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ELECTRONICS
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ISSUE 1 – Feb/March 2022 www.power-mag.com

SIC POWER MODULES

Maximizing Active Front End Efficiency Using Silicon Carbide

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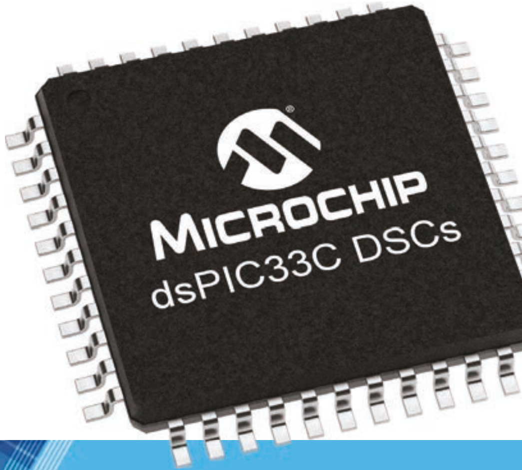

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Circulation and subscription: **Power Electronics Europe** is available for the following subscription charges. **Power Electronics Europe**: annual charge UK/NI £95, overseas $160, EUR 150. Contact: DFA Media, 192 The High Street, Tonbridge, Kent 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

Maximizing Active Front End Efficiency Using Silicon Carbide

Engineers designing UPS with great care to ensure smooth enterprise data center operation 24/7 are also aware that their power supplies are destined to be part of a setup that gulps for example 90 TWh of US electricity every year – enough to sustain thirty large and noxious coal-fired plants. Power engineers in another design camp, working to ensure their fast chargers can speedily top up EVs, are also aware of the cost of electricity and the environmental impact of its generation. Engineers targeting any application area are joined in their concerns over efficiency, power density, and cost. And, even if they have yet to design with it, they are aware that the solution may lie in Silicon Carbide (SiC) technology. An essential part of UPS and charger systems is the active front end (AFE), to explore improvements in size and power density, power losses and efficiency, and bill of materials (BOM) costs. It aims to turn that general awareness of SiC benefits into a clearer understanding, clearing a path through an entrenched less-efficient technology toward greater SiC-based design experience.
This article addresses these concerns and, by doing a side-by-side comparison, demonstrates that Silicon Carbide is by far the better choice over Silicon (Si)-based devices for high power applications. More details on page 29.

Cover supplied by Wolfspeed, USA

Innovation Never Stops

Passenger electric vehicle (EV) sales are set to jump over 80 % in 2021, to 5.6 million units. Improving battery technology and costs, faster roll-outs of charging infrastructure, a wider range of vehicle models on offer to customers, and longer range and faster charging speeds due to highly efficient power semiconductors and last but not least public incentives paves the way towards e-mobility – one of the major markets for power electronics in 2022.

Owing to the EV market's substantial demand for longer driving ranges and shorter charging times, automakers' race towards high-voltage EV platforms has noticeably intensified, with various major automakers gradually releasing models featuring 800V charging architectures, such as the Porsche Taycan, Audi Q6 e-tron, and Hyundai Ioniq 5. According to TrendForce demand from the global automotive market for 6-inch SiC wafers is expected to reach 1.7 million units in 2025 thanks to the rising penetration rate of EVs and the trend towards high-voltage 800 V EV architecture. The 800 V charging architecture will bring about a total replacement of Si IGBT modules with SiC power devices, which will become a standard component in mainstream EV VFDs (variable frequency drives). As such, major automotive component suppliers generally favor SiC components. In particular, Tier 1 supplier Delphi has already begun mass producing 800 V SiC inverters, while others such as BorgWarner, ZF, and Vitesco are also making rapid progress with their respective solutions. SiC usage in OBC (on board chargers) and DC/DC converters has been relatively mature, whereas the mass production of SiC-based VFDs has yet to reach a large scale. Power semiconductor suppliers including STM, Infineon, Wolfspeed, and Rohm have started collaborating with Tier 1 suppliers and automakers in order to accelerate SiC deployment in automotive applications. The upstream supply of SiC substrate materials will become the primary bottleneck of SiC power device production, since SiC substrates involve complex manufacturing processes, high technical barriers to entry, and slow epitaxial growth.

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

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

GaN-on-Silicon devices have been in volume production since 2010 and have demonstrated very high reliability in both laboratory testing and customer applications, such as 4G base stations, vehicle headlamps, or lidar for autonomous cars. What is missing is the powertrain.

But with GaN-on-GaN epiwafers the race for efficiency with SiC in the high-power devices market is opened. GaN epi-wafer is a material comprising multi-stacked III-N compound semiconductor films on a wafer. It is used in high-speed chargers, EV power conversion, and defense radars. SiC or Silicon wafers are used to stack III-N films depending on the application field, but GaN wafers are required in high-power devices such as EV powertrains. Saint-Gobain in France and some Japanese material companies, such as Sumitomo and Mitsubishi, are leading production technology of GaN wafers. With the acquisition of the GaN wafer business from Saint-Gobain, South Korean IVWorks has acquired state-of-the-art technology for mass production of 4- and 6-inch GaN wafers. Based on this acquisition, the start-up company claims that it will be able by supplying GaN-on-GaN epi-wafers in high-power application fields to compete with SiC materials in the EV market.

And with synthetic single-crystal diamond the next generation technology for future power electronics is on the horizon – waiting for commerzializaton. Thus the power electronics industry never stops innovating – even in difficult times caused by the pandemic.

Achim Scharf
PEE Editor

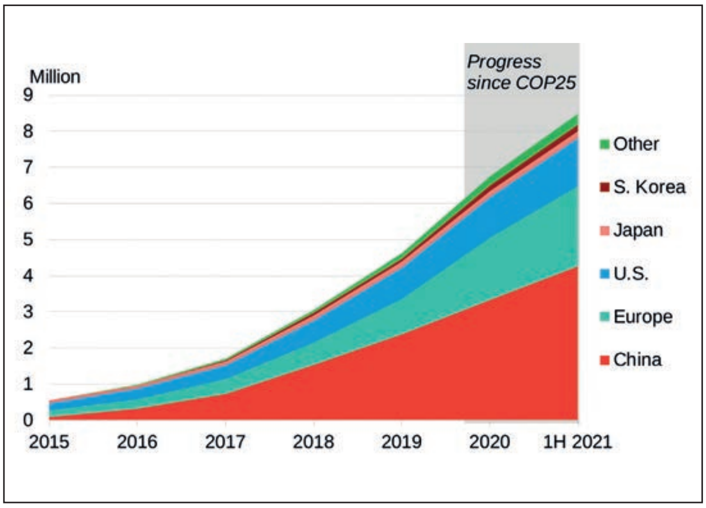
Electric Vehicle Sales Target 40 Million Per Year By 2030

Passenger electric vehicle sales are set to jump over 80 % in 2021, to 5.6 million units, off the back of unprecedented industry and government commitments around the world over the last two years, according to the Zero-Emission Vehicles Factbook, a special report published recently by BloombergNEF (BNEF).

The Factbook documents the progress that has been made towards global net-zero emissions in the road transport sector, and shows that the future is brighter than ever for zero-emission vehicles. In the first half of 2021, sales of passenger electric vehicles (including battery electric, plug-in hybrid and fuel cell vehicles) were 140 % higher than the same period in 2019, reaching 7 % of global passenger vehicle sales. This compares with just 2.6 % in 2019, the year of the last UN Climate Change Conference. The total global fleet of passenger electric and fuel cell vehicles now totals nearly 13 million, of which 8.5 million are true zero-emission vehicles (ZEVs), either battery electric or fuel cell (still, fuel cell vehicles account for a fraction of that total). The latter figure is up from just 4.6 million at the time of COP25. At the same time, by 1H 2021, the global fleet of zero-emission buses has increased by 22 % since 2019, and 18 % of all municipal buses on the road to be zero-emission at the end of 2021 are expected.

What is more, the future looks brighter than ever. A review of industry outlooks shows that zero-emission vehicle forecasts have been raised across the board. BNEF's own forecast for the global ZEV fleet in 2040 has been raised from 495 million vehicles in its 2019 forecast, to 677 million in its 2021 Electric Vehicle Outlook. The International Energy Agency (IEA) has raised its 2030 battery electric vehicle fleet forecast by 7 % since 2019, while the Organization of the Petroleum Exporting Countries (OPEC) has raised its 2040 estimate for the global electric and fuel cell vehicle fleet by 11 %. Underpinning these stronger forecasts are a range of factors, including improving battery technology and costs, faster roll-outs of charging infrastructure, a wider range of vehicle models on offer to customers, and longer range and faster charging speeds available on the newest vehicles. "Sales of internal combustion engine vehicles need to stop around 2035 to get global road transport to net zero by 2050. This report highlights the remarkable progress that has been made towards this goal in the last two years, powered by increasing ambitions of leading governments and vehicle manufacturers. However, there is still a large gap to fill if we are to meet the 2035 deadline globally," commented Aleksandra O'Donovan, electric vehicle analyst at BloombergNEF.

www.bloomberg.com/ZEVreport



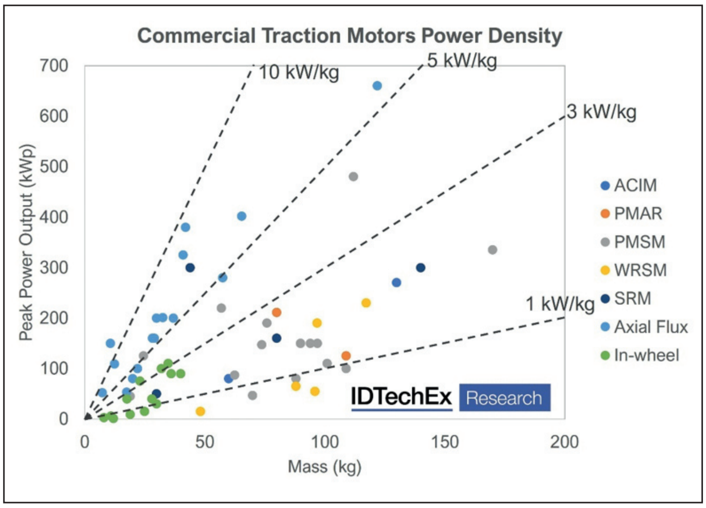
Global passenger ZEV fleet (excludes plug-in hybrids) **Source: BloombergNEF**

Increasing Demand for Automotive Axial Flux Motors

Electric motors are the driving force behind electric vehicles (EVs). In addition to the batteries and power electronics, the electric motor is a critical component within the drivetrain. IDTechEx expects over 100 million electric motors to be required per year by 2032 to meet the demand for the growing EV market.

Despite electric traction motors originally being developed in the 1800s, the market is still evolving today with new designs, improved performance and more considerations around the materials used. These are not just incremental improvements either, with developments such as axial flux motors and various OEMs eliminating rare-earths altogether. The latest report from IDTechEx, "Electric Motors for Electric Vehicles 2022-2032", takes a deep dive into this market, assessing trends, benchmarking, and giving market forecasts through to 2032.

There are several key performance metrics for electric motors. Power and torque density enables improved driving dynamics in a smaller and lighter package, with weight and space being at a premium in EVs. Another critical area is efficiency. Improving efficiency means that less of the precious energy stored in the battery is wasted when accelerating the vehicle, leading to improved range from the same battery capacity. Due to the many different considerations in motor design, the EV market has adopted several different solutions including permanent magnet, induction, and wound-rotor motors. In many cases, a combination of options may be used to give the best overall solution. Each has its own pros and cons in terms of performance but also in terms of materials costs and supply, with permanent magnet motors relying on



Key parameters of motors in BEVs and emerging alternatives **Source: IDTechEx**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rare earths with volatile pricing and a geographically constrained supply chain.

A key emerging motor technology is that of axial flux. The magnetic flux is parallel to the axis of rotation in an axial flux motor (compared to perpendicular in radial flux machines). Whilst almost the entire EV market is using a form of radial flux motor, axial flux motors present several benefits. These include increased power and torque density and a pancake form factor ideal for integration in various scenarios. Despite the previous lack of adoption, the technology has evolved to the state where we have seen significant interest. Daimler acquired key players YASA to use their motors in the upcoming AMG electric platform and Renault has partnered with WHYLOT to use axial flux motors in their hybrids starting in 2025. The axial flux market in automotive EVs is very small today but IDTechEx expects a huge increase in demand over the next 10 years, with first applications in high-performance vehicles and certain hybrid applications.

IDTechEx also sees some promising applications for other alternatives to typical EV motors such as in-wheel motors and long-debated switched reluctance motors. In-wheel motors can eliminate much of the drivetrain components that would normally take up space within the cabin of the vehicle and provide benefits such as torque vectoring. Lordstown announced the use of Elaphe's in-wheel motor for its electric trucks and other players like Protean are providing in-wheel motors to autonomous shuttles. Switched reluctance motors are by no means a new technology, but are making somewhat of a resurgence in certain segments with improvements to their design and control. Advanced Electric Machines (AEM) is providing commercial vehicles and developing a motor with Bentley. Switched reluctance machines are much simpler to manufacture than many others and utilize no rare earths, in fact, some like AEM and RETORQ motors are moving to aluminum windings in order to avoid copper.

www.IDTechEx.com

SiC Power Modules Reduce Energy Consumption of Streetcars

Considering the coming requirements of green mobility, Infineon will launch power semiconductors with CoolSiC™ MOSFET and .XT technology in the XHP™ 2 package – tailored specifically to the requirements of rail services.

The XHP 2 power module has already proven its worth in a joint field test conducted by Siemens Mobility and Stadtwerke München (SWM). An Avenio streetcar in Munich was equipped with these power modules and tested in passenger service for a year, covering around 65,000 km. Siemens Mobility concluded that this use of power semiconductors based on SiC had made it possible to reduce the energy consumption of streetcars by 10 %. and to significantly reduce engine noise during operation. "Innovative semiconductor solutions for rail technology are an important driver for green mobility. The successful field test with streetcars in Munich demonstrates the benefits of SiC technology for manufacturers, rail operators, and residents," said Dr. Peter Wawer, President of Infineon's Industrial Power Control Division. The tests were carried out under the European development and research project PINTA and are part of the extensive European research and innovation initiative Shift2Rail, which aims to create a sustainable European rail system through targeted investments.

