are using discrete devices, preferably in SMD packages for easy assembly.

Using SiC MOSFET power modules can result in inverter designs with good efficiency and high power density. The total space occupied by the SiC modules is about 1/3 to 2/3 of the area of the T-type modules used as reference. Using power modules also allows an easy and robust thermal design with a ceramic DCB as electrical insulation. Unfortunately, there is still no suitable module available with AEC-Q grade.

The widest range of available devices can be found for SiC MOSFETs in TO-247 packages. It is recognized that there are still significant differences in terms of RDSon and switching losses for different suppliers. Using two devices in parallel, most of the MOSFETs will outperform the efficiency of the reference solution at 60 kHz. At 120 kHz the switching losses of the devices in the large leaded standard package turn out to be a problem. SiC MOSFETs in a standard SMD package like the D2PAK-7L seem to be a very convenient solution to the presented application. With two devices in parallel the losses are low and the achievable power density is very high. There are qualified devices available from different suppliers and the assembly process is simple. This also makes the solution very interesting in terms of cost.

Compared to SiC, the available GaN devices have higher R_{DSon} but lower switching losses. Therefore paralleling of devices is inevitable to handle the peak current. In return especially the solutions with SMD devices result in the highest efficiency at 120 kHz. There is still a lack of suppliers for devices in compatible packages, but the technology will definitely be an option for high-speed drives with special requirements in terms of switching frequency.

Five different PCB layouts for different device technologies were designed, optimized, built and set into operation for further evaluation. Taking into account all defined evaluation criteria, the most promising solution is the one based on SiC power MOSFETs in a standard SMD package.



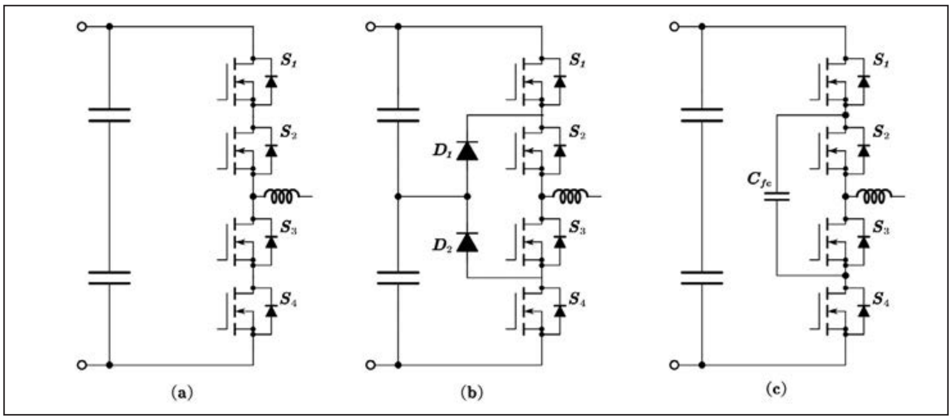
Summary of semiconductor losses for selected solutions

Series connection of 10 kV SiC MOSFETs

The paper "Analysis of Quasi-Two-Level Modulation for Neutral-Point-Clamped Three-level Converter with 10 kV SiC MOSFETs" presented by the Center for Power Electronics Systems (CPES) at Virginia Polytechnic Institute and State University **(www.cpes.vt.edu.cn)** proposed a solution for two series-connected SiC MOSFETs - a quasi-two-level modulation based on the neutral-point-clamped (NPC) three-level (3L) converter. The proposed solution is very attractive for the recent 10 kV SiC MOSFETs due to several reasons: 1) the blocking voltage could be increased to 20 kV, suitable for most medium voltage applications; 2) with NPC 3L structure, the voltage balancing of series-connected devices is avoided; 3) with Q2L modulation, the total loss on clamping diodes is significantly reduced so the clamping diodes don't significantly increase converter volume. With Q2L modulation, series-connected 3.3 kV SiC diodes with much smaller volume are chosen as an example as the clamping diodes to showcase the benefit of Q2L modulation.

In recent years, the SiC MOSFETs gained increasing popularity in medium voltage (> 1 kV) powerconversion applications due to the potential to improve efficiency and power density by adopting the simpler topology and fewer conversion stages. Despite the recent progress in 10 kV or 15 kV

SiC MOSFET, three-level (3L) converters or two-



Different approaches to increase the blocking voltage of converter: (a) direct series connection of devices; (b) 3L topology with clamping diodes; (c) 3L topology with flying capacitor

level (2L) converter with series-connected devices are still required for most of the medium voltage applications. Three-level topologies have better efficiency and no voltage balancing issue for series-connected devices but usually require more semiconductor devices or passive components. On the other hand, the 2L converter with series-connected MOSFETs requires less semiconductors but requires voltage balancing control to avoid device damage.

For the fast switching SiC MOSFETs, the voltage balancing becomes more complicated especially for more than two devices in series-connection. Quasi-two-level (Q2L) modulation of multi-level converter gains increasing attention for medium voltage applications recently, mainly because it has several benefits comparing to both traditional multi-level converter and two-level converter with series-connected devices by reducing conduction time of intermediate voltage level.

The Q2L modulation for NPC 3L converter is analyzed to be a better solution comparing to series-connected of 10 kV SiC MOSFETs. By using the zero voltage stage for the short transient period, the voltage balancing of series-connected SiC MOSFETs is avoided. With the Q2L modulation, diodes with smaller volume and no heatsink can be selected as the clamping diodesreduce the cost and improve the power density of the power stage. In the meantime, comparing to3L converter, the NPC 3L converter is more suitable for Q2L modulation with the benefit from switching loss of main devices, the volume of extra components, and fault protection.

Parasitic turn-on in SiC power modules

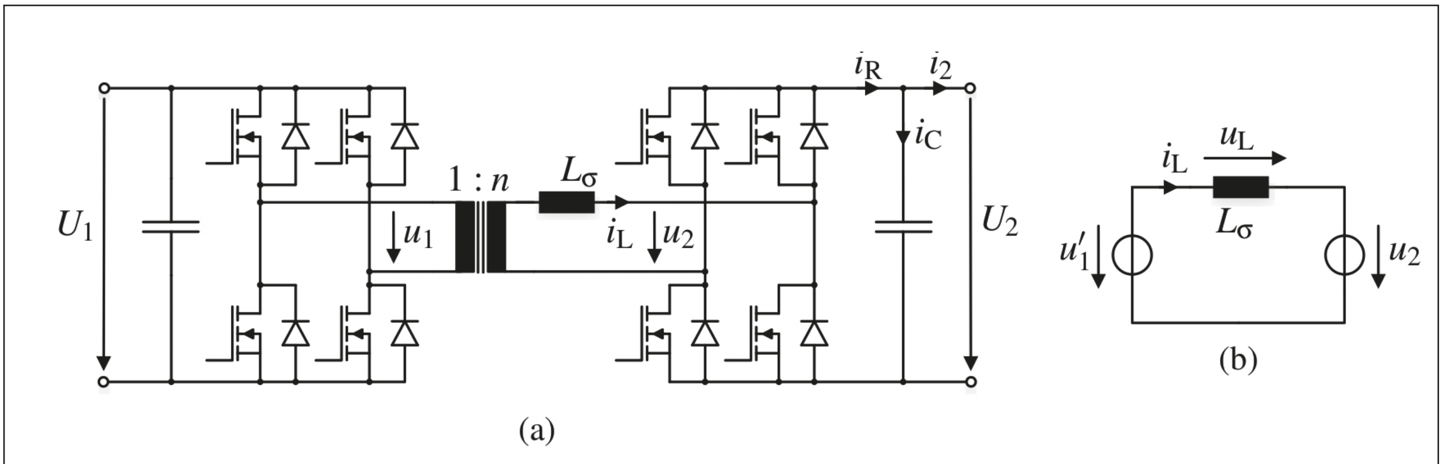
Parasitic turn on (PTO) in multichip SiC power modules can be substantially different and more complex than in single chip or discrete components. This paper "Assessing the Presence of Parasitic Turn On in SiC Mosfet Power Modules" by Danfoss Silicon Power **(http://powermodules.danfoss.com)** proposes a careful extension of the classical double pulse tests, introduce new quantitative MOSFET and Body Diode metrics, and combine these with static characterization data, in order for the user to decide whether a given SiC power module when driven with a certain gate driver scheme experiences PTO or not. Since PTO is a parasitic effect, to uncover its origins in a module we need to figure out all possible coupling mechanisms from an interference source, to the gate-source voltage of the victim chips. At the switching speeds which present day SiC devices operate three main coupling paths can exist - capacitive coupling, conducted coupling and magnetic coupling.

To ascertain PTO in a multichip-module-driver system the user should check the second and first turn on pulse in a DP test. Moreover, this should be done quantitatively sweeping the whole voltage, current temperature operating range, while computing specific characteristics as capacitive charge and auxiliary net charge (not just the reverse recovery charge). These metrics are more sensitive to PTO than usual classical characteristics as reverse recovery losses or peak reverse recovery current. The Err losses confound voltage and current, and heavily depend on the integration limits. The reverse recovery peak is a good metric, but it is aliased with capacitive currents (depending on voltage slopes) and the impact of the body diode third quadrant behavior.

Reducing losses in SiC-based inverters

The paper "Investigation of Gate Current Shaping for SiC-based Power Modules on Electrical Drive System Power Losses" presented by speakers from German Robert Bosch and Technical University of Munich dealt with reducing the losses in SiC-based traction inverters in electric verhicles. Improving the efficiency has always been the focus of interest. The inverter power losses are mainly due to the conduction and switching losses of the power semiconductors, which depend on the output power and switching frequency. Recently, advancements on WBG materials made it possible to increase the inverter efficiency due to the superior properties of these materials.

Utilizing higher switching frequencies and therefore higher voltage and current slopes brings a new challenge for gate driver's design to make use of the superior characteristics of WBG switches. Therefore, active gate driving techniques are being adopted to be used instead of the conventional voltage source driver which provides limited control capabilities. Influencing the switching operation at every step of a switching transient could be implemented by actively adjusting the gate resistors or using an active voltage source in the driver unit. However, this control strategies are complex and provide limited degree of flexibility. One promising driving technique is based on controlling the gate current using gate current profiles. This could be achieved by either open-loop or closed-loop control. Open-loop control approaches are simple to implement and rely on a fixed profile, or an operating point dependent action. Thus, they lack the capability to react to changes in the system like manufacturing tolerances, aging effects, or temperature variations. On the other hand, closed-loop control strategies address these issues but are complex to implement and require additionally high-bandwidth sensors. Furthermore, the very fast switching behavior of WBG semiconductors makes it unfeasible to compensate the large delays observed in the feedback loop. Thus, a compromise solution would be the implementation of a scheduling technique to adapt the current profiles based on sporadic measurements of the transistors' properties as well as the junction temperature. The different profiles are calculated offline and saved as a look-up table in the microcontroller. During operation, the microcontroller will send the control signals to an



DAB topology (a) and corresponding equivalent circuit (b), neglecting the magnetizing inductance and losses

ASIC gate driver, which will also reduce the overall effort.