Implementing SiC in power modules for traction propulsion systems can also pose major challenges: In addition to an efficient and very robust SiC chip, packages that allow high switching speeds are required, as well as interconnection technologies that enable a long service life. Since trains accelerate and decelerate frequently, the power cycles for semiconductors in rail applications are very demanding. The constant temperature fluctuations stress the interconnection technology. Infineon's .XT technology provides a solution to this challenge. The technology significantly improves the lifetime during power cycles and has been used for years in similarly challenging applications such as wind turbines.

Avenio streetcar in Munich equipped with .XT SiC power modules tested in passenger service for a year **Source: Infineon Technologies**

www.infineon.com/green-energy

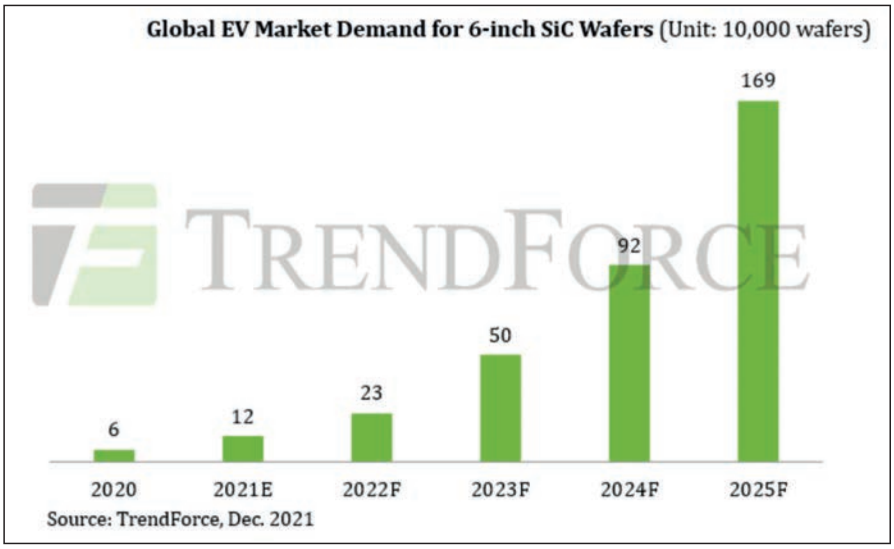
Electric Vehicles Drive SiC, PMIC and MLCC Demand

Owing to the EV market's substantial demand for longer driving ranges and shorter charging times, automakers' race towards high-voltage EV platforms has noticeably intensified, with various major automakers gradually releasing models featuring 800V charging architectures, such as the Porsche Taycan, Audi Q6 e-tron, and Hyundai Ioniq 5.

According to TrendForce demand from the global automotive market for 6-inch SiC wafers is expected to reach 1.7 million units in 2025 thanks to the rising penetration rate of EVs and the trend towards high-voltage 800 V EV architecture. The 800 V charging architecture will bring about a total replacement of Si IGBT modules with SiC power devices, which will become a standard component in mainstream EV VFDs (variable frequency drives). As such, major automotive component suppliers generally favor SiC components. In particular, Tier 1 supplier Delphi has already begun mass producing 800 V SiC inverters, while others such as BorgWarner, ZF, and Vitesco are also making rapid progress with their respective solutions.

EVs have become a core application of SiC power devices. For instance, SiC usage in OBC (on board chargers) and DC/DC converters has been relatively mature, whereas the mass production of SiC-based VFDs has yet to reach a large scale. Power semiconductor suppliers including STM, Infineon, Wolfspeed, and Rohm have started collaborating with Tier 1 suppliers and automakers in order to accelerate SiC deployment in automotive applications. It should be pointed out that the upstream supply of SiC substrate materials will become the primary bottleneck of SiC power device production, since SiC substrates involve complex manufacturing processes, high technical barriers to entry, and slow epitaxial growth. The vast majority of n-Type SiC substrates used for power semiconductor devices are 6 inches (150 mm) in diameter. Although major IDMs such as Wolfspeed have been making good progress in 8-inch (299 mm) SiC wafer development, more time is required for not only raising yield rate, but also transitioning power semiconductor fabs from 150-mm to 200-mm. Thus 150-mm SiC substrates will likely remain the mainstream for at least five more years. On the other hand, with the EV market undergoing an explosive growth and SiC power devices seeing increased adoption in automotive applications, SiC costs will in turn directly determine the pace of 800 V charging architecture deployment in EVs.

Global EV Market Demand for 6-inch SiC Wafers (Unit: 10,000 wafers)



Source: TrendForce, Dec. 2021

General-Purpose PMIC ASP, 2016-2021 (Unit: USD)

Source: WSTS; TrendForce, Dec. 2021

Also, due to material shortages caused by insufficient semiconductor supply, power management IC (PMIC) prices remain on an upward trend, according to TrendForce. Average selling price (ASP) for 1H 2022 is forecast to increase by nearly 10 %, reaching a record six year high. In terms of the global supply chain, in addition to the production capacity of major IDM manufacturers including TI, Infineon, ADI, STMicroelectronics, NXP, ON Semiconductor,

Renesas, Microchip, ROHM (Maxim has been acquired by ADI and Dialog by Renesas), IC design houses such as Qualcomm and MediaTek (MTK) have obtained a certain level of production capacity from foundries. Of these, TI is in a leadership position and the aforementioned companies possess a combined market share of over 80 %.

Recovery in the automotive market and rapid growth in electric vehicles, automotive electronics, and advanced driver-assistance systems (ADAS) have increased demand in power source control and management and charging technology. In addition, automotive-use ICs are required to pass a number of inspections and must guarantee consistency and a zero failure rate. Currently, IDM companies' automotive IC order backlog stretches until the end of 2022. Due to factors such as production running at full capacity and a shortage of raw materials, PMIC suppliers have currently announced longer lead times with consumer electronic IC lead times increasing to 12~26 weeks, automotive IC lead times reaching 40~52 weeks, and a cessation of orders for certain exclusive production models.

Led by IDM companies, PMIC pricing will remain high. Despite variables related to the pandemic and the difficulties of greatly increasing 8-inch wafer production capacity, TI's new fab RFAB2 will begin mass production in 2H22. In addition, due to the plans of foundries to carry forward a portion of 8-inch wafer PMIC manufacturing to 12-inch, there is a high likelihood of a moderation in PMIC shortages. However, close attention must still be paid to changes in future market supply.

TrendForce further indicates that the growth of the EV market and improvements in ADAS have resulted in a twofold increase in automotive MLCC consumption. While EVs' electrified drivetrain and high safety requirements represent a high barrier to entry for MLCC suppliers, these hurdles have also in turn raised MLCC products' ASP and profitability. Hence, the automotive electronics industry has been increasing its annual MLCC demand by double-digits in recent years. In particular, an analysis of different vehicles and their respective MLCC consumption reveals the following: a conventional EV requires 2.2 times the MLCC usage of a conventional gasoline vehicle, an ADAS-equipped EV requires 2.7 times, and an autonomous EV requires as much as 3.3 times.

Regarding MLCC suppliers, Japanese companies including Murata, TDK, and Taiyo Yuden continue to dominate the automotive MLCC market. These suppliers will expand their production capacities for automotive applications in overseas facilities in China, Philippines, and Malaysia next year, with powertrains, ADAS, and connected systems being among the most significant of the aforementioned applications. Korea-based Samsung, on the other hand, specializes in powertrain applications by leveraging its MLCC offerings' small form factor, high capacitance, and high voltage. Finally, Taiwanese suppliers, such as Yageo and Walsin, are actively invested in developing automotive products and High-Q products for RF applications in an effort to increase their presence in the infotainment system market and EV charging station market. Looking ahead to 2022, TrendForce expects annual automotive MLCC demand to reach 562 billion pcs, a 25 % YoY increase, primarily attributed to the continued electrification of vehicles.

www.trendforce.com/

Toshiba Invests in 300 Millimeter Wafer Fab for Power Semiconductors

Toshiba Electronic Devices & Storage Corporation announced in February that it will construct a new 300-mm wafer fabrication facility for power semiconductors at its main discrete semiconductor production base Kaga Toshiba Electronics Corporation. Construction will take place in two phases, with the production start of Phase 1 scheduled within fiscal year 2024. At full capacity, Toshiba's power semiconductor production capacity will be 2.5 times that of fiscal year 2021.

Current power semiconductor demand is expanding on vehicle electrification and the automation of industrial equipment, with very strong demand for low-voltage MOSFETs and IGBTs and other devices. To date, Toshiba has met this demand growth by increasing production capacity on 200-mm lines, and expediting the start of production on 300-mm production lines from the first half of fiscal 2023 to the second half of fiscal 2022. Decisions on the new fab's overall capacity and equipment investment, the start of production, production capacity and production plan will reflect market trends. The new fab will have a quake absorbing structure; enhanced BCP systems, including dual power supply lines; and the latest energy saving manufacturing equipment to reduce environmental burdens. It will also aim to achieve the "RE100" goal of 100 % reliance on renewable energy. Product quality and production efficiency will be improved by introducing artificial intelligence and automated wafer transportation systems.

The company also have established a new high-voltage laboratory in Germany. In line with the company's shift in focus towards more power-related products, Toshiba invested this year in infrastructure and equipment such as high voltage power sources, loads and measuring equipment.

The high-power facilities are compliant with German regulations such as VDE0100 and will have the capability to test and measure up to 1500V DC and 1000V AC. It will also enhance the already established engineering capabilities for ASSPs and MCUs, adding now SiC and GaN devices, digital isolators, gate drivers, optocouplers/relays while focusing on key applications in the automotive and industrial market. The high-voltage laboratory is in full operation since end December 2021.

https://toshiba.semicon-storage.com/

Infineon Operates 300-Millimeter Power Semi Plus 200-Millimeter SiC/GaN Fab

Infineon has made a successful start into the 2022 fiscal year. The company significantly increased both revenues and segment results. The new 300-mm power semiconductor fab should contribute to future groth.

"Demand for our products and solutions remains very strong. Utilization of our manufacturing capacities is very high and we are expanding them step by step. This will help us improve the availability of products that we manufacture in-house over the course of the year. Overall, demand for semiconductors is outstripping supply by far. Electrification and digitalization continue to drive substantial growth in our target markets. We expect the supply situation in some application areas to remain tight well into the current calendar year," said Dr. Reinhard Ploss, CEO of Infineon.

In September 2021 Infineon Technologies already opened its fab for power semiconductors on 300-mm wafers at its Villach site in Austria. At 1.6 billion Euros, this investment represents one of the largest projects in Europe in line with its Green Deal.

Infineon set the stage for long-term, profitable growth based on energy efficiency and CO_2 reduction at an early stage and announced the construction of the chip factory for power electronics in 2018. "The new fab is a milestone, and the timing to create new capacity in Europe could not be better, given the growing global demand for power semiconductors," the going CEO Ploss said. "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."

The Infineon site in Villach, Austria, with the new high-tech chip factory

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 % 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 CO_2 can be avoided each year. The extensive use of exhaust air purification systems will cut direct emissions to virtually zero. Another milestone 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.

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. 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 coming CEO 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".

The Villach site will continue to serve as the innovation base and global competence center for wide bandgap technology by converting existing Silicon facilities over the next years. 150- and 299-mm Silicon lines will be converted to SiC and GaN manufacturing by repurposing non-specific Silicon equipment. The Villach site is currently preparing for further growth opportunities.

Frontend manufacturing site of Infineon in Kulim, Malaysia

Source (2): Infineon Technologies

The company is also investing more than €2 billion to build a third module at its site in Kulim, Malaysia. Once fully equipped, the new module will generate €2 billion in additional annual revenue with products based on SiC and GaN. The expansion will benefit from the economies of scale already achieved for 200-mm manufacturing in Kulim and will complement the 300-mm manufacturing in Villach and Dresden. "Thus we are creating a winning combination of our development competence center in Villach and cost-effective production in Kulim for wide bandgap power semiconductors," Hanebeck underlined.

IVWorks Acquires Saint-Gabain's GaN Wafer Activities

To strengthen the competitiveness in the EV market with GaN-on-GaN epiwafers the race for efficiency with SiC in the high-power devices market is opened.

GaN epi-wafer is a material comprising multi-stacked III-N compound semiconductor films on a wafer. It is used in high-speed chargers, EV power conversion, and defense radars. SiC or Si wafer is used to stack III-N films depending on the application field, but GaN wafers are required in high-power devices such as EV powertrains. Saint-Gobain in France and some Japanese material companies, such as Sumitomo and Mitsubishi, are leading production technology of GaN wafers. With the acquisition of the GaN wafer business from Saint-Gobain, South Korean IVWorks has acquired state-of-the-art technology for mass production of 4- and 6-inch GaN wafers.

Saint-Gobain designs, manufactures and distributes materials and services for the construction and industrial markets, and developed the core technology to create state-of-the art GaN wafers that is better leveraged by a company solely focused on this opportunity. IVWorks is the sole South Korean enterprise specializing in semiconductor materials that has successfully mass-produced GaN epi-wafers of 4-, 6-, and 8-inch. It has to its credit the in-house development of the world's first epi-wafer production technology integrated with an artificial intelligence production system. The pioneering start-up has also recently installed a 12-inch production facility, for the first time in South Korea. "Recently, the use of GaN power devices are increasing significantly in all electronic products due to their advantages in terms of energy efficiency, and interest in GaN is high in the EV applications, a new market. Based on this acquisition, we will be able to expand our product portfolio by supplying GaN-on-GaN epi-wafers in high-power application fields and compete with SiC materials in the EV market," CEO Young-Kyun Noh of IVWorks commented.

www.ivwkr.com/

South Korean start-up IVworks announced in January that they acquired Saint-Gobain's GaN wafer business

Source: IVWorks

Cambridge GaN Devices Launches Data Center GaN Project

Fabless semiconductor company Cambridge GaN Devices Ltd. (CGD) has launched ICeData, a project aiming to develop and commercialize a highly efficient GaN-based IC for use in data centre server power supplies.

Data centres currently account for around 2 % of the world's energy use, with an annual electricity consumption rate of 400 TWh in 2018 set to double by the end of the decade. In power electronics applications, such as power supplies for consumer electronics and servers for data centres, GaN has the potential to massively reduce the energy wasted due to its structural and conductive properties.

The combination of higher efficiency and higher power density can also achieve significant savings on data centres' Capex and Opex, potentially reducing investment and running costs by up to 10 %. The proprietary ICeGaN(™) gate technology developed by CGD (which enables the simple driving of the GaN transistor without using a specialised GaN driver), the ICeData product will be a solution of choice. By the project's end CGD will have a qualified and production-ready set of GaN power IC solutions. CGD's first product line featuring ICeGaN(™) technology will be released in the first half of 2022. "Exponential growth in demand for data storage and processing, accelerated by the Covid19 pandemic where cloud-based connectivity became an essential tool for businesses around the world, is resulting in huge increases in data centre energy usage. Developing green technologies that deliver real reductions in CO2 emissions and create greater energy efficiency is vital if we are to meet low carbon targets on the path to net zero," commented Dr Giorgia Longobardi, CEO and founder of CGD.

https://camgandevices.com/

Innoscience Technology Launches US And European Operations

Innoscience Technology, a Chinese company based on GaN-on-Si power solutions, announced the launch of its international operations in the USA and Europe. Headquartered in Suzhou, China, Innoscience is now poised to support local customers through design and sales support facilities in Santa Clara, California, and Leuven, Belgium.

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

Innoscience produces normally-off e-mode GaN FETs. By introducing a stress enhancement layer, on-resistance is significantly reduced without affecting other parameters including threshold voltage and leakage. Both epitaxy as well as device processing have been optimized to obtain high reproducibility and yield. Parts have passed quality and reliability tests in excess of JEDEC standards. "The time is right for GaN, and Innoscience is ready to supply the world. We will surpass anyone on price for an equivalent device and our huge manufacturing capacity means that our customers are assured of security of supply, which is often uppermost in people's minds given the shortage of chips at the moment. We look forward to working with any company in order to proliferate GaN throughout the global electronics industry," comments Dr. Denis Marcon, General Manager, Innoscience Europe.

With the development of new technologies, the electric power grid and power electronic systems the world is undergoing a massive transformation. "Our vision is to create an energy ecosystem with the most effective and low-cost Gallium-Nitride-on-Silicon power solutions. In November, 2017 we established a mass production 8-inch wafer line in Zhuhai. In order to fulfill the rapidly growing power demand, a new facility has been inaugurated in Suzhou in September, 2020. Our 1,400 employees and over 300 R&D experts are dedicated to delivering high performance and high reliability GaN power devices that can be widely used in diverse applications including cloud computing, electric vehicles and automotive, portable devices, mobile phones, chargers and adapters," Jay Son, CEO of Innoscience, stated.

www.innoscience.com

Mass production 8-inch GaN-on-Si wafer line in Zhuhai
Source: Innoscience

Single-Crystal Diamond Technology for Future Power Electronics

Pittsburg-based II?VI Incorporated and Oxford-based Element Six announced on February 3 a collaboration that will expand II-VI's diamond platform, accelerating the development of new disruptive applications by licensing Element Six's single-crystal diamond technology. The unique characteristics of diamond materials offer breakthrough solutions for future generations of power and RF electronics, including for 6G wireless components, as well as other emerging applications in life sciences, sensing, thermal management, and quantum computing. Single-crystal diamond, a material is extremely challenging to manufacture but well known for its outstanding optical, mechanical, thermal, and electrical properties. Through this collaboration, II-VI is licensing from Element Six its intellectual property and equipment necessary to produce high-quality single-crystal diamond, thus expanding its core competency in diamond technology ahead of anticipated market opportunities.

With a track record spanning more than two decades of introducing single-crystal diamond-enabled solutions to the market, Element Six has already helped to unlock a range of new applications in sensing, optics, and semiconductors. The strategic collaboration between the companies represents the next milestone to expand single-crystal diamond applications, delivering its competitive advantages to an ever-growing range of customers. Element Six is part of the De Beers Group, and a leader in the design, development, and production of synthetic diamond and tungsten carbide advanced materials. The company operates worldwide with primary manufacturing facilities in Germany, Ireland, South Africa, the U.K., and the U.S. "Element Six has invested hundreds of millions of dollars for over 70 years to become a world leader in single-crystal diamond engineering and growth. Its unique capabilities complement IIVI's proprietary polycrystalline diamond, a material we already manufacture at scale," said Steve Rummel, Sr. Vice President, Engineered Materials and Laser Optics Business Unit, IIVI Incorporated. "This collaboration is consistent with II-VI's innovation strategy of making early investments in technology platforms that are process- and capital-intensive, and that require time to evolve, mature, and scale, so we can enable our customers' technology roadmaps." "With its diverse global manufacturing footprint, growth markets expertise, and a successful vertically integrated structure, II-VI is one of the largest listed photonics and compound semiconductor companies. These elements make it an ideal partner to accelerate the market adoption of this remarkable material," said Dr. Daniel Twitchen, Chief Technologist, Element Six. "Besides future opportunities for electronics, there is also a wide range of near-term applications driving the demand for accessible single-crystal diamond, including optics, high-durability parts, and thermal-management systems. We look forward to enabling these and many new markets through this strategic collaboration with II-VI."

www.e6.com, www.ii-vi.com

Element Six's single-crystal diamond technology is intended for future generations of power and RF electronics
Source: Element Six

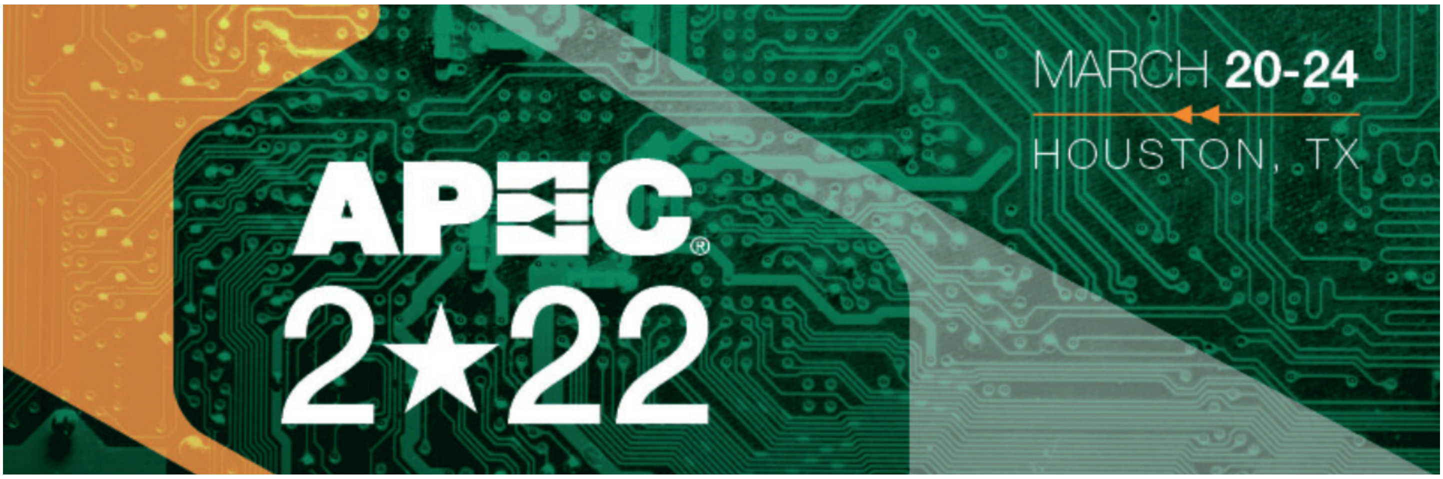
Digital Electricity Accelerates Digital Transformation

VoltServer, Inc. is changing the future of energy delivery with its patented Digital Electricity™ technology that transmits up to 2 kW of power across up to 2 km using off-the-shelf data cables.

VoltServer takes conventional electricity and breaks it into small pulses, or "energy packets." Each packet is sent to a receiver from a transmitter that contains local, embedded processing. Each energy packet is analyzed using a digital signal processing engine to determine that power is being precisely and safely distributed. If a fault is detected, the next energy packet is not sent. Each packet contains only a very small amount of energy, so individually they are not harmful to people, animals, systems or buildings. The receiver converts Digital Electricity back into analog AC or DC to power local loads. Similar to power-over-ethernet (PoE), this enables transport both digital data and power in a single hybrid cabling infrastructure, making it much easier and more economical to install than conventional 110/220 V electrical systems. This simplicity allows architects, designers and facility managers to configure and reconfigure wireless networks, office floorplans and agricultural grow rooms. And because the platform is natively digital, it provides unprecedented insights into energy use with a centralized dashboard.

Vicor Corporation has worked closely with VoltServer since they began product development. Vicor's passively-cooled BCM® DC/DC fixed-ratio bus converters are designed into the receivers transforming the higher transmission voltage to a safe low voltage to power the loads. The 97 % power efficiency allows reliable cooling without a fan within a smaller enclosure. They provide the power efficiency that allows the receivers to be placed in tight, enclosed spaces that are too small to accommodate cooling fans. "With the Vicor converter, we have 43 % less heat loss than a normal converter, and the heat sink size decreases proportionately," said Dan Lowe, VoltServer co-founder and Chief Business Officer.

www.vicorpower.com/resource-library/case-studies/voltserver



In-Person Event Again?!

The Applied Power Electronics Conference (APEC) in Anaheim/California was setting a land mark for the power electronics community in early 2019. The event attracted more than 6,600 delegates compared to the 5,500 in 2018. This year APEC will be held from March 20 – 24 in the George R. Brown Convention Center, Houston, Texas.

APEC's success story is largely due to the fact that power electronics are getting more importance in our daily life not only in powering our electric or electronic devices, but also industrial automation (Industry 4.0), transportation (EV/HEV/traction) or IT (cloud computing/datacenters). For all these applications active power devices such as transistors (Si/SiC/GaN), power moules and passive components (capacitors/inductors) play a vital role. After two years of a virtual event APEC 2022 intends to return to a fully in-person format in 2022, with no virtual attendance options at this time (February 10) in order to follow the 2019 trend, perhaps an ambitious decision due to the high number of Omikron infections in the US and elsewhere.

Healthcare at APEC

Thus APEC will incorporate current best practices to provide delegates with the best level of protection. Specific COVID-19 measures should ensure a safe environment that focuses on health and wellness. APEC will require all attendees to be fully vaccinated and show proof of vaccination or for those who are not vaccinated, proof of a negative COVID-19 test obtained within 72 hours of attendance. To monitor the status of attendees' health, CLEAR Health Pass should ensure the safety of all. Health Pass by CLEAR provides secure, digital proof of COVID-related health insights via the free CLEAR mobile app. There is no fee associated with the use of CLEAR for our meeting attendees. No one at APEC will have access to any of other personal health information. All data is held by CLEAR. APEC staff will only be able to see if you have or have not completed and passed the Health Pass. To ensure expedited check-in and conference entry it is recommended to download the CLEAR app and complete the Health Pass PRIOR to coming to Houston. All attendees have to complete this process at least 24 hours prior to arrival at the conference. CLEAR is not able to read vaccination cards from places outside of the US. EU attendees are asked that they present their digital vaccine passport to the registration personnel upon arrival. All other international travelers will need to present a photo ID and vaccination card upon arrival. And the Houston Health Department recommends wearing a mask while indoors in public to maximize protection.

Extensive program

Professional Education Seminars are scheduled in advance of the official opening on Monday, March 21. Delivered by electronics professionals and academics and covering a range of topics, the seminars are designed to provide practicing power electronics engineers a deep dive into subjects critical to their design activities. Professional Education Seminars are divided into five tracks, each comprising three sessions. Session One and Session Two are scheduled for Sunday, March 20, and Session Three for Monday morning, March 21, prior to the opening of the APEC 2022 conference and exhibition in Houston. Detailed speaker, time and location information about each session can be found on the APEC 2022 website. Tracks inlude Control and Design, Design and EMI, Topologies, Wide Bandgap, and Modeling and Wireless Power Transfer.

The Plenary Session continues the tradition of addressing issues of immediate and long-term interest to the practicing power electronic engineer. The technical program includes papers of broad appeal scheduled for oral presentation. The various technical venues cover all areas of technical interest for the practicing power electronics professional. Industry Sessions presents information on current topics in power electronics from sources that would not otherwise present at APEC. The target audience for these sessions is also extended to include system engineers/architects and business-oriented people such as purchasing agents, regulatory agencies, along with other people who support the power electronics industry. RAP Sessions allow for dialogue among attendees and presenters.

Plenary session

The conference starts on the Monday, March 21, 1:15 – 5:00 pm, with the Plenary featuring six invited presentations from distinguished speakers coming from industry and research.

Alexander Gerfer, Managing Director and Chief Technology Officer of Würth Elektronik eiSos Group, Waldenburg/Germany, is the first speaken on **"Space M: The Magnetics Universe and Challenges".** We have a huge variety of inductors and transformers in the magnetics universe. Orders of magnitude in size and power, a large range of application frequencies into the MHz and hundreds of core materials. Is it any wonder that most designers find it hard to navigate through this deep cosmos to find the best solution for their design goal. This presentation will give a comprehensive overview of new, interesting design tools. It will highlight the importance of increased co-operation between research institutes, manufacturers and consultants to overcome existing design barriers. Solutions are around the corner: AI and 3D printing

Power Up – that is certainly the hope of APEC organizers at this year`s in-person event **Photo: AS**

will more and more help us, to build low loss and volume optimized magnetic components.

John H. Scott, Principal Technologist – Power and Energy Storage NASA Space Technology Mission Directorate, will talk about **"On the Moon to Stay: Challenges Presented to Power Electronics Technology by Sustained Operations on the Lunar Surface".** NASA's Artemis Program seeks not only to return humans to the Moon for the first time since the 1970's but also to provide the technological basis for infrastructure that will enable permanent and expanding scientific and industrial exploitation of the Lunar surface. The primary purpose of this infrastructure is to generate and distribute power to a diverse and growing range of scientific and industrial assets, and the keys to success for this function are power management and control circuits that are highly reliable and maintainable for a decade of operation in the extreme thermal, radiation, and dust environment of the Lunar surface. While various combinations of wide band gap semiconductors, electronic devices, circuit topologies, and shielding schemes have been successfully developed for mission environments ranging from low Earth orbit to the Jovian system, power management technology has not been optimized to meet the full combination of mission requirements for the Lunar surface. To accomplish this, NASA requests the dedicated focus of the power electronics industry.