This optimization technique is based on a two-stage sequential algorithm in which the optimal current profiles are identified. The obtained gate current profiles reduce the switching energies while maintaining similar device stress during turn-on and turn-off events. The evaluation showed superior switching performance for the current shaping compared to a voltage and unshaped current source drivers. The switching losses over the entire operating range were significantly reduced, especially at partial loads. At system level, the inverter losses were reduced by 45 % leading to a 7.6 % reduction of the total electrical drive losses over the WLTP driving cycle.

Control Algorithm for a dual active bridge

The Dual Active Bridge (DAB) converter is a galvanic isolated, bidirectional DC/DC converter. It consists of two full bridges, connected by a Medium FrequencyTransformer (MFT). The advantages of the DAB include high power density, good component utilization and high efficiency due to low switching losses. Advanced modulation schemes can improve Zero Voltage Switching (ZVS) behavior, converter efficiency in partial load or wide voltage gain scenarios.

The paper "Transient Power Control Algorithm for a Dual Active Bridge" by Karlsruhe Institute of Technology **(http://eti.kit.edu)** presents a novel approach for transitions between operating points. The method is applicable to arbitrary modulation schemes. Steady state operation is attained after one switching period while the correct power transfer during the transition is ensured.

The novel TPC scheme for operation point transitions of the DAB, considering prevention of a transient offset in the inductor current and controlling the demanded power during the transition period, is based on the calculation of the rectifier current i_R, using a switching scheme derived from SPS modulation. While the measurement results show the expected behavior, small deviations due to neglected parasitic effects can be observed. It is shown that it is possible to combine the novel TPC scheme with other modulation schemes, which allows for efficient operation in steady state condition while preserving a good transient behavior. If a voltage controller is used, the improved dynamic behavior results in a faster response time of the DAB, enabling a better performance of the controller. **AS**

Smart Automotive High-Voltage Circuit Breakers

The cooperation between the e-mobility specialists of Rutronik's Automotive Business Unit (ABU) and Vishay's Automotive Division realised a new reference design for a high-voltage (HV) circuit breaker with a maximum breaking capacity of 40 kW. This replaces previous options that used mechanical relays with a resettable and low-loss semiconductor solution.

High-voltage (HV) switches are an indispensable link within an HV architecture of modern Battery Electric Vehicles (BEV). They are used to safely and unambiguously separate auxiliary units from the rest of the vehicle's electrical architecture on the high-voltage side (400/800V side) - depending on the platform architecture - and thus prevent major damage.

Next-generation electric vehicles will have up to three different voltage levels:

- 12V electrical system for small actuators and all control units
- 48V electrical system for larger power consumers such as water pumps, EPS or radiator fans
- 400 to 800V electrical system containing the battery pack and the largest consumers such as the inverter, the high-voltage heater, the OBC, the HV/LV DCDC and the HVAC.

Especially the latter requires a maximum of safety and reliability for all installed components.

BEV of the future

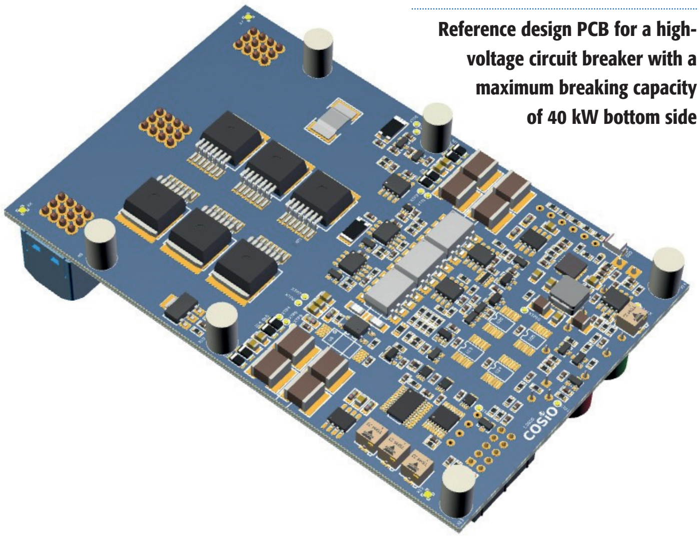
In terms of circuitry, the HV disconnector consists of an isolated 800 V power stage with 12 V measurement and evaluation electronics and an AURIX TC375 Lite Kit. The concept of the HV isolator switch is realized in the switching stage with SiC MOSFETs from ROHM, galvanic isolation of the measuring channels, high-precision shunts, new optocouplers and all protective components from Vishay. In addition, a second-generation AURIX microcontroller from Infineon controls the device.

With the 1200V SiC MOSFETs of the fourth generation in SMD housing and a precisely tuned control via a SiC gate driver, the HV disconnector is able to switch powers of up to 40 kW. The resulting power loss reaches approx. 16 W. The resulting heat can be passively dissipated at room temperature (25°C).

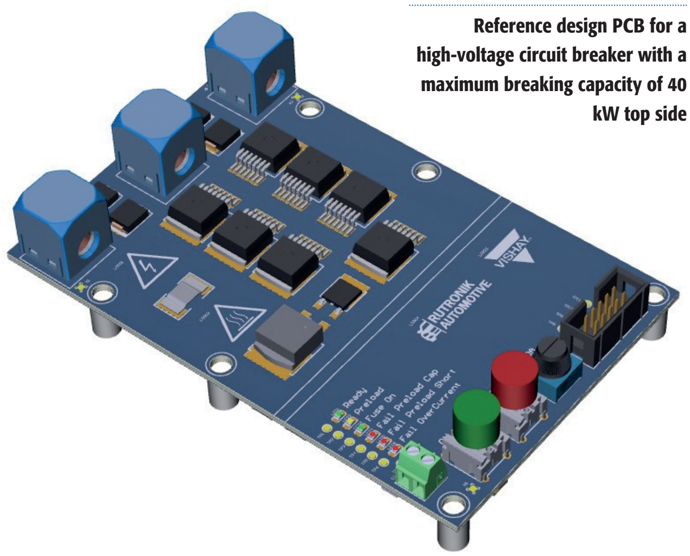
The HV circuit breaker has a pre-charge path that allows capacitive loads to be pre-charged via a SiC MOSFET, series-connected pre-charge resistors and two implemented pre-charge modes (13 ms and 130 ms respectively), thus preventing a possible over-current at switch-on. The control of the main MOSFETs is realized via a galvanically isolated SiC driver, which is buffered via a new polymer tantalum capacitor (T51 series from Vishay). The pre-charge MOSFET is driven via a galvanically isolated optocoupler with phototransistor output (VOMA617A). The maximum load current of the disconnector can be set either via the microcontroller or individually via a potentiometer in stand-alone mode.

The Powerstage features high-precision shunts from Vishay, which are characterized by their accurate bi-directional measurement of the battery current. The current and voltage measurement signals are transmitted galvanically isolated (floating measurement), processed by measurement signal amplifiers and passed on to the microcontroller. The newly developed VOA300 linear optocouplers from Vishay provide galvanic isolation from the 12 V side. Two series-connected high-voltage MLCCs from Vishay provide the galvanically isolated supply of the op-amps.

This supply includes a push-pull driver stage with 50 kHz. The AURIX board is connected via a cable connection and, after successful connection, can output the processed measured values via an already implemented software. The configuration and readout of measured values of the eFuse with AURIX control is done via an existing CAN interface.



Reference design PCB for a high-voltage circuit breaker with a maximum breaking capacity of 40 kW bottom side



Reference design PCB for a high-voltage circuit breaker with a maximum breaking capacity of 40 kW top side

Precise measurements, diagnostic function and protective measures

In addition to the precise current and voltage measurements, the concept also has a diagnostic function and further protective measures, such as over-current detection with adjustable threshold, in- & output transient protection as well as additional TVS diodes for power supply protection. The input and output voltage is monitored via ratiometric thresholds, which thus also enables use for 400 V systems. In addition, the reference design has a status display with LEDs as well as two push buttons for manual control. Equipped with a housing that allows access to all measuring points, protection against accidental contact is also guaranteed.

Rutronik makes the reference design available to selected customers with above-average requirements, thus enabling fast and high-quality implementation of a state-of-the-art circuit concept in future projects.

www.rutronik.com

A New Approach to Circuit Breaker Design Using Silicon Carbide Switches

Mechanical circuit breakers can be low cost with minimal losses, but they operate slowly and wear out. Solid state versions overcome the problems and are becoming increasing viable as replacements at ever-high currents. This article discusses the issues and introduces a new Silicon Carbide semiconductor, the DG-FET as an enabler for better performance.
Anup Bhalla, VP Engineering, UnitedSiC, Princeton, USA

Mechanical circuit breakers have been around for a long time and do the basic job very well – they are low loss when on and provide excellent isolation when off. They do have their downsides though, with slow make/break times and arcing across the contacts, degrading their operating lifetime, particularly with DC power lines. Complex arrangements have been devised to disconnect quickly but it might still take around 10 milliseconds, allowing significant and possibly damaging energy to pass after a short circuit is detected, for example. Similarly, DC arcs can be suppressed to an extent with labyrinth clearances, a magnetic bias field or even blasts of compressed air. However, there are new applications for high current DC circuit breakers where this complexity cannot be afforded such as in EVs, where cost, size and weight are major issues.

Feature	Solid state (Si, SJ, SiC, IGBT, IGCT)	Electromechanical
Full controllability	★★★★★	★★★
High speed	★★★★★	★★
Conduction loss	★★	★★★★★
No arcing	★★★★★	★★
Use cycles: no maintenance	★★★★★	★★
Cost per amp	★★	★★★★★
Voltage rating vs. on Rds(on)	★★★	★★★★★

Table 1: **Mechanical and solid-state circuit breakers compared**

Solid-state breakers have been a partial solution

Solid-state circuit breakers (SSCBs), typically using IGBTs, can break power lines perhaps a thousand times faster than mechanical types with no arcing or aging problems, but they are imperfect switches, dropping around 1.5 V, producing tens or hundreds of watts of dissipation at the current levels seen in EV traction drives, for example. The unit and heatsinking costs are substantial and the power loss effectively reduces battery energy available for driving range, so in EVs, IGBT-based SSCBs are not seen as viable.

Silicon MOSFET-based SSCBs have been an alternative, with their on-resistance potentially dissipating less power than IGBTs which have a fixed saturation voltage. However, at high current levels with high voltage devices, sufficiently low on-resistances are not yet available. For example, at 500 A, an IGBT could drop

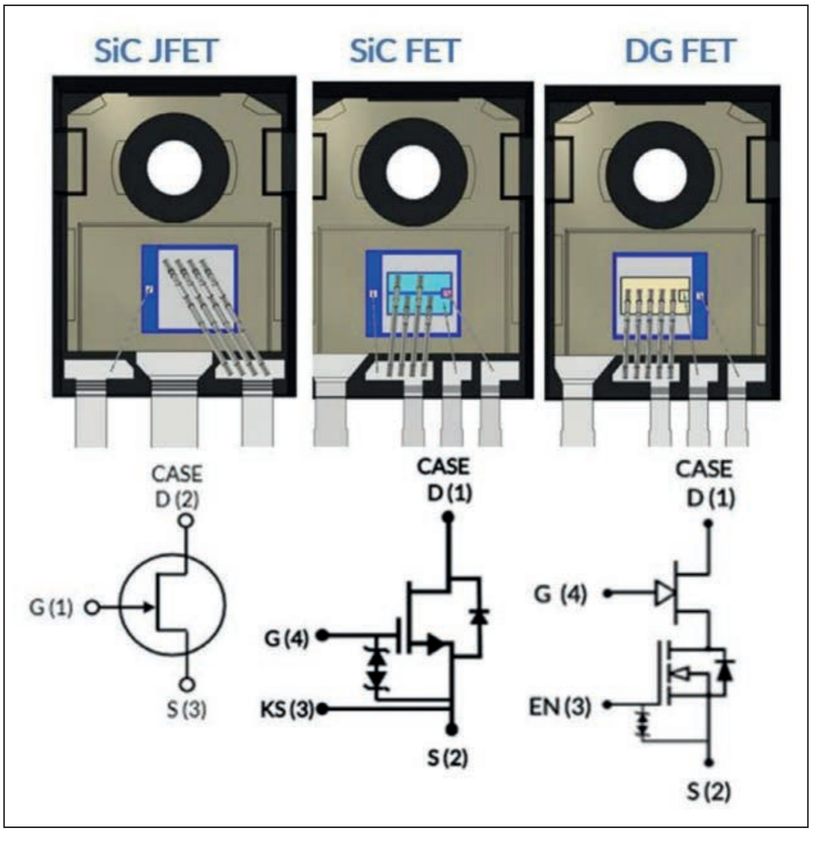


Figure 1: **A SiC JFET (left), SiC FET (middle) and a DG-FET (right)**

around 1.7 V with 850 W dissipation, equivalent to a MOSFET with 3.4 mΩ on-resistance, which is not available from single devices rated at 400 V and higher. Paralleled MOSFETs reduce dissipation, but ten plus would be needed to match an IGBT in this scenario and if bi-directional conduction is required, as would be typical in an EV application, the number doubles anyway and costs spiral. Table 1 summarizes the relative performance attributes of mechanical and solid-state circuit breakers.

A new technology for SSCBs

Wide band-gap semiconductors such as Silicon Carbide types (SiC) usually hit the headlines for their fast switching speed, but they also have inherently around 10x better on-resistance for a given die area and voltage rating than Silicon. This makes them potential candidates for small, efficient SSCB switches, and the high material operating temperature and better thermal conductivity are additional benefits for peak power dissipation considerations.

Although SiC MOSFETs are most common, the simpler JFET construction (Figure 1, left) can be preferred in the SSCB application with its better on-resistance, $R_{DS(ON)}$. The device is normally-on with no gate drive but this is often a better characteristic for SSCBs, defaulting to the conducting state with no bias voltages present. Another arrangement is the SiC FET (Figure 1, middle). This device is a 'cascode' combination of a SiC JFET and a Silicon MOSFET which is normally-off, with a simple 0-12 V gate drive. On-resistance is 5-15 % higher than the SiC JFET on its own though, for the same voltage and current class of device.

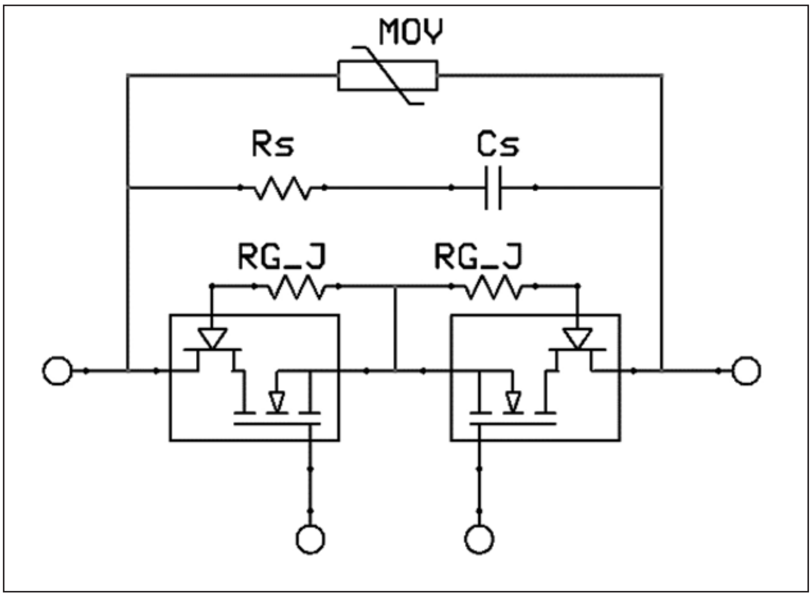


Figure 3: **DG-FETs as a bi-directional solid-state circuit breaker**

A new device has now appeared, the 'Dual Gate FET' or DG-FET (Figure 1, right) which is the SiC FET cascode with its two gates uncommitted and brought out to separate pins. The advantage is that the gate drive voltages can now be 'fine-tuned' for the absolute minimum on-resistance, typically by driving the JFET gate a little positive in voltage. The Silicon MOSFET gate then acts just as an 'enable' signal. The two die are 'stacked' for minimum connection distance and losses.

Temperature sensing with a DG-FET

When the gate of the JFET In a SiC DG-FET is taken positive, at around 2 V, a diode action appears and current flows. If the current is accurately limited to say 1 mA, the voltage at the gate has a direct relationship to the die temperature, so can be used as a sense for over-temperature protection or even long-term state-of-health monitoring. This is a valuable feature in SSCB applications to detect any long-term degradation of cooling efficiency, for example, as the DG-FET may have continuous high current passing and significant dissipation. The effectiveness of current sharing in parallel device can also be monitored by evaluating differences in die temperature. Figure 2 shows the typical relationship between die temperature and SiC JFET gate-source voltage.

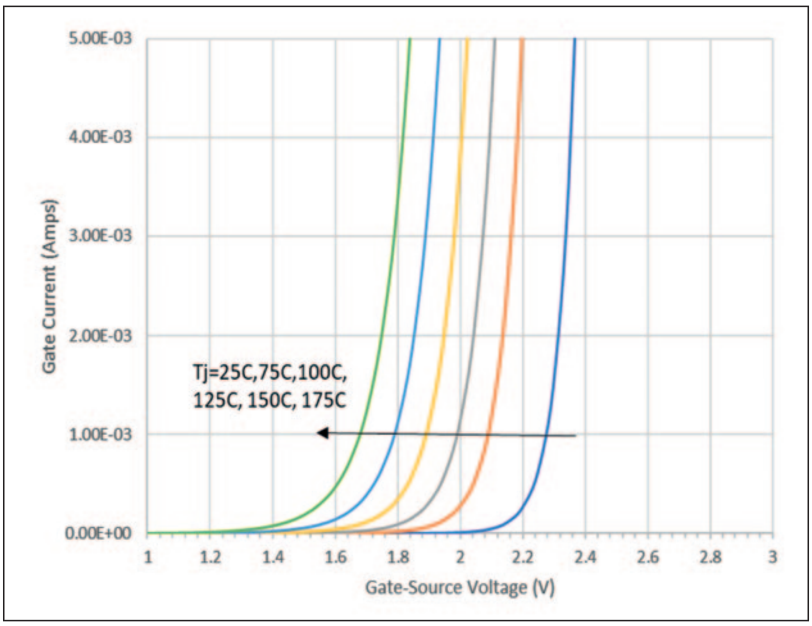


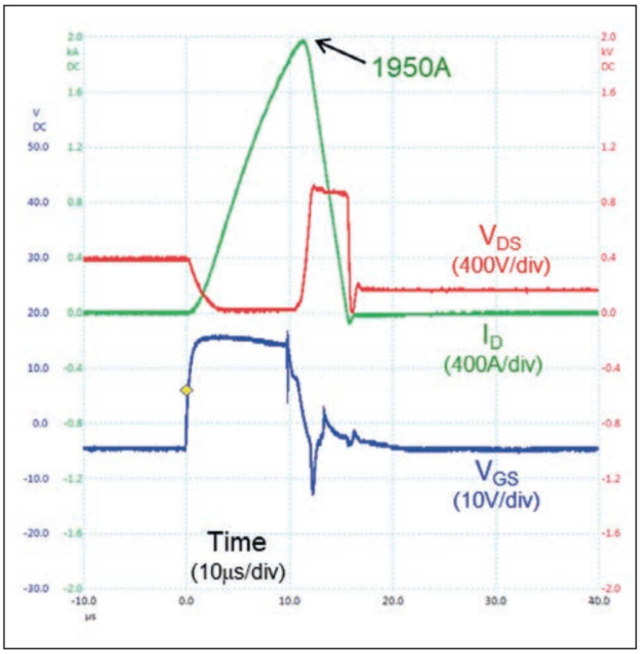
Figure 2: **SiC JFET gate-source voltage scales with die temperature at fixed current**

SSCBs with SiC DG-FETs

Figure 3 shows a practical circuit using SiC DG-FETs for a bi-directional SSCB. Gate resistors slow switching to avoid EMI and instability, and the snubber network helps prevent damaging voltage overshoot on switch-off. The MOV also clamps voltage transients induced by line inductance between the DC source and load during switching. Although the DG-FETs do have a robust avalanche rating, it can be beneficial to employ an MOV to absorb the energy stored in the line inductance between source and load, since this can become quite large. A large energy MOV is going to cost a lot less than a SiC FET with the same energy rating in avalanche. With this technique, the cost of the SiC used can be reduced. In fact, using a MOV that better limits peak voltage, lower voltage rating SiC devices can be used, which in turn reduces on-state resistance and cost.