"Energy Access: Challenges, Opportunities, and our Contributions", that is the subject of the third keynote to be given by Jelena Popovic, IEEE Empower a Billion Lives (EBL) II Vice-Chair and Associate Professor University of Twente/Netherlands and Liuchen Chang, IEEE Power Electronics Society (PELS) President and Professor Emeritus, University of New Brunswick, Fredericton/Canada. Ensuring universal, affordable and sustainable energy access is one of the biggest societal challenges of our time. Energy poverty has far reaching consequences on health, education and livelihoods for almost 1 billion people with no access to electricity and over 2 billion people with poor and unreliable access. Decentralized approaches, such as solar home systems and minigrids have emerged in response to the shortcomings of centralized grid extension, sparked start-up innovation and are increasingly being integrated in national electrification plans. However, affordability, scalability, quality, interoperability, business models, technology obsolescence and lifecycle sustainability remain challenges. This plenary talk will frame the energy access challenges, benchmark existing solutions, highlight opportunities for the power electronics community, and present the engagement of the IEEE Power Electronics Society with energy access. Flagship initiatives are IEEE Empower a Billion Lives, a recurring global competition aimed at fostering innovation to develop technically, economically and socially viable energy access solutions and IEEE Global Energy Access Forum, a platform to facilitate multistakeholder engagement in discussions on how rapid technology developments, forward leaning policies and new financing mechanisms intersect and can accelerate the development and deployment of scalable solutions for energy access.

Gideon van Zyl, Technical Fellow Advanced Energy, Fort Collins/USA, will talk about **"Driving Plasma: Advancing Power Conversion in Critical Semi and Medical Applications".** Plasma processing is well established and known in semiconductor wafer manufacturing and for creating highly engineered coatings in advanced industrial applications. The ability to precisely power and drive plasma loads has also enabled electrosurgical applications. For the power electronics engineer, plasma loads present unique challenges, including wide swings in load impedance, the highly nonlinear and time-varying nature of the load, arcing, and the difficulty in precisely measuring and controlling power delivery. In the semiconductor industry, higher etch rate requirements for 3D memory devices result in ever-increasing power being applied to bias the workpiece. This results in severe modulation of the plasma impedance creating problems for other generators that are also coupled to the plasma load. In medical applications, where a small plasma is created at the tip of a powered electrosurgical probe to cut and ablate tissue, challenging plasma impedance variations create the same challenge for power delivery and control. We will show how advances in power electronics devices, circuits, and measurement and control are enabling advanced plasma processing.

The **"History of PSMA Power Technology Roadmap: from AAA TripTik to Google Maps"**, will be revealed by Ritu Sodhi, PSMA Roadmap Committee, and Consultant Power Transistor R&D at ROHM. Our success as individuals, as companies, and as institutions, depends on anticipating and being equipped to deal with the future. To help the power electronics industry in this endeavor, PSMA published its first Power Technology Roadmap (PTR) in 1994 using a collaborative approach. A lot has changed since then in our industry and in the way that we do the roadmapping. Along with increased participation from the community, our methodology has adapted to the times to stay relevant, with an aim to provide wide ranging perspectives to the growth and evolution of power conversion technology. In this talk, we will walk down memory lane and track the evolution of the PSMA PTR –from a single, in-person, roundtable event in the early years to a multidimensional, multimedia, multiyear activity to track key trends across a broad variety of power conversion markets. See how the community anticipated industry trends such as efficiency, digital control and the shift from Silicon to wide bandgap materials. And revisit what we got wrong. The PTR will continue to evolve.

The last keynote covers **"Inverters for the Future Grid – Challenges and Opportunities"**, to be presented by Professor Deepakraj Divan, GRA Eminent Scholar, and Director, GT Center for Distributed Energy, ECE Georgia Institute of Technology. Hundreds of gigawatts of PV solar, wind and storage are being deployed globally on the grid every year. Over the next 5-10 years, millions of geo-dispersed inverters will replace the rotating synchronous generators that are the heart of today's grid. These inverters will have to work together collectively and autonomously to also form and sustain the grid as an ecosystem and will have to do so without causing stability issues or interacting with each other or with other grid elements. This will require new hardware, software and control principles. It will also drive the industry towards multiport power converters that are flexible, modular and scalable, and which can simultaneously and safely interface with PV solar, batteries, generators and loads, managing power flows between various sources/loads and ensuring stable operation under normal, transient and fault conditions. Fast-moving technologies, lagging standards, diverse communications protocols, cybersecurity issues, hundreds inverter vendors, and hundreds of grid codes to comply with, pose a very challenging set of issues – but they need to be solved soon. Availability of a next generation inverter for the future grid can be a key factor in addressing climate change and saving the only planet that we have.

After the keynotes the exhibition covering all major names will be opened.

Example session

Most of the sessions checked in the extensive program reveal that the majority come from academics with a high portion of Chinese authors, illustrating that the region far east has already catched up in power electronics technology.

As an example I have selected the session "T04 GaN/Silicon/Passive Devices" on the Tuesday morning with its abstracts.

The first paper **"Overvoltage Ruggedness and Dynamic Breakdown Voltage of P-Gate GaN HEMTs in High-Frequency Switching Up to Megahertz"** will be presented by Ruizhe Zhang from Virginia Polytechnic Institute and State University, Blacksburg/USA. This work developed a testbed for high-voltage GaN HEMTs enabling continuous overvoltage testing up to 1-MHz switching frequency. Two types of 600/650-V commercial p-gate GaN HEMTs were tested under overvoltage at an switching frequency up to 0.2-1 MHz. The Gate Injection Transistor showed a nearly frequency-independent dynamic BV, while the Schottky-type p-gate GaN HEMT showed a decreasing BV at higher, e.g., 120-V lower when Fsw increases from 2 kHz to 200 kHz. The behaviors were explained by the buffer trapping/de-trapping in two types of GaN HEMTs. This work unveils the true overvoltage margin of GaN HEMTs in high-frequency converters.

"Short-Circuit Protection for GaN Power Devices with Integrated Current Limiter and Commercial Gate Driver" is the subject of Davide Bisi, Member of Technical Staff at Transphorm Inc., Goleta, California/USA. He will demonstrate a short-circuit protection technology for GaN power devices paired with a commercial gate driver. The GaN power devices are equipped with integrated Short-Circuit Current Limiter (SCCL) to achieve a sufficiently long short-circuit withstanding time of 1.2 ?s at 400 V with a relatively small penalty in on-resistance (+0.2x). The gate-driver is equipped with desaturation detection (DESAT) and soft shutdown circuitry to achieve a fast protection response (less than 600 ns) with high noise immunity (tested up to 70 V/ns). The combination of GaN power devices with SCCL and a commercial gate driver with fast DESAT and high noise immunity allows short-circuit protection and fail-safe operation of GaN power electronics for additional robustness in motor drive applications.

"Thermal Design Considerations for GaN-Based Power Adapters with Multi-Heat Sources" are analyzed by Rahil Samani, University of Calgary/Canada. GaN transistors have paved the way to enable high power density and high efficiency in AC adapters. As power density increases and size reduces, more attention to thermal management across the components inside the adapter increases. This paper presents some general design rules for the thermal management of GaN-based AC adapters. Moreover, a mutual thermal resistance study is conducted to isolate the impact of heat sources on GaN. This enables the designers to prioritize the thermal optimization based on the contribution of each heat source. These analyses are conducted using finite element method (FEM).

A **"Characterization of GaN HEMT Under short-Circuit Events"** will be performed by Javier Galindos from CEI UPM in Spain. In this digest, an analysis of the failure mechanisms and degradation indicators of GaN HEMTs is presented. Understanding how this technology fails is critical, especially for space applications. Due to radiation, a common failure mechanism in space applications for GaN devices is the short-circuit event. A systematic method is proposed to perform on-board measurement of the critical electrical parameters and analyze the behavior of DUTs under short-circuit failures to build a reliability model. A setup to characterize GaN HEMTs devices is developed, and multiple tests at different conditions have been performed. The reliability challenge of GaN devices could be addressed by having on-board, in-system prognostics and device health monitoring techniques to predict device failures well ahead of time.

"Short Circuit Capability Design and Thermal Management for High Efficiency Solid-State Contactor" will be introduced by Yuzhi Zhang, ABB APEX/USA. This paper introduces the design of short circuit capability and thermal management of a solid-state contactor for high efficiency ac motor application. This solid-state contactor employs a hybrid combination of semiconductor devices which involves Thyristors (SCR) and Field Effect Transistors (FET) in a parallel arrangement. The key design factors such as wire bond, semiconductor short circuit capability, power module design, and heatsink design are presented. The performance of the thermal and short-circuit of the proposed solid-state contactor are validated through the circuit simulation and full power experimental validation for a 480 V, 7.5 hp induction motor.

"Operation and Characterization of Low-Loss Bidirectional Bipolar Junction Transistor" is the subject of Alireza Mojab, Director of Device Engineering at Ideal Power Inc./USA. A detailed operation and characterization of the recently developed B-TRAN as a very low-loss power semiconductor device is provided in this paper. DC characterization of B-TRAN has been already performed by probing the device on wafer-level setup and will be verified again at package-level measurement. The breakdown voltage, on-state voltage, and current gain (?) were measured to be about 1280 V, 0.2-0.5 V, and 3, respectively. A special 4-terminal TO package with double-sided cooling capability and a bidirectional driver have been designed and developed for the product sampling. Switching characterization will be performed on the TO package, using the designed bidirectional driver, and transient performance parameters will be reported.

"K-TEM: KEMET Thermal Expectancy Model" will be explained byDario Zuffi, R&D Product Engineer at KEMET Bologna/Italy. The KEMET Thermal Expectancy Model is an effective tool for estimating the thermal behavior of film capacitors under different electrical conditions. The applied ripple current or ripple voltage at different frequencies and ambient temperatures are used as inputs to provide a thermal map among 3D surfaces through an element finite analysis of the capacitor. The thermal expectancy model gives a temperature map considering different convection and cooling conditions and steady-state or transient analysis.

Finally, a **"Paralleled SiC MOSFETs DC Circuit Breaker with SiC MPS Diode As Avalanche Voltage Clamping"** is proposed by Taro Takamori, Tokyo Metropolitan University/Japan. This paper proposes a solid-state DC circuit breaker consists of SiC MOSFETs and SiC diode using avalanche voltage clamping. To realize a solid-state DC circuit breaker it is necessary to reduce

All major names of the power electronics industry will attend APEC 2022 as with the 2019 event **Photo: AS**

conduction loss and to increase breaking capability. Parallel connection of power semiconductor devices is the most suitable solution to those issues. The proposed solid-state DC circuit breaker can be clamped to SiC MPS diode with high avalanche tolerance and robust characteristics under repetitive avalanche events. Experimental results show that the proposed solid-state DC circuit breaker can interrupt the 50-A current under UIS tests circuit with a 400-V DC distribution system.

RAP sessions

On the Tuesday, March 22, the so-called interactive RAP-sessions will take place in the afternoon from 5:00 - 6:30 pm.

Session 1 **"Switch Capacitor vs. Inductor Based Topologies"** feature the panelists Robert Pillawa – *University of California Berkley*, Loai Salem – *University of California Santa Barbara*, Jose Cobos – *Universidad Politécnica de Madrid*, Roger Chen – *Texas Instruments*, Nicola Femia – *University of Cassino,* and FC Lee – *Virginia Tech*. In the search for higher power density, higher efficiency, and lower cost, power supply designers have pursued a wide range of alternative topologies. The panelists for this session have explored different topologies that are centered on either switched capacitor structures or inductors. Come explore the benefits of each approach and the applications where they can provide distinct benefits, and learn from experts about their vision for the future of high-density power conversion.

Session 2 **"Challenges and potential of AI based design vs. conventional design"** feature Alfonso Martínez – *Frenetic*, Minjie Chen – *Princeton University*, Joao Pinto – *Oakridge National Labs,* Alex Huang – *University of Texas at Austin*, Dushan Broyevich – *Virginia Tech*, and Dragan Maksimovic – *University of Colorado Boulder*. The past few years have seen a remarkable growth in artificial intelligence in many applications. Power electronics is no exception in that researchers are investigating new ways to model and design power electronics using some form of artificial intelligence. This panel is comprised of several thought leaders in the area of power electronics design – both utilizing AI techniques and without. They will discuss aspects of power electronics design that AI can improve or at least provide keener insight, and where traditional design methods remain superior or necessary.

Session 3 **"Magnetics in IC vs. Magnetics in PCB"** feature Matt Wilkowski – *Enachip*, Francesco Carobolante – *IoTissimo*, Alex Hanson – *University of Texas at Austin*, P. Markondeya Raj - *Florida International University*, Doug Hopkins – *North Carolina State University,* and Khurram Afridi – *Cornell University.* As the journey to miniaturize the power supply and quest for higher efficiency continues, integration of magnetics creates new challenges and opportunities. To this effect a considerable amount of innovation has been done to integrate magnetics in ICs and PCBs. This includes Magnetics implemented on chip, in package, embedded in PCB, on PCB and new magnetics technologies. Each approach has its own tradeoffs in terms of efficiency, size, power delivery, reliability, cost and EMI. What would be the right approach for your application?

Thus APEC will provide an overview on current and future trends in power electronics. Hopefully this event can be held as intended. **AS**

Focus on Power Integration

The 12th International Conference on Integrated Power Electronics Systems (CIPS) will be held from March, 15 – 17 in Berlin, Germany. For those of you who cannot attend the conference in-person, a live streaming is provided as well. The conference is chaired by Leo Lorenz and Thomas Harder from the European Center of Power Electronics (ECPE).

In the next decades, power electronic system development will be driven by energy saving systems, intelligent energy management, power quality, system miniaturization and high reliability. Monolithic and hybrid system integration will comprise advanced device concepts including wide bandgap devices, new packaging technologies and the overall integration of actuators/drives (mechatronic integration).

CIPS is focused on the main aspects such as

- Éassembly and interconnect technology for power electronic devices and converters
- Éintegration of hybrid systems and mechatronic systems with high power density
- Ésystems' and components' operational behaviour and reliability

Basic technologies for integrated power electronic systems as well as upcoming new important applications will be presented in interdisciplinary invited papers.

Conference topics

Applications are wide spread over areas such as transportation; Épower electronics in the grid, in particular for renewable energy such as wind and solar as well as drives and power supplies.