To take our example of requiring 3 mΩ devices to be equivalent to a current IGBT, for a uni-directional SSCB, one 1200V dual-gate device from UnitedSiC could be used, which contains six paralleled 9 mΩ FETs, achieving 2.2 mΩ with 1200 V withstand and 300 A rating. These can be packaged in a SOT-227 module, comparable with an IGBT solution with similar performance.

UnitedSiC have trialed this arrangement and demonstrated the device interrupting a peak fault current of 1950 A safely (Figure 4). SiC JFETs have an inherent current limiting characteristic from an internal channel 'pinch-off' effect and the positive temperature coefficient of their on-resistance helps with current sharing between the paralleled devices, in contrast to IGBTs which do not naturally share current when paralleled.



LEFT Figure 4: **A SiC FET SSCB interrupts nearly 2000 A safely**

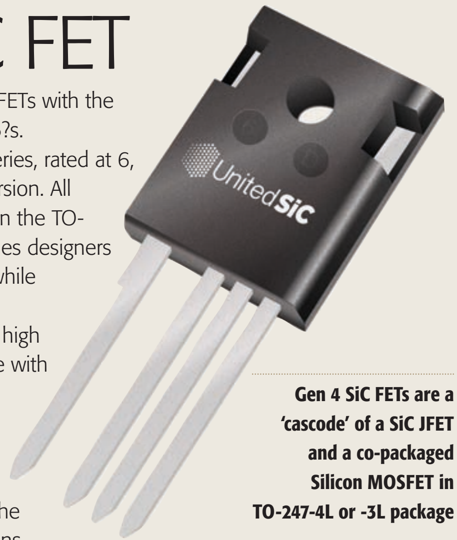
Future SSCBs

Mechanical circuit breakers, with their speed, arcing and lifetime problems will surely give way to solid state versions at higher and higher power levels as semiconductor performance advances. Even today, an automotive-grade breaker is expensive and as the market expands, particularly in EVs, the solid-state version costs will drop quickly, making it a compelling alternative given the added benefits in speed and reliability. SiC devices are still in their relative infancy and it can be expected that prices will anyway fall over the coming years, with wafer costs predicted to halve. On-resistance performance will also improve, as the technology is some way from its theoretical best, so for a given voltage rating and die size, SiC RDS(ON) should drop to less than a third of its current value, with overall resistance approaching that of a mechanical solution, with all associated connector and cable resistances included. When the lifetime costs of mechanical breaker maintenance and regular replacement are factored in, the SiC version looks more attractive still.

UnitedSiC Announces 6 mΩ SiC FET

The company has responded to the power designer's requests for higher-performance, higher-efficient SiC FETs with the announcement of the 750 V 7 6 mΩ device which provides a robust short-circuit withstand time rating of 5?s.

The announcement of September 14 includes nine new device/package options in the 750 V SiC FET series, rated at 6, 9, 11, 23, 33, and 44 mΩ. The contribution of wiring in TO-247 package amounts to 1mΩ in the 6 mΩ version. All devices are available in the TO-247-4L package while the 18, 23, 33, 44, and 60 mΩ 7devices also come in the TO-247-3L. Complemented by the already available 18 and 60 mΩ devices, this 750 V expanded series provides designers with more device options, enabling more design flexibility to achieve an optimum cost/efficiency trade-off while maintaining generous design margins and circuit robustness.



Gen 4 SiC FETs are a 'cascode' of a SiC JFET and a co-packaged Silicon MOSFET in TO-247-4L or -3L package

Gen 4 SiC FETs are a 'cascode' of a SiC JFET and a co-packaged Silicon MOSFET. These together provide high speed and low losses with high temperature operation, while retaining an easy, stable, and robust gate drive with integral ESD protection. The advantages are quantified by Figures of Merit (FoM) such as RDS(on) x A, a measure of conduction losses per unit die area. Gen 4 SiC FETs achieve the lowest values in the market at both high and low die temperatures. FoM RDS(on) x EOSS/QOSS is important in hard-switching applications. FoM RDS(on) x COSS(tr) is critical in soft-switching applications. "With SiC FETs the switching losses are controlled by the SiC JFET and not directly the the gate charge of the low voltage MOSFET, thus the typical FoM = Ron x Qg is not useful with SiC FETs," Anup Bhalla explains.

For hard switching applications, the integral body diode of SiC FETs is superior in recovery speed and forward voltage drop to competing Si MOSFET or SiC MOSFET technologies. Other advantages incorporated into the Gen 4 technology are reduced thermal resistance from die to case by advanced wafer thinning techniques and silver-sinter die-attach. "Sintering is the mechanism by which the SiC JFET chip is attached to the Cu leadframe of the package, and by which the low voltage MOSFET is attached to the top of the Sic JFET", Bhalla underlines.

With their latest improvements in switching efficiency and on-resistance, the new UnitedSiC SiC FETs are ideal for challenging, emerging applications. These include traction drives and on- and off-board chargers in electric vehicles and all stages of uni- and bi-directional power conversion in renewable energy inverters, power factor correction, telecoms converters and AC/DC or DC/DC power conversion generally. Established applications also benefit from use of the devices for an easy boost in efficiency with their backwards compatibility with Si MOSFET and IGBT gate drives and established TO-247 packaging. Pricing (1000-up, FOB USA) for the new 750 V Gen 4 SiC FETs range from $4.15 for the UJ4C075044K3S, to $23.46 for the UJ4SC075006K4S. All devices are available from authorized distributors.

LEFT: "Sintering is the mechanism by which the SiC JFET chip is attached to the Cu leadframe of the package, thus reducing thermal resistance and avoiding solder cracking," Anup Bhalla explains

Designing Transformer Coupled Gate Drive Circuits and Gate Drive Transformers

Metal oxide semiconductor field effect transistor (MOSFET) and Insulated gate bipolar transistor (IGBT) are amongst the most popular, efficient semiconductor devices for switching power supplies. For medium to high power switching applications, dedicated gate drivers are essential, because it would take too long to charge the gate capacitance for the gate of a power switch to be driven by the output of a logic IC. So, what are the circumstances under which gate drivers offer the best solution – and how can their design be optimised? **Bhuvana Madhaiyan & Sampath Palaniyappan, Design and Development Engineers, Talema Group, Ireland**

Isolated drivers are essential, for safety and other reasons. Most popular implementations of isolated gate drivers use either magnetic (Gate Drive Transformers, or GDTs) or optical (Opto Coupler) isolation techniques. Advantages of GDTs include a lack of propagation delay in carrying signals from the primary side to the secondary; no requirement for a separate isolated power supply; the provision of a step-up / step-down facility; and high efficiency. But there are some disadvantages too, including their unsuitability for DC, for low frequency AC, and for "normally on" devices.

Gate drivers

The MOSFET and IGBT are amongst the most popular, efficient semiconductor devices for medium to high power switching power supplies. Both are driven into conduction by making the gate terminal positive relative to the source/emitter (Figure 1).

Charging the gate capacitor turns the power device on, allowing current to flow between its drain and source terminals when the gate voltage reaches the threshold voltage (VTH). Discharging turns the device off. The device is operated as a switch by applying a voltage sufficiently larger than VTH between the gate and source/emitter terminal.

In high power applications, it would take too long to charge the gate capacitance for the gate of a power switch to be driven by the output of a logic IC (PWM controller). Instead, dedicated gate drivers are used to apply voltage which can be integrated within PWM controller ICs or implemented as dedicated ICs, discrete transistors, or transformers. Thus gate driver circuit design is critical to the achievement of the required DC/DC converter/SMPS output (Figure 2).

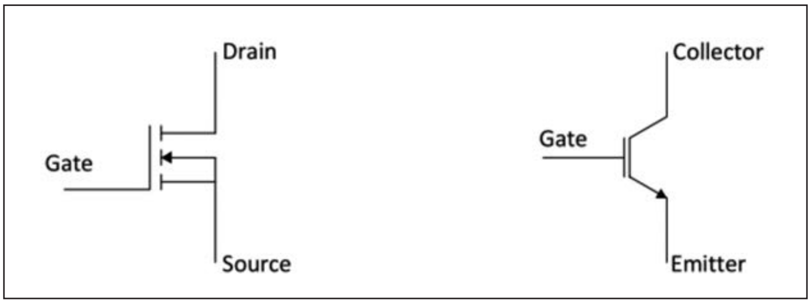


Figure 1: MOSFET (left) and IGBT symbols

Figure 3 shows the two alternative switch arrangements. "Low side drivers" drive ground referenced switches, whereas "high side–low side" drive a floating and a ground referenced switch using a bridge arrangement. Typical applications include solar inverters, converters for wind turbines, welding equipment, electric vehicles, and medical devices.

Isolated gate drivers

Isolation may be defined as the electrical separation between circuits in a system. Signals and power can pass between isolated circuits by inductive, capacitive or optical means. Isolation is mandated for safety for power inverter and converter gate drive circuits, where it also protects low voltage electronics from any damaging faults.

An isolated gate drive circuit is used for power converters where high power density and high efficiency are required. Such a circuit uses high and low switches such that the low side driver cannot directly drive an upper power device. That upper power device requires an isolated gate drive, because its source/emitter is at floating potential.