1. Components to be integrated

- advanced silicon devices and monolithic integration
- wide bandgap devices and monolithic integration
- gate drivers
- passive components
- sensors and actuators

2. General aspects of packaging

- system and component packaging
- assembly concepts, embedded power, 3D integration
- new materials and interconnects
- additive manufacturing
- high voltage insulation
- design for high temperature applications
- cooling concepts
- interface materials
- multidomain CAD (electrical, thermal, mechanical, chemical) as design tool

3. Power packages and modules

- bare chip packaging
- discrete semiconductor packages
- hermetic semiconductor packages
- power semiconductor modules
- heterogeneous integration, power system-in-package

4. System and application aspects

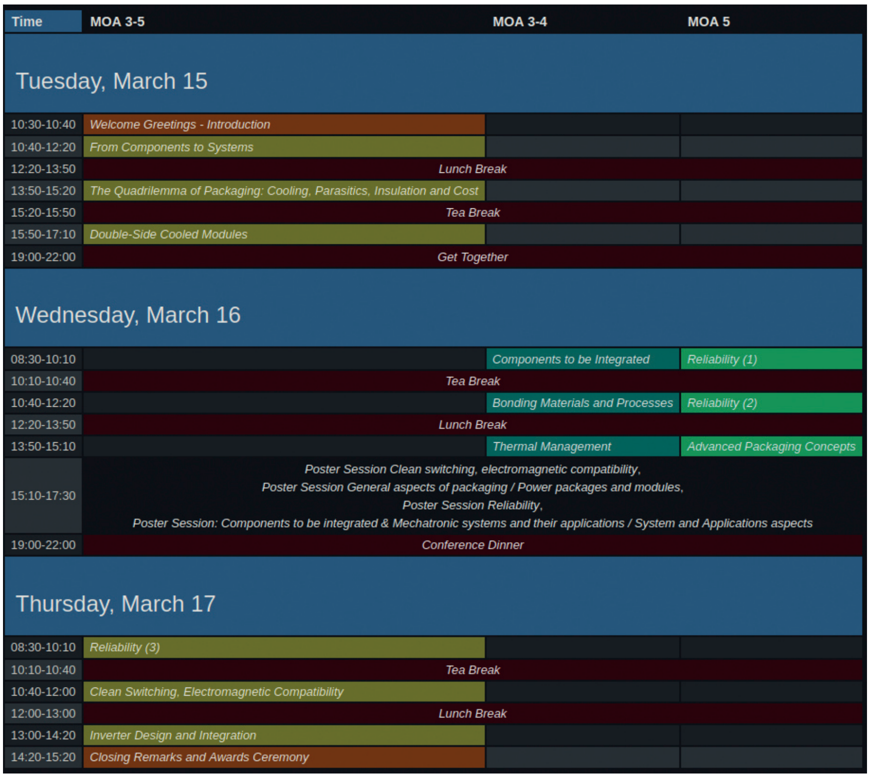
- mechatronic systems and their applications
- integration of power electronics into electric machines
- challenges of fast switching on circuit/system level – winding insulation, bearing currents, earth leakage, touch current, ...
- integration with sensors and actuators
- overall system optimisation

5. Reliability and availability

- r|eliability requirements, mission profiles
- robustness validation, physics of failure, failure analysis modelling and simulation of lifetime
- intelligent reliability testing
- prognostics and health management
- fault tolerant designs and applications

6. Clean switching, electromagnetic compatibility (EMC)

- parasitics and interferences; design for low inductance, coupling capacity
- electrodynamically optimised design
- optimised control through driving scheme filters



Time	MOA 3-5	MOA 3-4	MOA 5
Tuesday, March 15			
10:30-10:40	*Welcome Greetings - Introduction*		
10:40-12:20	*From Components to Systems*		
12:20-13:50	*Lunch Break*		
13:50-15:20	*The Quadrilemma of Packaging: Cooling, Parasitics, Insulation and Cost*		
15:20-15:50	*Tea Break*		
15:50-17:10	*Double-Side Cooled Modules*		
19:00-22:00	*Get Together*		
Wednesday, March 16			
08:30-10:10		*Components to be Integrated*	*Reliability (1)*
10:10-10:40	*Tea Break*		
10:40-12:20		*Bonding Materials and Processes*	*Reliability (2)*
12:20-13:50	*Lunch Break*		
13:50-15:10		*Thermal Management*	*Advanced Packaging Concepts*
15:10-17:30	*Poster Session Clean switching, electromagnetic compatibility,* *Poster Session General aspects of packaging / Power packages and modules,* *Poster Session Reliability,* *Poster Session: Components to be integrated & Mechatronic systems and their applications / System and Applications aspects*		
19:00-22:00	*Conference Dinner*		
Thursday, March 17			
08:30-10:10	*Reliability (3)*		
10:10-10:40	*Tea Break*		
10:40-12:00	*Clean Switching, Electromagnetic Compatibility*		
12:00-13:00	*Lunch Break*		
13:00-14:20	*Inverter Design and Integration*		
14:20-15:20	*Closing Remarks and Awards Ceremony*		


AIR-TECH EXHIBITION 2022
COMPRESSED AIR • VACUUM • GENERATORS
DRIVES & CONTROLS 2022
THE AUTOMATION POWER TRANSMISSION & MOTION ENGINEERING EVENT
FIVE SHOWS UNDER ONE ROOF
OVER 400 EXHIBITORS
OVER 13,500 VISITORS
THREE-DAY SEMINAR PROGRAMME
SMART INDUSTRY EXPO 2022
THE FUTURE OF INTEGRATED AUTOMATION
FLUID POWER & SYSTEMS 2022
The Exhibition for Hydraulics & Pneumatics Industries
PLANT & ASSET MANAGEMENT 2022

pcim
EUROPE

Nuremberg, 10 – 12 May 2022

PCIM Europe 2022 – Analog And/Or Digital

The power electronics community can come together (live) again in Nuremberg from 10 – 12 May 2022. This year, the PCIM Europe will be complemented by a digital offering.

Exhibitors, visitors, attendees and speakers can also network, learn about the latest industry trends and expand their knowledge on the digital event platform as part of the hybrid event concept. The on-site event in Nuremberg is accompanied digitally beforehand, in parallel and afterwards. By linking the digital and analog worlds, organizer Mesago aims to create a holistic event experience that provides insight and exchange and offers all event participants around the world the chance to join the power electronics community.

Like every year, trend topics of the industry will be addressed on specific exhibition areas. One of the highlights will be the Batteries & More - Energy Storage Pavilion. The demand for stable energy storage systems is growing constantly. Power electronics as the heart of a stationary energy storage system plays an important role here. With the Batteries & More - Energy Storage Pavilion, a special platform for presentations and professional exchange will be dedicated to this topic. A special focus will be on the application area of "Batteries".

Suppliers of power electronics, who are in the product group "Power Quality and Energy Storage", will be presenting as part of the joint stand and Industry Forum. The Industry Forum is a platform for lectures, presentations and panel discussions on research and development topics. Here energy storage will also feature as a topic in the conference program.

Conference program

Over 300 lecture and poster presentations have been selected out of the vast amount of submitted papers. The conference program offers keynotes at the beginning of each conference day, special sessions and a range of user-oriented seminars and tutorials on the two days prior to the conference.

Keynotes

The first keynote on the Tuesday covers **"Hydrogen – Key Element to Achieve Net Zero CO_2"** by Jürgen Rechberger, AVL List, Austria. The energy transition to a net zero CO_2 society is widely recognized as a monumental challenge. Austria is in the preferred condition to have already a renewable energy production of 70 % but only related to electricity. If the complete primary energy demand is considered, only about 30 % are from renewable resources (incl. biogenic and geothermal). For all developed countries around the world, mobility and industry are the main challenges for decarbonization. AVL has created a study for energy end-use in a fully decarbonized energy scenario towards 2050. In this scenario, the electricity consumption will more than double compared to 2019 levels. This electricity demand can not be met by locally harvested renewables and as today Austria will stay an energy importer. In an optimistic scenario for energy import hydrogen could be available for as low as 2 €/kg (equivalent to 6 cent(€)/kWh). In such a scenario hydrogen production will be a key technology for decarbonization. AVL is since 2002 heavily involved in hydrogen technologies development from PEM stacks and systems for automotive, marine, rail and aviation applications to SOFC power-generation solutions to hydrogen production technologies based on PEM and Solid Oxide electrolysis. Various of these developments will be shown, together with industry trends and the role of hydrogen in the future mobility & energy system.


Jürgen Rechberger

The second keynote on the Wednesday morning is entitled **"Power Electronics for a Future Sustainable Society"** to be presented by Ichiro Omura, Kyushu Institute of Technology, Japan. Fifty years after 'The Limits to Growth' the famous report from the Club of Rome, we are now forced to recognize 'the dimensions of our finite planet' in terms of CO_2 emissions. In this presentation, he will explore the critical boundary in the relationship between economic growth and CO_2 emissions by introducing simple model, and recognize the gap between the net zero emission scenario and the current situation. He will then discuss the role that power electronics technology development should play in bridging this gap.


Ichiro Omura

The Thursday keynote **“From State of the Art to Future Development Trends of Power Supply Technologies”** will be given by Peter Wallmeier, Senior Director, Delta Energy Systems, Germany. The application of Switched Mode Power Conversion technology started in consumer electronics and information technology more than 40 years ago. It spread out to almost all industries over the past decades to benefit from higher power conversion efficiency, lighter weight and increased power density at lower costs. The presentation will review the technology innovations increasing the conversion efficiency from below 75 % to now 98 % at power densities from initial 0.2 kW/l to now 6 kW/l over the past decades. It will outline future trends to achieve ultra-efficient and ultra-dense power conversion technology. This ”innovation-rallye” from past to future is detailed out showing the persistent conflict between higher conversion frequency to reduce the size of passives and magnetics and at the same time increased switching losses, ZVS/ZCS circuit losses, eddy current and hysteresis losses in the magnetics.


Peter Wallmeier

Special sessions

On the Tuesday May 10. 11:00 – 12:30, after the opening and award ceremony, the first Special Session on **“Cognitive Power Electronics”** will take place.

The opening paper is entitled **0**, and will be presented by Nicolas Lehment from NXP Semiconductors (www.nxp.com). Evolving sensing and AI-compute capabilities realized in modern silicon products enable novel architectural choices in embedded controllers and the power systems they govern. This contribution explores the impact of high precision analog measurement when paired with embedded AI and emerging new network technologies. NXP considers both the individual elements realizing these capabilities and the overall architectures enabled by them. To show the resulting impact on overall system design, the concepts will be illustrated with the example of an industrial robot.

“Cognitive Power Electronics 4.0 –An Enabler for Smart Systems”, will be introduced by Martin Schellenberger from Fraunhofer Institute for Integrated Systems and Device Technology IISB, Germany (www.iisb.fraunhofer.de). Power electronic devices are at the heart of modern electrical and electronic equipment and applications in households, industrial plants or in mobility. They convert electrical energy, switch loads, control electrical drives and much more. For this purpose, they continuously record and frequently control parameters such as current, voltage and their change over time. When combined with artificial intelligence, such intelligent power electronics evolve to what we call “Cognitive Power Electronics 4.0” - an enabler for the aforementioned systems to become a smart energy network, a smart production plant, or a smart electric motor. At Fraunhofer IISB, the new research field “Cognitive Power Electronics 4.0” (CPE4.0) was established to develop power electronic converters that can be used as intelligent edge devices and are able to make intelligent decisions regarding the connected system - not least in the context of smart drives or Industry 4.0.

Cognitive Power Electronics for Smart Drives in Unmanned Aerial Vehicles, are presented by Georg Roeder, also from Fraunhofer IISB. Unmanned aerial vehicles (UAV) with electric propulsion rely, amongst other conditions, on the motor and the rotor for safe operation. The propulsion system can be exposed to harsh operating conditions, which poses stress to the motor bearings, typically limiting the service interval of the whole UAV. A frequent estimation of bearing condition can help to reduce maintenance efforts. The solution proposed is based on the measurement of the motor phase currents, and a machine learning approach based on manifold learning to detect bearing faults as anomalies from healthy motor states.

“Modular ultra-low-power IoT-Core – Bridging the gap between power electronics and distributed sensor networks”, is the title of the fourth paper given by Carsten Brockmann from Fraunhofer IZM (www.izm.fraunhofer.de). In this paper, the authors present an innovative ultra-low-power IoT-Core that can be used as an extension for efficient DC/DC converters. The module equips the overall system with computation and communication capabilities for Industry 4.0 and IoT applications without adding significant power requirements. The research focuses on optimizing energy consumption by taking an overarching view of hardware and software at the system level. In the active state, the IoT-Core can adjust its power consumption at runtime by matching the application demands to the existing energy budget. In sleep state, the module uses a novel wake-up receiver in the 868 MHz frequency band with an average power consumption of 3.5μW, allowing the system to wake up in 32 ms. The results are demonstrated on a DC/DC converter, with an efficiency of up to 99.8 %, which uses the plug-and-play IoT-Core to become a smart device that can save additional energy when being in idle mode.

In parallel an other Special Session **“Advanced Measurement Technology in Power Electronics”** covering four papers is taking place.

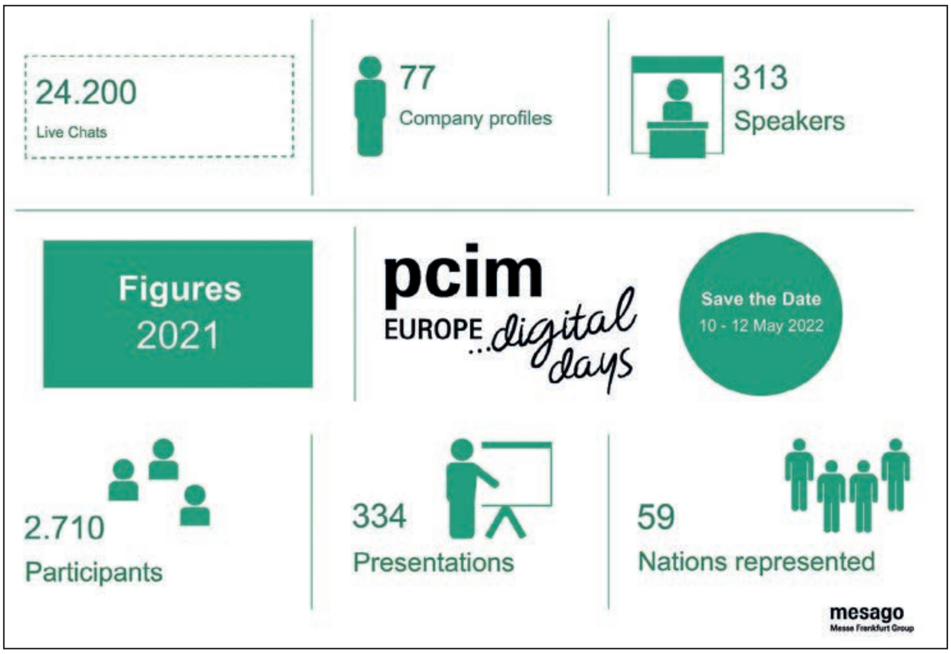
The first **“Common-Mode / Differential-Mode Noise Separation Using Oscilloscopes for More Efficient EMC Filter Design”** is presented by Markus Herdin, Rohde&Schwarz, Germany. Nowadays, conducted emissions testing often happens already as pre-compliance test performed during development phase. In this case, the designer can obtain an early feedback whether the EMC filter design has to be optimized. In most cases, adjustments to the input filter are necessary because of passive component value variations and limitations in the accuracy of simulations done during the filter design process. For an effective iterative filter design process, the designer needs to know some details on the noise spectrum, in particular whether the noise is generated by a common mode source or by a differential mode source. While a separation of common-mode and differential-mode noise can be done by external combiners, it is also possible to do this using two input channels of an oscilloscope without any additional combiner hardware. Calculating the sum and difference signals after A/D conversion and converting into spectral domain via FFT directly delivers common-mode and differential-mode noise. In this presentation this measurement method as well as practical aspects and limitations will be discussed. Finally, we also the method by showing measurement results with different common-mode and differential-mode filter components will be verified.

“Probing Techniques for GaN Power Electronics: How to Obtain 400+ MHz Voltage and Current Measurement Bandwidths without Compromising PCB Layout” by Harry Dymond from the University of Bristol/GB (www.bristol.ac.uk) are introduced in the second paper. PCB layout critically influences the performance of wide-bandgap power electronic circuits, in terms of switching speed, overshoots, ringing, and generated EMI. Typically, low-impedance layout of gate-drive loops and switching cells is vital for performance. This paper briefly examines the bandwidth needed for measurement of GaN switching waveforms, and the circuit impedances required for adequate performance. This leads to many high-bandwidth voltage and current probing methods not being compatible with the circuit-layout requirements. The paper then presents PCB layout and probing techniques that achieve both high-fidelity, wide-bandwidth (400+ MHz) voltage and current measurements, and clean, efficient switching.

“Using Near Field Probes in Electronic Circuits” by the University of Zaragoza, and **“How IsoVu Probe Breaks the Barrier of Wide Bandgap Dynamic Testing”** by Tektronix, are the subjects of the other papers within this session.

The **“DC-DC Converters”** session covering four papers also runs between 11:00 and 12:30 on May 10.

A high-power density GaN converter introduces Michael de Rooij from EPC/USA with the paper **“Exceeding 5 kW/in3 Power-Density in a 48 V to 12 V LLC Resonant DC-DC Bus Converter Using GaN FETs”**. High power density converter design requires special attention to lowering total system losses as well as superior thermal management to be able to extract and remove the generated heat in a very limited area. Recently, a 1kW high efficiency high power density LLC converter was presented achieving a power density of 1.227 kW/in^3 peak efficiency of 97.5 % and a full load efficiency of 96.7 %. Analysis of various loss components along with the latest generation of GaN FETs, show promising performance improvement to further shrink the size of the converter presented in earlier work. Hence, this paper will present an ultra-high power-density converter with the full load power density of greater than 5 kW/in^3. The paper will explain the steps taken to achieve the ultra-high power-density.



The second paper describes a **"500 kHz SiC- and GaN-Based Dual Active Bridge with Voltage Conversion Between 48 V and 650 V"** by Patrick Lenzen, TU Dortmund University/Germany. Bidirectional DC/DC converters are used in many applications. The DC/DC converters should be compact, which can be achieved with high frequencies. This paper presents a 2 kW Dual Active Bridge converter operating at 500 kHz with a high conversion ratio of 15. A peak efficiency of 96 % is reached. The converter uses wide-bandgap semiconductors on the input and output side, which leads to a high dv/dt and reduces switching losses at hard-switching operation points. However, ringing occurs at low power which can be reduced with the presented asymmetric dead time between the low- and high-side switch. Both SiC and GaN devices are used to handle the high voltage on the DC bus as well as the low voltage of the supercapacitor. Moreover, the switches allow switching frequencies of 500 kHz.

The two other papers are entitled **"Clamped Topology Morphing of the Isolated Full-Bridge Converter for Reduced Rectifier Semiconductor Blocking Voltages and Transformer Volume"** by Paderborn University/Germany, and **"3-Level Switched Capacitor Resonant Converter-Based DCX"** by Federal University of Santa Catarina/Brazil.

More in our next issue. **AS**

Report on GaN Reliability and Physics-Based Models to Project Device Lifetime

EPC released recently its Phase-14 Reliability Report, documenting the strategy used to achieve a remarkable field reliability record. The rapid adoption of GaN devices in many diverse applications calls for the continued accumulation of reliability statistics and research into the fundamental physics of failure in GaN devices. The Phase-14 Reliability Report presents the strategy used to measure and predict lifetime based upon tests that force devices to fail under a variety of conditions.

GaN devices have been in volume production since 2010 and have demonstrated very high reliability in both laboratory testing and customer applications, such as lidar for autonomous cars, 4G base stations, vehicle headlamps, and satellites to name just a few. Test-to-fail testing can isolate intrinsic failure mechanisms and their behavior over all stress conditions. This information can then be used with confidence to predict device lifetime under a wide range of actual mission profiles. "The release of EPC's Phase-14 reliability report represents the cumulative experience of millions of devices and five generations of technology to lead to a deeper understanding of the behavior of GaN devices over a wide range of stress conditions," said Alex Lidow, CEO and co-founder of EPC.

Why test-to-fail in addition to standard qualification testing?

Standard qualification testing for semiconductors typically involves stressing devices at or near the limits specified in their datasheets for a prolonged period of time, or for a certain number of cycles. The goal of qualification testing is to have zero failures out of a relatively large group of parts tested.

This type of testing is inadequate since it only reports parts that passed a very specific test condition. By testing parts to the point of failure, an understanding of the amount of margin between the datasheet limits can be developed, and more importantly, an understanding of the intrinsic failure mechanisms can be found. By knowing the intrinsic failure mechanisms, the root cause of failure, and the behavior of this mechanism over time, temperature, electrical or mechanical stress, the safe operating life of a product can be determined over a more general set of operating conditions

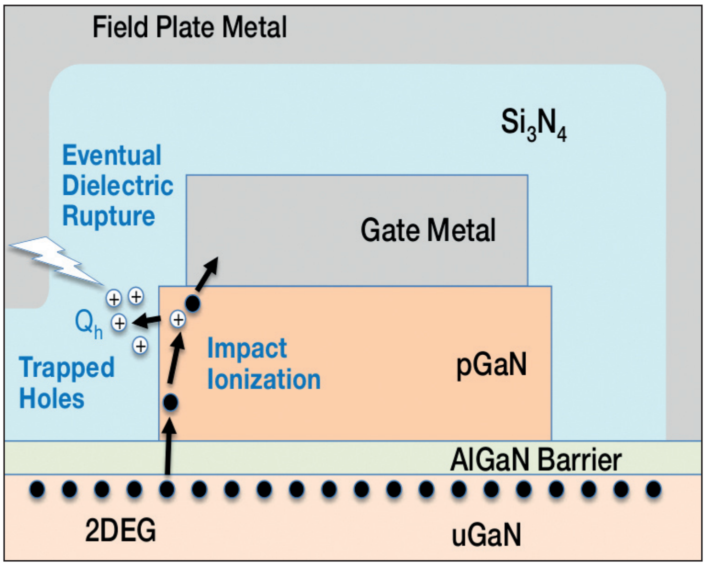


Figure 1: Schematic of gate failure mechanism in an GaN transistor. A small current of electrons tunneling through the AlGaN front barrier enter the pGaN gate region, where they are accelerated in high fields toward the gate metal. A small percentage gain sufficient energy to cause impact ionization,particularly near the gate metal. The resulting holes are mostly swept away, but some trap and accumulate in the Si_3N_4 dielectric layer. Once sufficient trapped hole density, Q_h, has accumulated, fields concentrate in the dielectric, ultimately leading to catastrophic rupture.

As with all power transistors, the key stress conditions involve voltage, current, temperature, and humidity, as well as various mechanical stresses. There are, however, many ways of applying these stress conditions. For example, voltage stress on a GaN FET can be applied from the gate terminal to the source terminal (V_{GS}), as well as from the drain terminal to the source terminal (V_{DS}). These stresses can be applied continuously as a DC bias, they can be cycled on-and-off, or they can be applied as high-speed pulses. Current stress can be applied as a continuous DC current, or as a pulsed current. Thermal stresses can be applied continuously by operating devices at a predetermined temperature extreme for a period of time, or temperature can be cycled in a variety of ways.

By stressing devices with each of these conditions to the point of generating a significant number of failures, an understanding of the primary intrinsic failure mechanisms for the devices under test can be determined. To generate failures in a reasonable amount of time, the stress conditions typically need to significantly exceed the datasheet limits of the product. Care needs to be taken to make certain the excess stress condition does not induce a failure mechanism that would never be encountered during normal operation. To make certain this is not the case, the failed parts need to be carefully analyzed to determine the root cause of their failure.

Only by verifying the root cause can a true understanding of the behavior of a device under a wide range of stress conditions be developed. It should be noted that, as more understanding of intrinsic failure modes in eGaN devices is gained, two facts have become clear; eGaN devices are more robust that Si-based MOSFETs, and MOSFET intrinsic failure models are not valid when predicting eGaN device lifetime under extreme or long-term electrical stress conditions.

Physics-Based Derivation of Gate Lifetime Model

A host of basic experiments aimed at clarifying the root cause of gate failure were conducted. For the lowest voltage legs, the total stress period exceeded 2000 hours, allowing the generation of more failures and tightened statistical confidence intervals. In addition, the breakdown strength of the of Si3N4 dielectric layer was thoroughly characterized, using dedicated test structures and alternating field direction. Finally, electro-luminescence (EL) studies were conducted on devices to understand the dynamics in time leading up to catastrophic gate rupture.

As a result of these collective observations, a multi-step process was theorized to be responsible for gate failure at high V_{GS}. This process is depicted schematically in Figure 1. In the first step, electrons are injected into the pGaN gate layer from the 2DEG. They are injected via tunneling or thermionic emission over the AlGaN hetero-barrier. Once inside the pGaN layer, the electrons gain energy rapidly from the electric field, with some gaining sufficient energy to cause impact ionization. This leads to the generation of electron-hole pairs, particularly in the high field region just under the gate metal.

In the second step of this process, holes move away from the gate metal under the influence of the field. Near the sidewall of the gate, a certain fraction of holes scatter into the Si_3N_4 dielectric, where they become trapped in deep states. This process is aided by the fact that the Si_3N_4 /GaN interface has a Type II staggered band alignment, whereby the valence band maximum in Si_3N_4 is higher than in GaN. This means holes generated in GaN near the interface have no (or low) barrier for emission into the dielectric.

In the final step of this process, holes become trapped in the dielectric, leading to a growing positive charge density Q_h. This charge, in turn, leads to an increasing electric field in the dielectric between the metal field plate and gate metal in the vicinity of the gate sidewall. Once this charge density reaches a critical density (Q_c), the dielectric ruptures, leading to the kind of catastrophic damage near the sidewall observed in failure analyses of gate failures.

Stress on the drain

One common concern among GaN transistor users is dynamic on-resistance. This is a condition whereby the on-resistance of a transistor increases when the device is exposed to high drain-source voltage (V_{DS}). The traditional way to test for this condition is to apply maximum-rated DC V_{DS} at maximum-rated temperature (typically 150°C). If there are no failures after a certain amount of time – usually 1000 hours – the product is considered good.

The dominant mechanism causing the on-resistance to increase is the trapping of electrons in trap-states near the channel. As the trapped charge accumulates, it depletes electrons from the two-dimensional electron gas (2DEG) in the ON state, leading to an increase in $R_{DS(on)}$. By applying DC V_{DS} at maximum temperature, the electrons available to be trapped come from the drain-source leakage current, IDSS. In order to accelerate trapping, devices can be taken to voltages above their rated maximum.

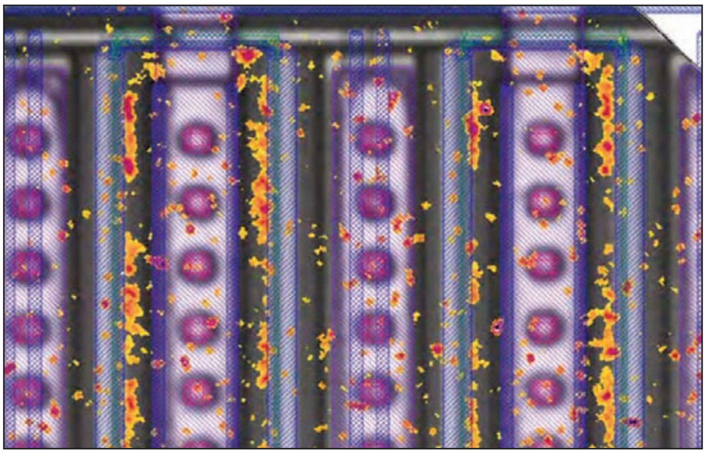


Figure 2: A magnified image of an EPC2212 eGaN FET showing light emissionin the 1–2 μm wavelength range (SWIR) that is consistent with hot electrons. The SWIR emission (red-orange) has been overlaid on a regular (visible wavelength) microscope image

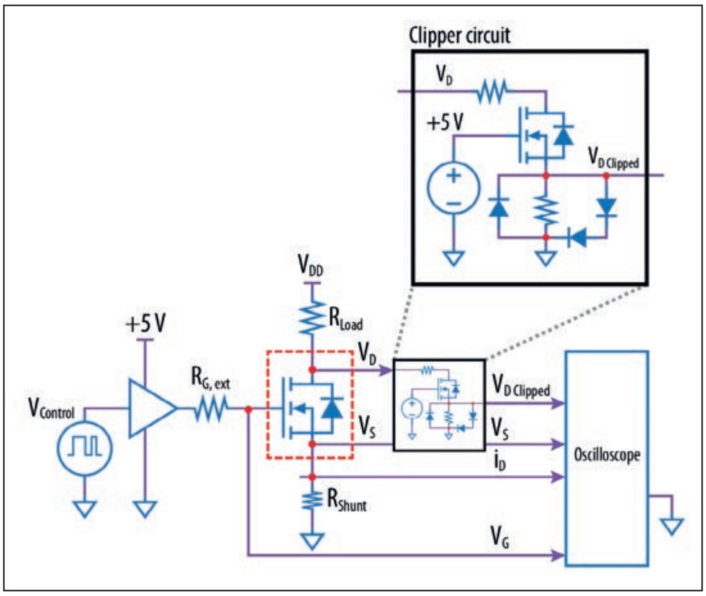


Figure 3: Hard-switching circuit consistent with JEDEC JEP173

Figure 2 is a magnified image of an EPC2016C GaN transistor showing thermal emissions in the 1–2 μm optical range. Emissions in this part of the spectrum are consistent with hot electrons and their location in the device is consistent with the location of the highest electric fields when the device is under drain-source bias.