In Figure 4, the source terminal of switch 1 is allowed to float between

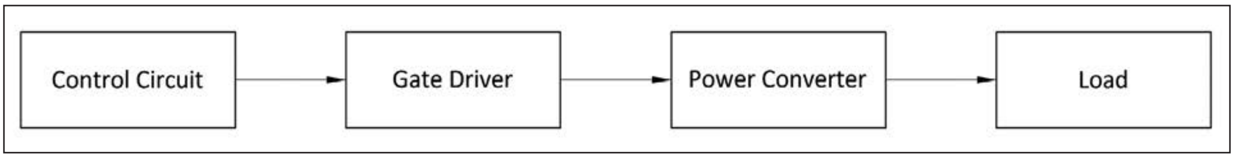


Figure 2: Schematic of typical power electronic system layout

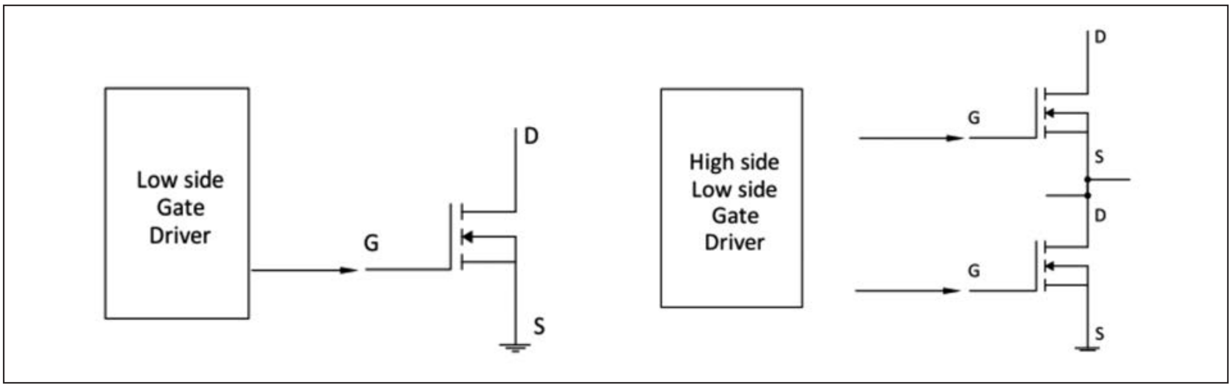


Figure 3: Alternative switch arrangements

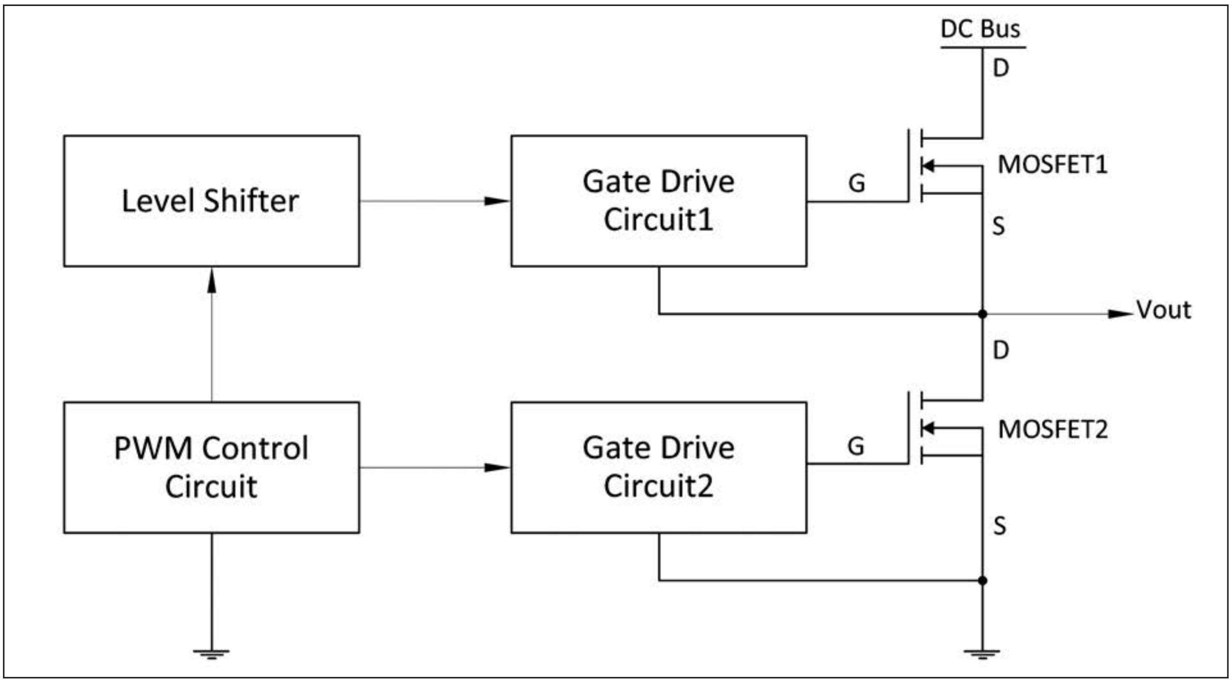


Figure 4: Isolated gate driver topology

ground and DC bus potential implying a requirement for both a floating supply, and a level shifter to transmit the PWM control signal to the floating driver circuitry. Most popular implementations of isolated gate drives use either magnetic (GDTs) or optical (Opto Coupler) techniques.

Gate drive transformers

A transformer coupled gate drive remains the best option for high power applications. Galvanically isolated output windings mean that a single transformer can drive all switches in the bridge and facilitate the driving of parallel switches (MOSFETs/IGBTs). A negative gate bias when the device is off also reduces dv/dt susceptibility to false switching, which can cause permanent damage. Transformer coupled solutions suffer negligible delays, and can operate across comparatively high potential differences.

GDTs are optimized to transmit rectangular electrical pulses with fast rise and fall times to activate or deactivate the switching device, handling low power but high peak currents to drive the gate of a power switch. Power ratings range from µW to several kW. They provide both the floating supply and the level shifting of the switching signal eliminating the need for a separate floating power supply.

MOSFET/IGBT gates can be driven directly, or an isolated control signal can be applied to a gate driver IC. Impedance matching is provided, and separate primary and secondary windings facilitate isolation and offer the option of voltage scaling.

When operating at switching frequencies above 100 kHz, designers of GDTs must guard against the adverse effects of leakage inductance and distributed capacitance.

GDTs are also known as pulse, trigger, wide band or signal transformers, mostly dependent on their application. The moniker "gate drive transformer" is used where the transformer directly drives a power device gate, whereas "pulse transformer" references a device used as a means to transmit rectangular voltage signals/pulses to a semiconductor gate. Generally, a pulse transformer transfers a pulse of current/voltage from the primary/generating side of the circuit to the secondary/load side, with shape and other properties maintained. A pulse transformer that initiates an action may be known as a trigger transformer.

Basic circuit

The basic circuit of a transformer-based isolated gate drive (Figure 5) includes reset components such as a blocking capacitor C, primary resistor R, gate resistor Rg, and a back to back Zener diode.

When a square pulse is applied at the primary terminals, it is transmitted by the secondary as a square wave or as a derivative of the input voltage. The blocking capacitor C is placed in series with the primary winding of the transformer to

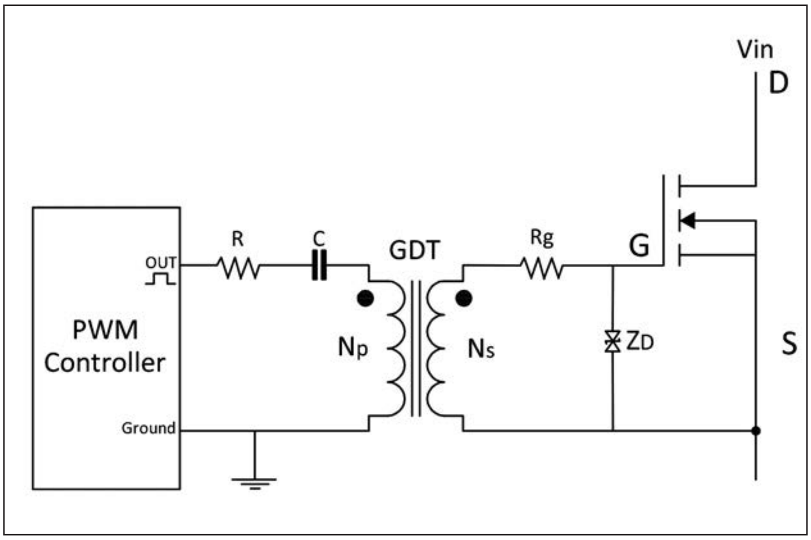


Figure 5: Basic circuit of a transformer based isolated gate drive

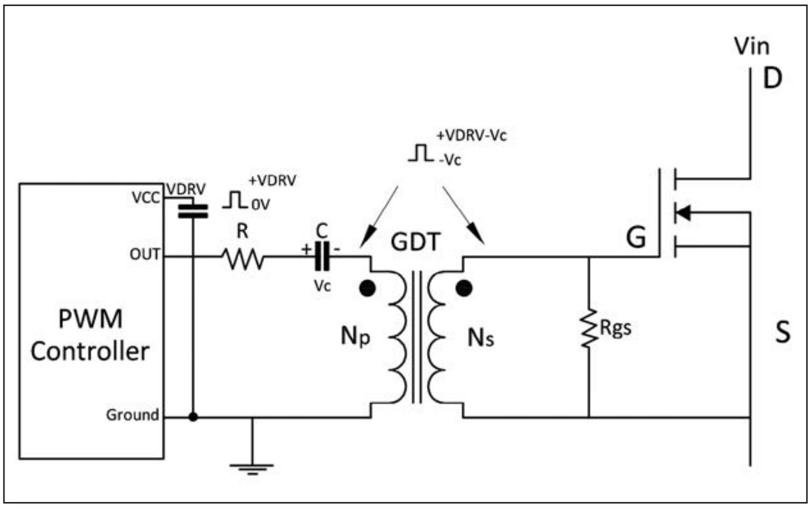


Figure 6: Single ended transformer-coupled gate drive

provide the reset voltage (negative bias) for the magnetizing inductance, preventing transformer saturation. The amplitude of output voltage reduces with the duty ratio increase, hence this circuit limits the duty cycle to less than 50 %. This approach works well in SMPS circuits, where the frequency is high and the duty cycle ratio is small.

Gate drive voltage, V_c, changes with duty ratio. Sudden changes in duty ratio will excite the L-C resonant tank formed by L_m & C, an effect that can be damped by the low value resistor (R). The gate is driven between $-V_c$ and V_{DRV}-V_c levels as opposed to original output voltage range of the driver, 0 V and V_{DRV}. A back to back Zener diode is used to clamp the device gate voltage, and gate resistor R_g is used to avoid gate transient surge current

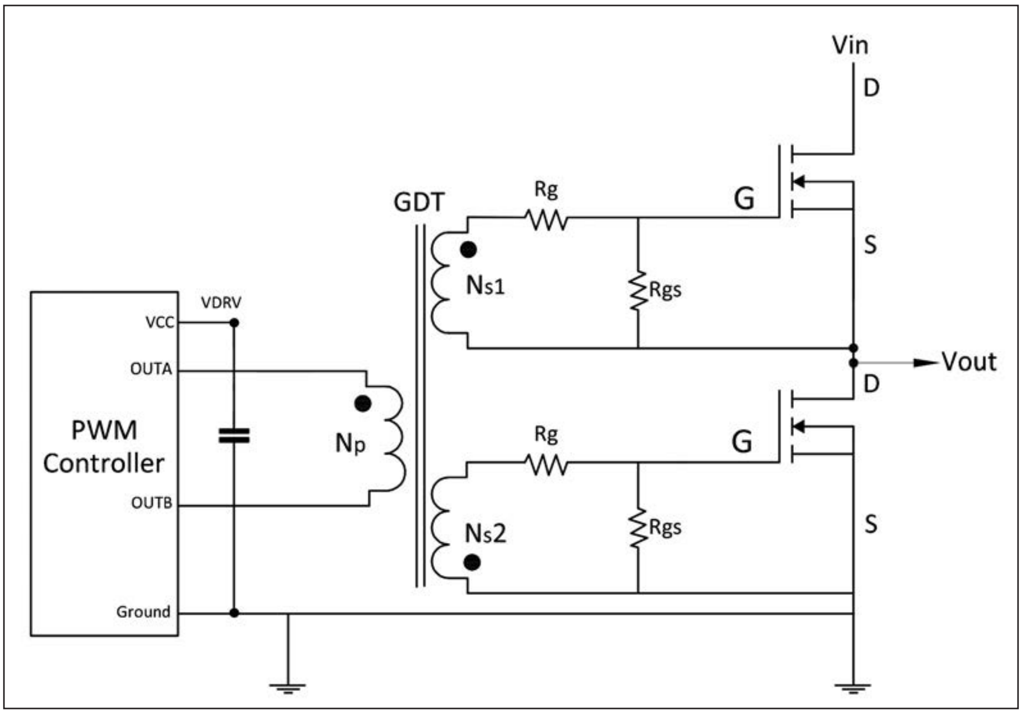
Core saturation limits the applied volt-time product across the windings, and the design must accommodate the maximum volt-time product.

The GDT is driven by a variable pulse width as a function of the PWM duty ratio. Amplitude may be constant or variable according to configuration.

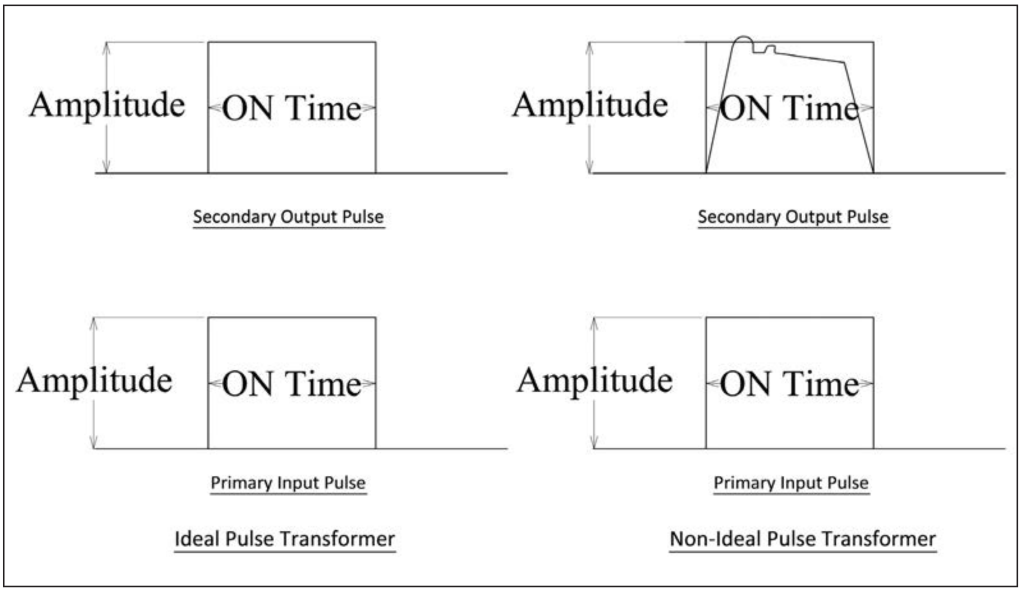
Single ended and double ended circuits

All GDTs operate in both the first and third quadrant of the B-H plane.

Single ended gate drive circuits are used with a single output PWM controller to drive a high side switch. The GDT is driven by a variable pulse width and variable amplitude (Figure 6). This circuit is limited to 50 % duty ratio. For wide duty cycle applications, a DC restoration circuit on the

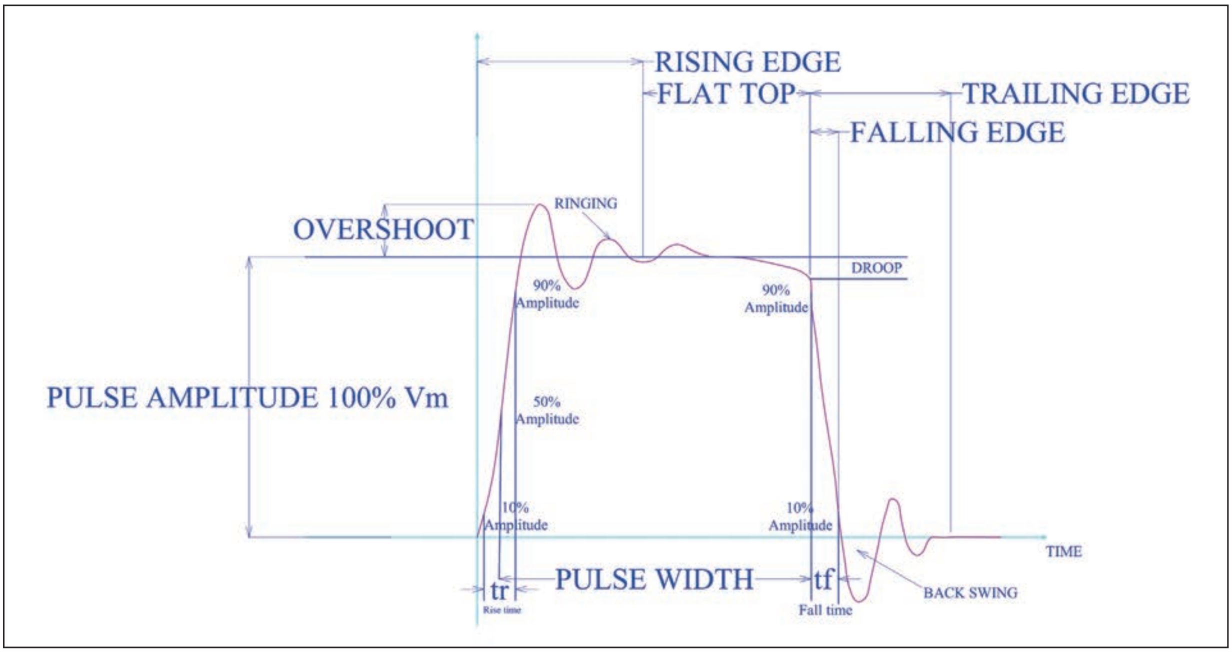


LEFT Figure 7: Double ended transformer-coupled gate drives



LEFT Figure 8: Pulse response deviates from the ideal

BELOW Figure 9: Pulse response regions and parameters



secondary side of the transformer (capacitor & diode) ensures adequate gate drive voltage and restores the original gate drive amplitude on the secondary side of the transformer.

Double ended gate drive circuits are used with a double output PWM controller to drive 2 or 4 switches in high power applications (Figure 7). The GDT is driven by a variable pulse width and constant amplitude. OUTA and OUTB are opposite polarity and symmetrical. When OUTA is on, positive voltage is applied. The average voltage across the primary for any two consecutive switching periods is always zero, removing the need for any AC coupling.

Pulse response characteristics

It is important that a pulse transformer reproduces the shape of input pulse as accurately as possible at its secondary terminals. Performance is specified in terms of its ability to do so. In practice, output response is distorted. Current cannot change instantaneously resulting in finite rise and fall times, and the input voltage is of discontinuous nature (Figure 8).

The pulse width varies from less than 1 µs to about 25 µs, with parasitic elements causing overshoot, delay and ringing and non-ideal components (transients) causing deviations in the flat portion.

The aim of transformer design is therefore to minimize leakage inductance and distributed capacitance. As illustrated in Figure 9, a typical pulse wave has four regions, and permissible distortion is defined in terms of the illustrated parameters.

Conclusion

Most popular implementations of isolated gate drives use either magnetic (Gate Drive Transformers, or GDTs) or optical (Opto Coupler) techniques. Advantages of GDTs include a lack of propagation delay in carrying signals from the primary side to the secondary; no requirement for a separate isolated power supply; the provision of a step-up / step-down facility; and high efficiency. There are some disadvantages including their unsuitability for DC, for low frequency AC, for normally on devices, and for high power, high density synchronous rectification applications; the need for AC coupling capacitors and Zener diodes where high duty ratios are necessary, and a complexity and costliness resulting from the requirement for a transformer primary to be driven by a high speed buffer.However, where GDTs can be used, careful design can ensure a highly effective and efficient solution.

Is the 12V Lead-Acid Battery Dead?

Yes, the 12 V lead-acid car battery is dead. Europe has decreed that no new cars will have lead-acid batteries after 2030, creating a considerable challenge for OEMs to find alternative solutions. While this may seem like a daunting task, it also presents a tremendous opportunity to eliminate the environmentally toxic battery while also reducing weight in a vehicle and improving overall efficiency.

Nicolas Richard, Director Automotive Business Development, Vicor Europe

The 12 V battery and power delivery network (PDN) are standard across the globe, supporting hundreds of loads, including some critically related to safety, so the solution will need to be both innovative and robust. High-density, high-power and efficient power modules used to interconnect high-voltage, 48 V and 12 V PDNs offer the most flexible and scalable solution to this impending challenge.

When considering potential solutions, OEMs must take into account a number of key factors: adding more power to support new features with better performance, increasing efficiency for longer range and better thermal management, reducing CO2, optimizing cable routing, reducing harness weight and meeting EMI requirements are some of the variables within this complex equation.