Knowing that hot electrons in this region of the device are the source of trapped electrons, a better understanding of how to minimize the dynamic on-resistance can be achieved with improved designs and processes. By understanding the general behavior of hot electrons, their behavior over a wider range of stress conditions can be generalized.

In addition, by providing more hot electrons, the trapping mechanism can be accelerated. To accomplish this, the circuit shown in Figure 3 that pushes high IDSS through the device at maximum rated V_{DS} was created. In other words, instead of just using the leakage current generated by DC bias at high temperatures as the source of electrons that can get trapped, orders of magnitude more trapping candidates can be generated independent of temperature by making a switching circuit such as shown in Figure 3, one of the proposed hard-switching topologies by JEDEC JEP173.

Continuous hard switching

The resistive hard-switching system was used to test six samples of EPC2218

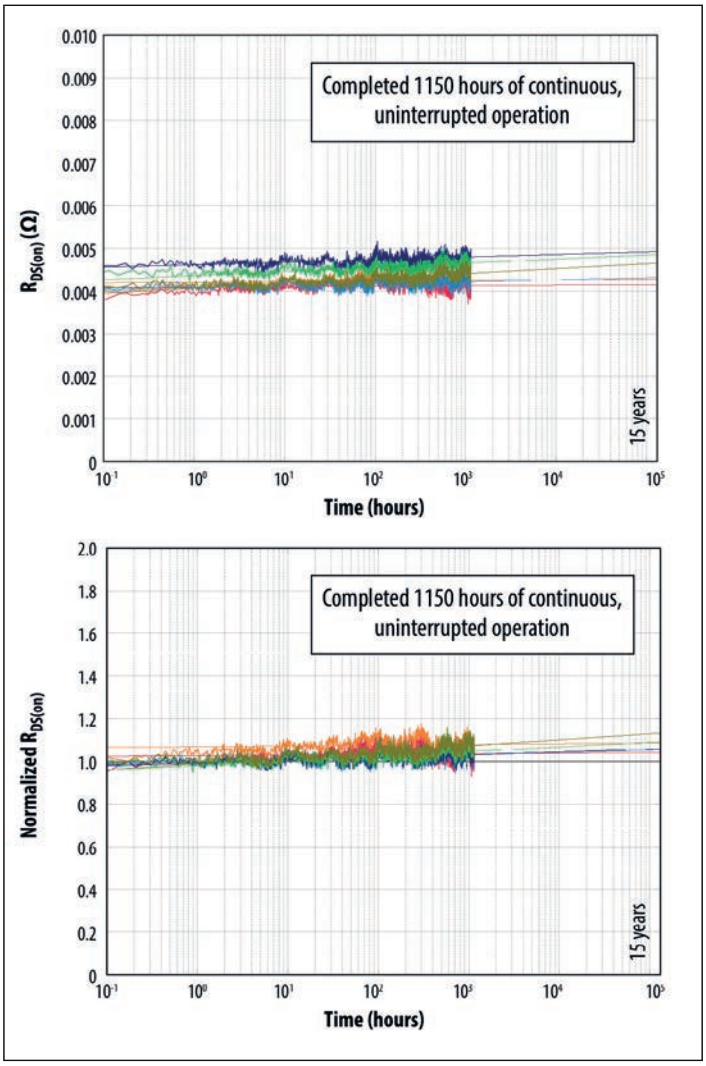


Figure 4: Long-term dynamic $R_{DS(on)}$ for six samples of EPC2218 eGaN FETs under continuous resistive hard-switching operation for over 1000 hours at ambient temperature and a bias of 100 V. The graph on the top shows $R_{DS(on)}$ versus Time, while the bottom graph shows $R_{DS(on)}$ normalized to its value after the first 10 minutes. Note that even over 1000 hours of operation, $R_{DS(on)}$ does not deviate from a simple log(time) growth dependence

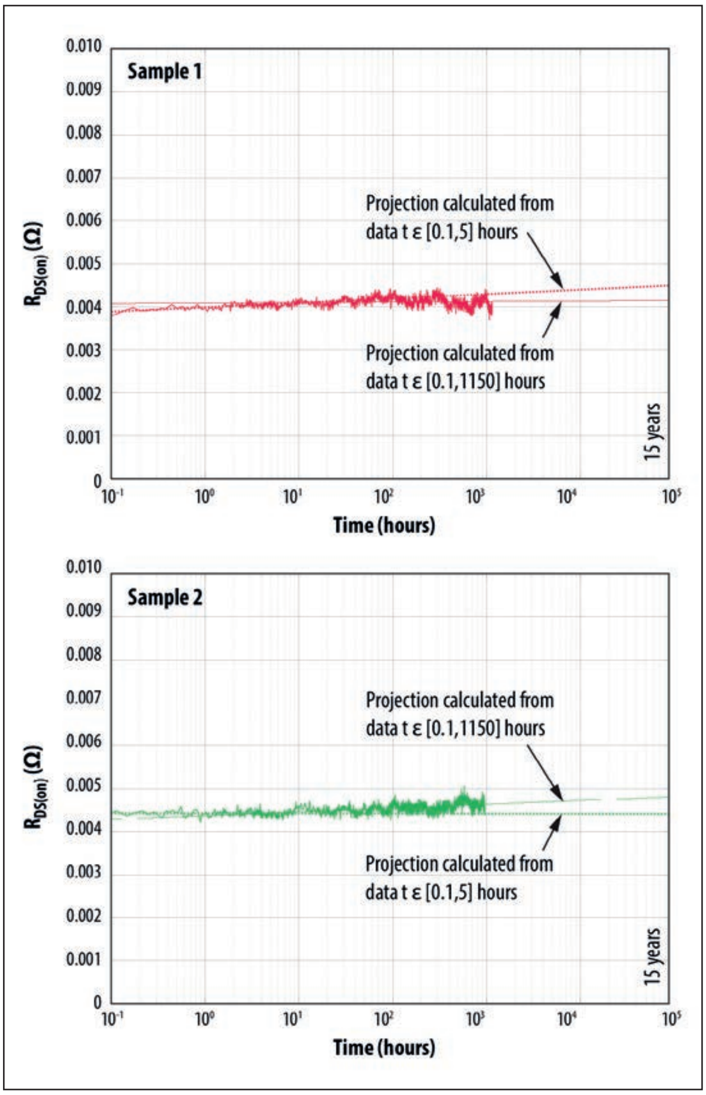


Figure 5: Comparison of log(time) fits to the RDS(on) data, where the dashed line represents the fit over the first 5 hours, while the solid line represent the fit over the full 1150 hours. Data for two samples of EPC2218 are shown. Note that the short-term fit has a similar projection to the long-term fit, with small random differences of ± 10% on the 15 year projection

GaN transistors simultaneously for over 1000 hours of continuous operation. The purpose of this test is to show that the charge trapping mechanism responsible for a long-term increase of $R_{DS(on)}$ follows a log(time) trend. If this trend is maintained over the long-term, then data from the first few hours can be used to project the expected $R_{DS(on)}$ after 10 or 15 years. Figure 4 shows the normalized $RD_{S(on)}$ over time of all the samples under test, and Figure 5 shows the difference between the line fits using either the first five hours of data, or the full 1150 hours.

The main source of error in the five-hour line fits are small temperature changes in the ambient temperature. These (random) temperature fluctuations tend to cancel out as the length of the test increases. Nevertheless, the short duration and long duration tests agree to within 10 % on the projected $RD_{S(on)}$ after 15 years. This lends credence to the idea that short-term data collection (over a few hours) can be used to accurately project long-term dynamic $R_{DS(on)}$ behavior. This log (time) extrapolation is valid when the changes in $R_{DS(on)}$ are relatively small. When the changes are larger, the case where a sizeable percentage of the available 2DEG electrons are trapped, there needs to be a more refined extrapolation.

Inductive versus resistive hard switching

Designers have raised concerns that resistive hard switching is not truly representative of the kind of hot-carrier stress that occurs during inductive hard switching. These concerns have also been voiced in the academic literature, at conference proceedings, and by other GaN manufacturers. The argument centers on the loci the part traverses in current-voltage space during an on-transition. For an inductive transition, the FET experiences higher current during the critical interval of time when both voltage and current are high, precisely the conditions that lead to hot-carrier effects. Though plausible, these arguments are mostly hand-waving, and are never supported by hard data or solid theory.

To address this question, both inductive and resistive hard switching conditions were measured. The measurement system was able to alternate from inductive to resistive modes (and back) on the same device under test. For inductive mode, the test circuit is a boost converter operating in Continuous Conduction Mode (CCM). In both modes, the part is switching continuously at 200 kHz, and oscilloscope traces are captured periodically, allowing monitoring of both short term and long term dynamic $R_{DS(on)}$.

Figure 6 shows data for an EPC2204 GaN transistor switching at 80 V. For the first four hours, the part was operated in inductive mode. After that, it was operated in resistive mode for the ensuing four hours. To guarantee a fair comparison, the off-state voltage across the device, frequency, duty cycle, and current at turn-on were kept the same for the resistive and inductive cases. As can be seen in the figure, there is no discernable difference in the slope or intercept of the log(t) growth characteristic: resistive and inductive hard-switching are essentially indistinguishable in terms of dynamic $R_{DS(on)}$. The same is true of short-term effects within the first microsecond of the transition; for neither mode displayed any "fast" recovery effects.

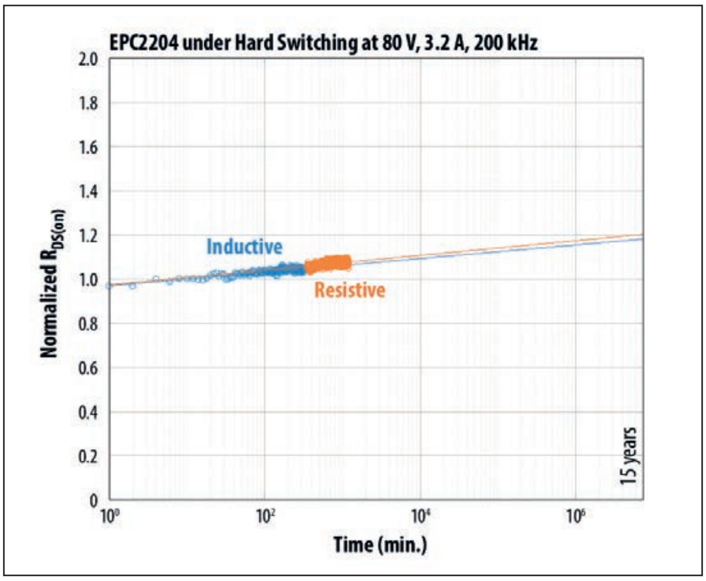


Figure 6: Comparison of inductive versus resistive hard switching on an EPC2204 FET switching at 80 V, 200 kHz. The same part was tested under inductive mode for the first four hours, followed by resistive mode for the next four hours. Both modes are essentially indistinguishable in terms of dynamic RDS(on)

This result implies that the mechanism responsible for $R_{DS(on)}$ shifts in GaN transistors is either independent, or weakly dependent on the detailed loci of current-voltage traversed during a transition. In both switching cases, there is simultaneous voltage and current during turn-on. While in resistive switching, the voltage across the transistor decreases as the current rises; whereas, in a purely inductive turn-on, the current rises before the voltage collapses. The fact that dynamic $R_{DS(on)}$ is so similar between the modes suggests that the electron current has a weak influence on hot-carrier trapping.

Physics-based dynamic on-resistance models

The physics-based model of dynamic $R_{DS(on)}$ explains the results. This model predicts that switch current (or the switching loci) has no impact on slope of the log(t) growth line, as observed. Furthermore, the model predicts that switch current does affect the intercept of the line, but only weakly. In fact, the

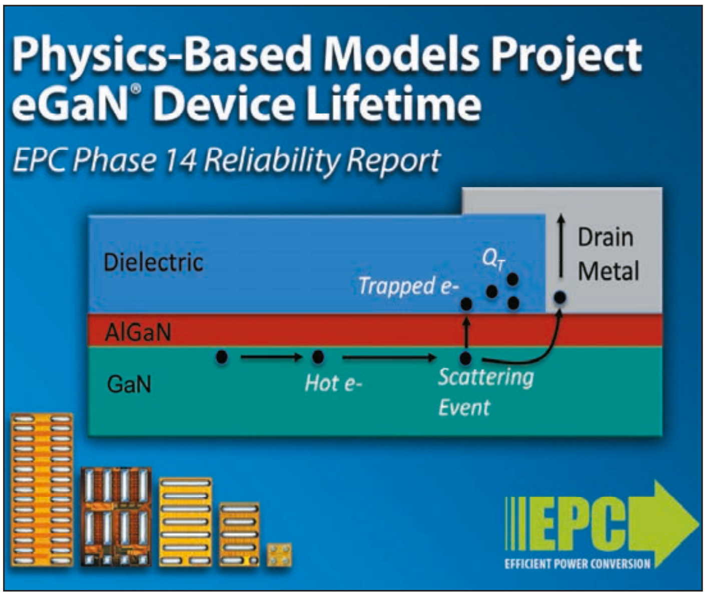


Figure 7: Hot electron scattering into the surface dielectric near the drain contact. To enter this dielectric, electrons must have sufficient energy to surmount the potential barrier. Once in this dielectric, they fall into deep electron trap states and are trapped effectively indefinitely

intercept (or additive vertical offset) of the line will increase like the logarithm of the switch current. For the same reason, the fine details of the switching loci have almost no impact, and inductive and resistive hard switching are equally valid methods to characterize dynamic $R_{DS(on)}$.

While equally valid to an inductive test circuit, a resistive circuit presents several practical advantages when it comes to evaluating dynamic $R_{DS(on)}$. For one, the circuit is simpler and more compact, allowing it to be integrated on probe cards for wafer-level characterization. For another, the lack of voltage overshoot during turn off allows for testing at voltages closer to the breakdown voltage, achieving operating points in the switching loci even more severe than possible with an inductive switching circuit.