There are two primary options for solving this equation. Replacing the 12 V lead-acid battery with a 12 V Li-ion battery is one option. While it does slightly reduce weight, it retains the decades-old legacy of the 12 V PDN, which yields no additional benefits. The other option is to support a 12 V PDN powered from the primary 400 V or 800 V battery in EV and HEV/PHEV. There are many benefits to the latter option, but both merit further exploration.

Switch to 12V Li-Ion battery

Simply replacing the 12 V lead-acid battery with a 12 V Li-ion battery saves ~55 % weight; however, it has a high cost impact. The 12 V Li-ion battery needs a Battery Management System (BMS) to control the charging and maintain the full battery operation over the vehicle life. It is the direction taken for instance by Tesla [1] and Hyundai [2].

Furthermore, adding a bulky DC/DC converter from HV to 12 V (with voltage and current regulation feature) is needed to recharge the 12 V Li-Ion battery and supply the electrical loads. But this adds no benefits. What it does add is weight, vehicle packaging complexity, and system cost; it also reduces overall vehicle reliability. By contrast, eliminating the 12 V battery altogether removes 13 kg from the vehicle and can improve the cargo space by 2.4 % [3].

Legacy 12 V PDNs are inefficient

Maintaining a physical 12 V battery means maintaining an inefficient PDN with unnecessary redundancy. In a typical automotive 12 V PDN, all the 12 V loads connected to the 12 V bus have internal pre-regulators able to convert wide input voltage range typically from 6 to 16 V to regulated rails of 5 V, 3.3 V or lower. From a global system view for an EV, HEV or PHEV, there is redundancy of series regulator stages. A high-voltage-to-12 V DC/DC converter regulates the 12 V bus (with efficiency hit) and the pre-regulator provides the suitable internal rail voltage for each load (Figure 1).

This legacy architecture originated when vehicles had an alternator, a sensitive 12 V PDN that needed regulation to charge the battery, keep the radio operating during cranking event or maintain incandescent headlights at the right intensity. OEMs were very creative to bypass the 12 V power limitation and complex electrical architectures have been designed in recent years with two 12 V batteries, one 24 V battery for power steering and several DC/DC converters between them.

Replacing the 12 V with a virtual battery

A better approach to solving this problem is to completely rethink the PDN in a vehicle: eliminate the physical 12 V battery and replace it with a 12 V "virtual" battery from the primary EV battery (Figure 2). Every EV carries a main battery, so it does not make sense to transport additional energy storage devices. The ideal vehicle architecture would be one high-voltage (HV) battery used to power

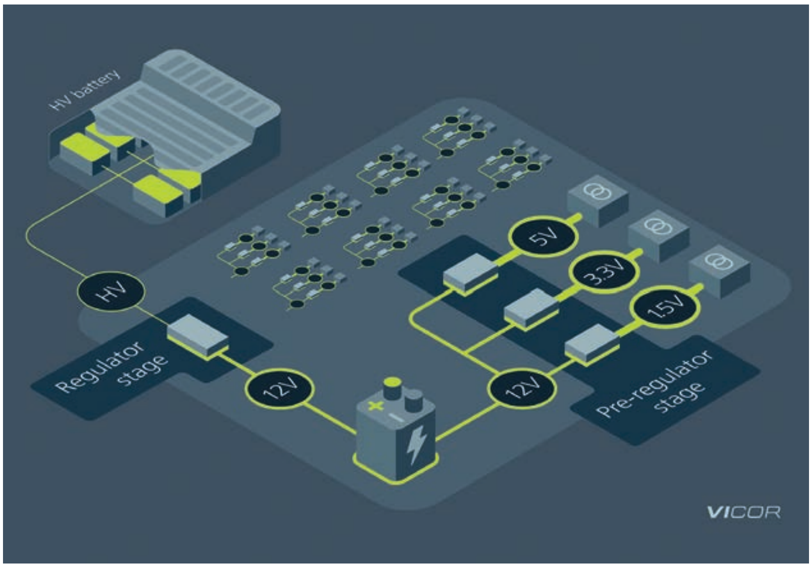


Figure 1: Typical E/E used in xEVs with 12V battery using redundant voltage regulator stages. The HV-to-12 V DC/DC regulates the 12 V output to charge the 12 V battery. Every 12 V load in the vehicles has a pre-regulator stage to supply the proper rail voltage needed for the load to operate.

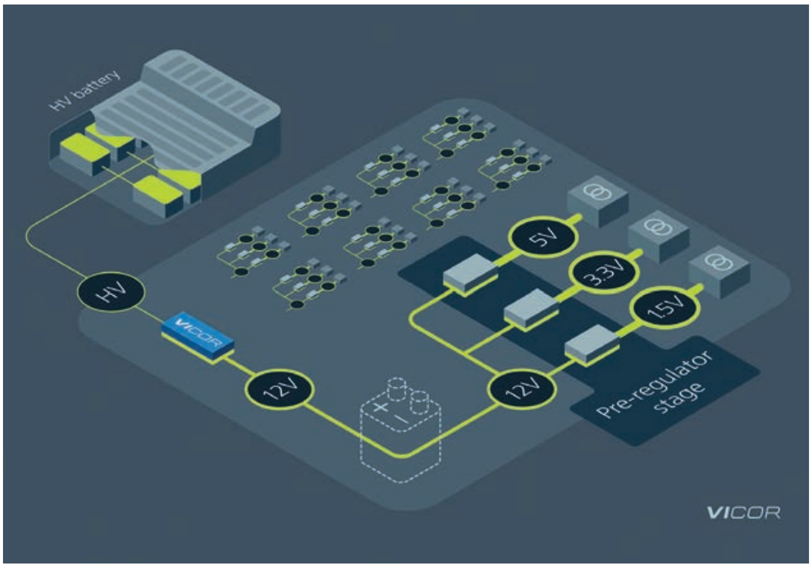


Figure 2: Optimized E/E architecture eliminates the physical 12 V battery. A virtual 12 V battery is created by transforming the high-voltage battery with Vicor BCM® Bus Converter technology

the powertrain and all the auxiliary loads. Vicor high-density bus converter module technology enables this approach by virtualizing a low-voltage battery (48 V or 12 V) directly from the HV battery (400 or 800 V).

Utilizing zero-voltage, zero-current switching (ZVS/ZCS), CM® Bus Converters operate at higher frequencies than conventional converters making them more responsive than a physical battery. For example, the BCM6135 operates at 1.2 MHz and, unlike a conventional ZVS/ZCS resonant converter, the BCM operates within a narrow band frequency (Figure 3). The BCM's high-frequency operation provides a fast response to changes in load currents and a low-impedance path from input to output. Fixed-ratio conversion, bidirectional operation, fast transient response (higher than 8 MA/s), and a low-impedance path collectively enable the BCM to make HV battery appear like a 48 V battery, which we term "transformation." This ability to transform a power source is both the key benefit and key differentiator when compared to conventional converters.

The BCM operates as a fixed-ratio converter where the output voltage is a fixed fraction of the input voltage. The BCM6135 converter is isolated and provides 2.5 kW of power in a 61 x 35 x 7 mm package with over 97 % peak efficiency. It can be paralleled easily in an array to deliver even more power.

The fixed-ratio nature of the BCM ensures that the virtual battery will stay within its appropriate operating range. For example, the HV battery is guaranteed to stay between 520 V and 920 V on an 800 V battery-powered electric vehicle. A BCM6135 with 1/16 ratio virtualizes a 48 V battery with a voltage range guaranteed to stay between 32.5 and 57.5 V. A BCM6135 1/8 ratio could be used for 400 V EVs (Figure 3, 4).

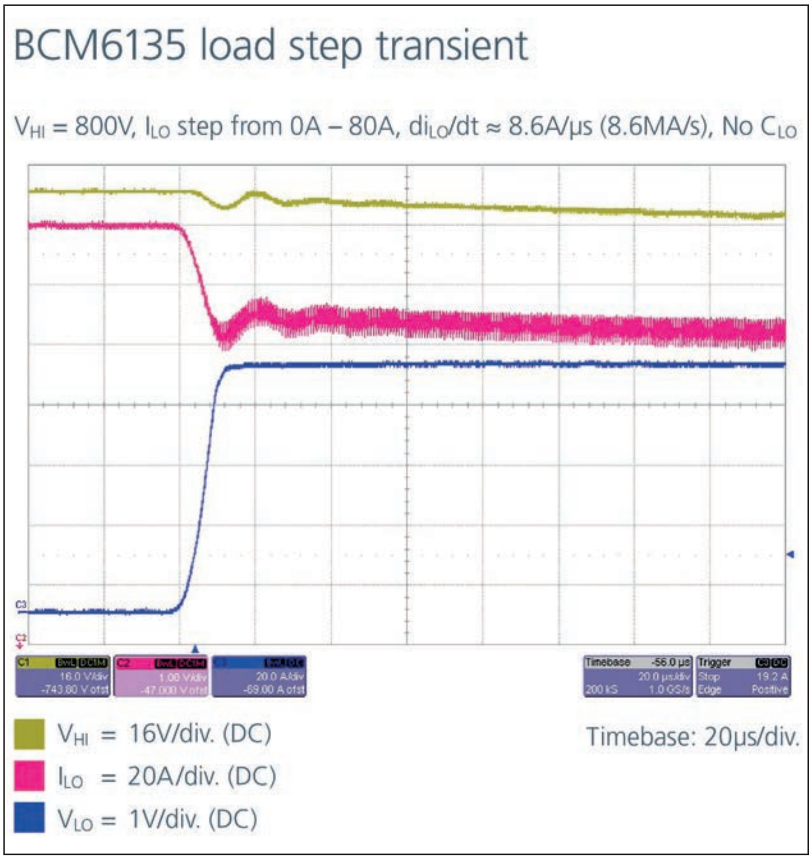
The battery virtualization can also be extended to the 12 V bus with a fixed-ratio converter of 1/4. In that case, galvanic isolation is not required and a NBM™ Bus Converter could be used. Identical in all other features to a BCM, the NBM non-isolated bus converter has all the same benefits previously described: fast transient response, low impedance, and bidirectional operation. The voltage range on the 12 V stays between 8.125 and 14.375 V with a fixed ratio to the HV battery voltage. BCM and NBM technology are ideal transformers connecting each of the vehicle power networks (Figure 5).

Ensuring redundancy of power delivery for functional safety loads is essential. Because Vicor power modules are fully scalable in power and delivery, they can be designed to act as redundant PDNs enabling functionally safety-critical loads to be supplied with two dedicated power conversion paths. Ultimately, OEMs could implement localized energy storage to ensure functionally safe operating of critical systems such as ADAS, steering and braking.

EV power delivery network at a crossroads

The 12-volt lead-acid battery will soon meet its demise in Europe. And the timing is perfect given all the innovation that is driving the redesign of the EV power delivery network.

The automotive electrical PDN is at a crossroads with 12 V power delivery. More and more demanding power loads are



LEFT Figure 3: The fast load transient response of BCM6135 is the key to supporting the 12 V loads (yellow : input voltage (800 V DC), red: output voltage (48 V), blue: output current)

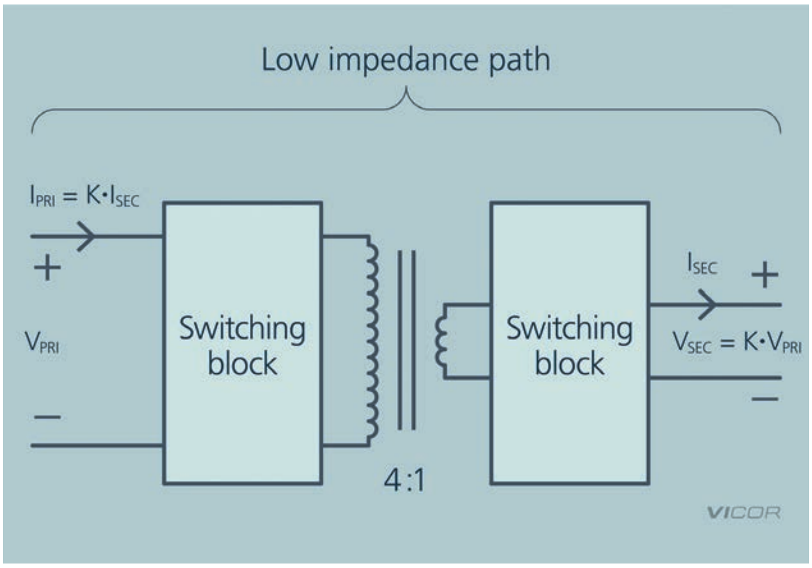


Figure 4: Functional block diagram of BCM Bus Converter. Even though it converts DC to DC, the BCM uses a transformer to convert AC to AC at high efficiency, scaling the magnitude by the K factor and using the switching blocks to convert between AC and DC. The switching is done at a high frequency, and, due to the transformer-like energy transfer the conversion, has a fast response to transient load changes and presents a low-impedance path between input and output

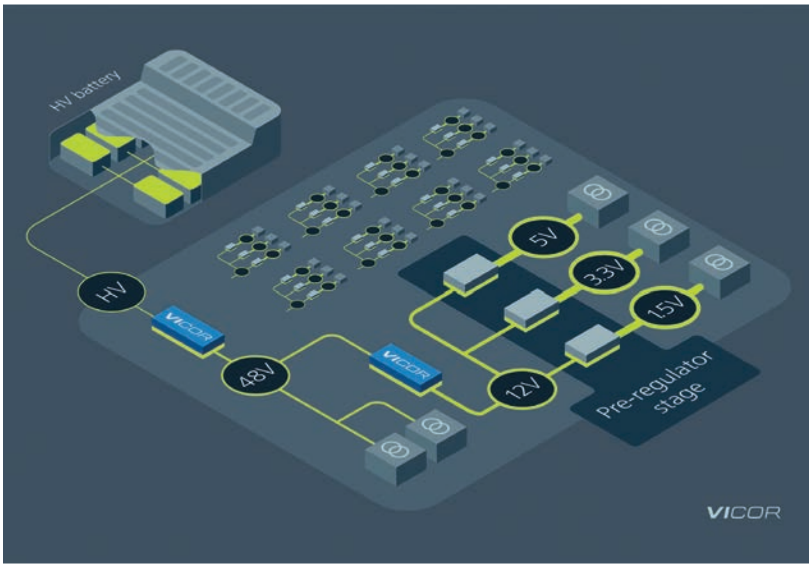


Figure 5: E/E architecture with 12 V and 48 V battery virtualization based on BCM6135 and NBM2317 modules

being implemented in vehicles while trying to keep architectural changes to a minimum. "What are we still doing at 12 volts? Twelve volts is very much a vestigial voltage, it's certainly low," said Elon Musk, Tesla CEO [4].

OEMs are scrambling to design better PDNs to deliver more EV range and performance. Eliminating the 12 V battery altogether is the obvious long-term solution that reduces weight and space and delivers better transient response and system performance. Vicor technology not only enables these benefits but also offers a combination of flexibility, scalability and power density. The Vicor module approach to PDNs offers building blocks to address the near-term challenge of 12 V power delivery network for next generation of xEVs.

Literature

[1] Charles Morris, "Refreshed Tesla Models S and X to ditch lead-acid for Li-ion 12 V battery"; Electric Vehicles Magazine, (Feb. 9, 2021) https://chargedevs.com/features/a-closer-look-at-dc-dc-converters/

[2] Bengt Halvorson, "All 2020 Hyundai hybrids have a clever 12-volt lithium-ion accessory battery", www.greencarreports.com (Apr 28, 2020) https://www.greencarreports.com/news/1127972_all-2020-hyundai-hybrids-have-a-clever-12-volt-lithium-ion-accessory-battery

[3] Jeffrey Jenkins, A closer look at DC-DC converters; Electric Vehicles Magazine (Aug. 6 2018) https://chargedevs.com/features/a-closer-look-at-dc-dc-converters/

[4] Charles Morris, "Refreshed Tesla Models S and X to ditch lead-acid for Li-ion 12 V battery"; Electric Vehicles Magazine (Feb. 9, 2021) https://chargedevs.com/features/a-closer-look-at-dc-dc-converters/

Accelerated Life Test Instruments

www.accelrf.com
Accel-RF Instruments Corporation
Tel: 001 858 278 2074

Arbitrary 4-Quadrant Power Sources

www.rohrer-muenchen.de
Rohrer GmbH
Tel.: +49 (0)89 8970120

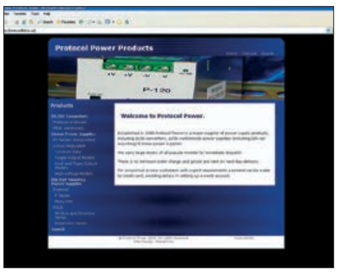
Busbars

www.auxel.com
Auxel FTG
Tel: + 33 3 20 62 95 20

Capacitors

www.cde.com
Cornell Dubilier
Tel: 001 508 996 8561

DC/DC Converters



www.protocol-power.com
Protocol Power Products
Tel: +44 (0)1582 477737

Diodes

www.neutronltd.co.uk
Neutron Ltd
Tel: +44 (0)1460 242200

Diodes

www.proton-electrotex.com/
Proton-Electrotex JSC/
Tel: +7 4862 440642;

Discrete Semiconductors

www.digikey.com/europe
Digi-Key
Tel: +31 (0)53 484 9584

Hall Current Sensors

www.dgseals.com
dgseals.com
Tel: 001 972 931 8463

High Voltage and High Power Electronics

Dean Technology, Inc.
www.deantechnology.com
+1 (972) 248-7691

IGBTs

www.microsemi.com
Microsemi Tel: 001 541 382 8028

Magnetic Materials/Products

www.dextermag.com
Dexter Magnetic Technologies, Inc.
Tel: 001 847 956 1140

Mosfets

www.aosmd.com
Alpha and Omega Semiconductor
Tel: 001 408 789 3233

www.neutronltd.co.uk
Neutron Ltd
Tel: +44 (0)1460 242200

Optoelectronic Devices

www.digikey.com/europe
Digi-Key
Tel: +31 (0)53 484 9584

Packaging & Packaging Materials

www.curamik.co.uk
curamik® electronics GmbH
Tel: +49 9645 9222 0

Power Amplifiers

www.rohrer-muenchen.de
Rohrer GmbH
Tel: +49 (0)89 8970120

Power ICs

www.digikey.com/europe
Digi-Key Tel: +31 (0)53 484 9584

Power Modules

www.picoelectronics.com
Pico Electronics
Tel: +44 1634 298900

www.fujielectric-europe.com
Fuji Electric Europe GmbH
Tel: +49 (0)69-66902920

www.proton-electrotex.com/
Proton-Electrotex JSC/
Tel: +7 4862 440642;

Power Semiconductors

www.proton-electrotex.com/
Proton-Electrotex JSC/
Tel: +7 4862 440642;

Power Substrates

www.universal-science.com
Universal Science Ltd
Tel: +44 (0)1908 222211

Resistors & Potentiometers

www.isabellenhuette.de
Isabellenhütte Heusler GmbH KG
Tel: +49/(27 71) 9 34 2 82

RF & Microwave Test Equipment.

www.ar-europe.ie
AR Europe
Tel: 353-61-504300

Simulation Software

www.power.ti.com
Texas Instruments
Tel: +44 (0)1604 663399

www.universal-science.com
Universal Science Ltd
Tel: +44 (0)1908 222211

Solder

www.indium.com
Indium Corporation
Tel: +44 (0) 1908-580400

Switched Mode Power Supplies

www.citapower.com
Bias Power, LLC
Tel: 001 847.419.9118

Thermal Management & Heatsinks

www.abl-heatsinks.co.uk
ABL Components Ltd
Tel: +44 (0) 121 789 8686

www.dau-at.com
Dau GmbH & Co KG
Tel: +43 3143 23510

Thyristors

www.proton-electrotex.com/
Proton-Electrotex JSC/
Tel: +7 4862 440642;


CDE
CORNELL DUBILIER
ENERGIZING IDEAS
IF IT'S NOT THE HEAT,
∼AC
ALH SERIES
DC ⎓
BLH SERIES
IT'S THE HUMIDITY
Meet the 1,500-hour THB-rated ALH/BLH capacitors
At 85°C and 85% relative humidity, with rated voltage applied, our new inverter-grade film capacitors are tested 50% longer than the industry standard requirements for Temperature-Humidity-Bias. Improve the reliability of your power electronics design with outstanding capacitor performance at high humidity.
cde.com/harsh-environments
1,500 HOURS
85°C
85% RH
AEC-Q200