The model is predicated on the assumption that hot electrons inject over a surface potential into the conduction band of the surface dielectric. Once inside, the electrons quickly fall into deep mid-gap states, where they are assumed to be trapped permanently (no de-trapping). Hot electrons are created during the switching transition, where the transient combination of high injection current and high electric field leads to a significant number of high energy carriers.

Figure 7 shows a cross-section of an GaN transistor in the immediate vicinity of the drain contact. During a hard-switching transition, electrons rush toward the drain, and become highly accelerated by the electric fields there. Under the right conditions, some electrons gain sufficient kinetic energy to scatter into the conduction band of the dielectric above. To do so, they need kinetic energy > 2 eV. Once inside the dielectric, they trap in deep mid-gap states, and become permanently trapped. When the device is turned on, the trapped charge reduces the normal channel electron charge, leading to a rise in RDS(on). By expanding on this simple dynamical picture of charge trapping in the discussion to follow, the model explains all the observed characteristics.

More details can be found in "GaN Reliability and Lifetime Projections: Phase 14", https://epc-co.com/epc/DesignSupport/eGaNFETReliability/ReliabilityReportPhase14.aspx

Automotive-Qualified Flyback Switcher ICs with 1700 V SiC MOSFET

Electric vehicles are increasingly driving on our roads, the majority of them are powered by a battery (BEV) and only a few models by a fuel-cell. The foreseeable future for passenger vehicles is in BEVs and for trucks perhaps in hydrogen-driven fuel cells, since trucks have to run for long distances without long charging stops. Nevertheless, both types of drive trains operate at increasingly higher voltage levels in order to decrease power losses (well-to-wheel), whereas this figure is around 70 % for fuel-cell vehicled and 30 % for BEVs. And for BEVs another point is important – the range and associated range anxiety as well as the charging time. The higher the DC charging power the lower the charging time – and the higher the charging voltage at a given current the higher the power according to P = V x I.

"The future of BEVs is above 1000 volts", expects Peter Vaughan, Director of Automotive Business Development at Power Integration in Santa Clara. "Battery voltage levels of 900 volts are already common in electric vehicles such as the Lucid Air, generating only 20 percent of the heat losses compared to a 400 volts sytem. Thus automakers are looking at 1000 and 1200 volts as the next step! And here 1700 V power switches and particularly Silicon Carbide MOSFETs come into play."

On February 1, 2022, the company announced with its second SiC attempt two AEC-Q100 qualified, 1700-V rated ICs to its InnoSwitch™3-AQ family. The devices are the industry's first automotive-qualified switching power supply co-packaged ICs to incorporate a primary switching SiC MOSFET. Delivering up to 70 watts of output power, the new ICs are targeted for use in 600- and 800-V battery and fuel-cell electric passenger vehicles, as well as electric buses, trucks and a wide range of industrial power applications (Figure 1).

InnoSwitch ICs reduce the number of components required to implement a Flyback power supply by as much as 50 %, saving significant circuit-board space, enhancing system reliability and mitigating component sourcing challenges. Synchronous rectification and a quasi-resonant (QR) / CCM flyback controller achieves greater than 90 % efficiency. These new parts consume less than 15 mW at no-load, reducing self-discharge in battery management systems.

Devices from the InnoSwitch family are now available with Silicon, Gallium Nitride (GaN) and high-voltage SiC transistors. "InnoSwitch devices allow the electronics to safely sip from the firehose of energy available on the main bus, using minimal board area. Most exciting is the opportunity to simplify the emergency power supply for the main traction inverter, which may be called upon at a moment's notice to operate from any voltage between 30 volts and 1000 volts. Our SiC-based InnoSwitch3-AQ handle this vast range with incredible ease," Vaughan states.

Offered in a compact InSOP™-24D package, the new ICs use a FluxLink™ magneto-inductive feedback link, providing reinforced isolation up to 4.5 kV hi-pot production testing. FluxLink enables direct sensing of the output voltage, providing benefits such as accurate regulation (3 %) and fast transient response. The circuit will start from 30 V without external circuitry – critical for functional safety. Additional protection features include input under-voltage, output over-voltage and over-current limiting. Switching frequency is with 60 kHz relatively low due to the transformer´s characteristics.

The InnoSwitch3-AQ 1700-V parts are also suitable for industrial markets, where the integrated solution can replace discrete controller-plus-MOSFET designs in applications such as renewables, industrial motor drives, battery storage and metering.

Devices are priced at $5.64 for part number INN3947CQ-TL and $9.02 for part number INN3949CQ-TL in volume product quantities. A reference design, DER-913Q, and hardware kit RDK-919Q, are available.

Design example 35 W isolated flyback

The engineering report describes a 40 VDC to 1000 VDC input, 24 V output, 35 W power supply utilizing the INN3947CQ (Figure 2).

One end of the transformer primary is connected to the DC bus, the other is connected to the integrated power SiC MOSFET inside the INN3947CQ IC package (U1). High-voltage ceramic capacitor C1A, C1B & C1C is used for the decoupling capacitor for the DC input voltage, and a low-cost RCD clamp formed by D1, R1, R2, R3, R4 and C2 limits the peak drain voltage due transformer leakage inductance.

The IC is self-starting, using an internal high-voltage current source to charge the BPP pin capacitor, C4, when DC input voltage is first applied. During normal operation the primary-side block is powered from an auxiliary winding

Figure 1: AEC-Q100 qualified, 1700-V rated ICs InnoSwitch™3-AQ family for transportation and industrial applications

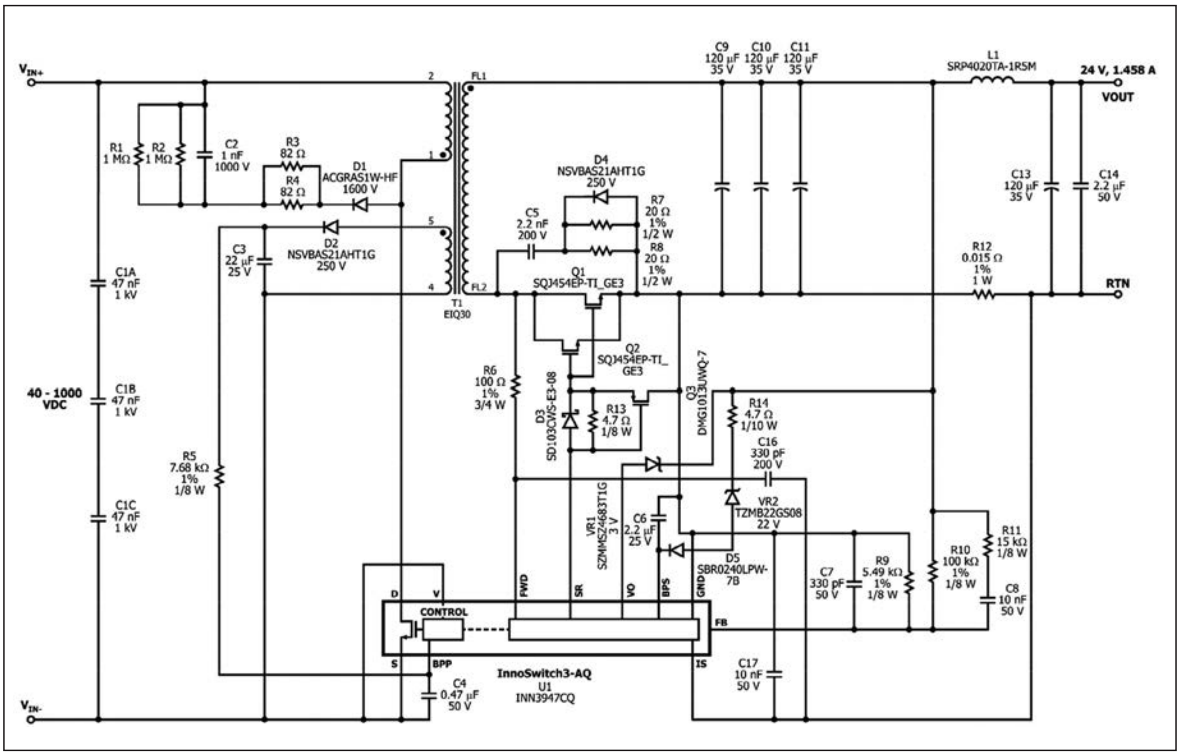


Figure 2: Flyback switcher 35 W power supply 40 VDC to 1000 VDC input featuring 1700 V SiC MOSFET

on the transformer. The output of this is configured as a flyback winding which is rectified and filtered using diode D2 and capacitor C3, fed in the BPP pin via a current limiting resistor R5.

In this design the input primary under and overvoltage features were disabled by connecting the V pin to source.

The secondary-side of the INN3947CQ IC provides output voltage, output current sensing and drive to a MOSFET providing synchronous rectification.

The 24 V output rectification is provided by SR FETs Q1 and Q2. Low ESR capacitors, C9, C10, C11, C13, C14 and output inductor L1 provide filtering. RC snubber network comprising D4, R7, R8, and C5 for Q1 and Q2 damps high frequency ringing across SR FETs, which results from leakage inductance of the transformer windings and the secondary trace inductances. The gates of Q1 and Q2 are turned on based on the winding voltage sensed via R6 and the FWD pin of the IC. Capacitor C16 is used to suppress high frequency spikes on the FWD pin. In continuous conduction mode operation, the SiC MOSFET is turned off just prior to the secondary-side controller commanding a new switching cycle from the primary. In discontinuous mode the SiC MOSFET is turned off when the voltage drop across the MOSFET falls below ground.

Secondary-side control of the primary-side SiC MOSFET ensures that it is never on simultaneously with the synchronous rectification MOSFET. The MOSFET drive signal is output on the SR pin. A gate enhancement circuit comprising D3, R13 and Q3 prevents V_{gs} to turn-on during primary turn-ons. The secondary-side of the IC is self-powered from either the secondary winding forward voltage or the output voltage. The output voltage powers the device, fed into Zener diode VR1 which is connected to the VO pin. Zener VR1 is used to reduce the voltage stress on the VO pin. It will charge the BPS pin capacitor C6 via an internal regulator. The OVP sensing circuit, R14, VR2 and D5, connected to BPS pin provides secondary-side protection.

Resistors R9 and R10 form a voltage divider network that senses the output voltage. INN3947CQ IC has an internal reference of 1.265 V. Capacitor C7 provides decoupling from high frequency noise affecting power supply operation, and C8 and R11 is the feedforward network to speed up the response time to lower the output ripple. The output current is sensed by R12 and filtered by C17 with a threshold of approximately 35 mV to reduce losses. Once the current sense threshold across these resistors is exceeded, the device will go into auto-restart.

Available output power at elevated ambient (Figure 3) can be increased by providing a thermal path from the PCB area connected to the SOURCE pin of the InnoSwitch3-AQ to a surface that is lower in temperature. This is typically the outer wall of the inverter or internally above the water channel cooling the power modules. A very simple approach is a compliant thermal pad (e.g. TGP 1500 from Berquist) placed between the PCB and bottom or top surface of the enclosure. In the design of the cast enclosure features may be added at no cost to provide a location to place the pad for manufacturing simplicity and reduce the thickness of pad needed to reduce cost of pad needed. Figure 4 shows the populated top side circuit board.

https://www.power.com/products/innoswitch/innoswitch3-aq

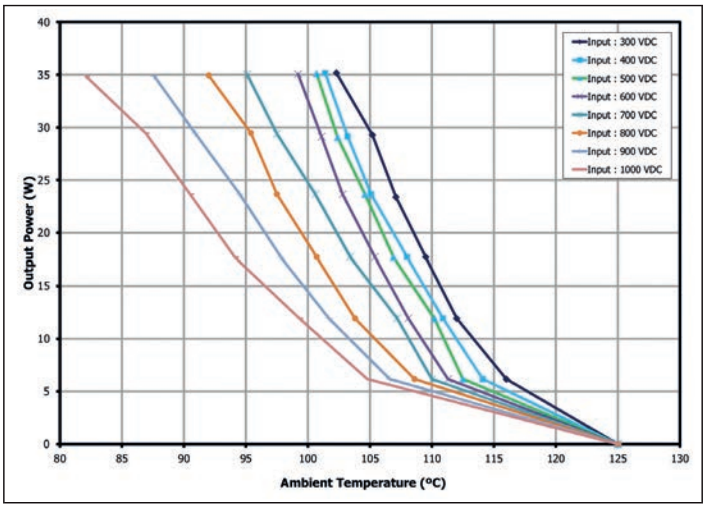


Figure 3: Maximum output power vs. ambient temperature (based on 125°C junction temperature of INN3947CQ)

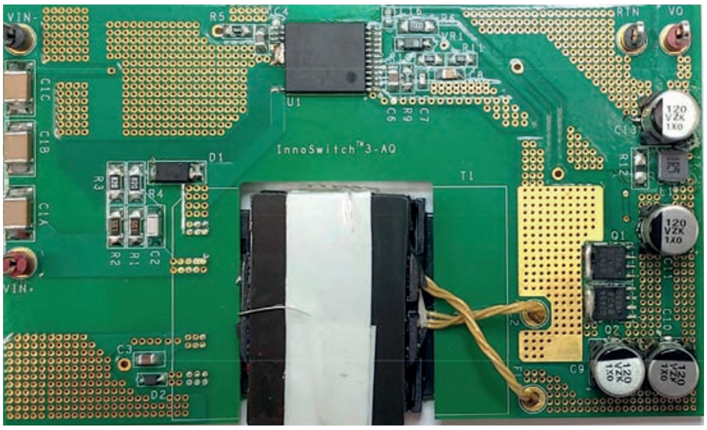


Figure 4: Populated top side DER-913Q circuit board

Maximizing Active Front End Efficiency Using Silicon Carbide

Engineers designing UPS with great care to ensure smooth enterprise data center operation 24/7 are also aware that their power supplies are destined to be part of a setup that gulps for example 90 TWh of US electricity every year – enough to sustain thirty large and noxious coal-fired plants. Power engineers in another design camp, working to ensure their fast chargers can speedily top up EVs, are also aware of the cost of electricity and the environmental impact of its generation. This article addresses these concerns and, by doing a side-by-side comparison, demonstrates that Silicon Carbide (SiC) is by far the better choice over Silicon (Si)-based devices for high power applications. **Daniel Martin, Sr. Manager applications Engineering, and Jonathan Hayes, Application & Systems Engineer, both Wolfspeed, USA**

Engineers targeting any application area are joined in their concerns over efficiency, power density, and cost. And, even if they have yet to design with it, they are aware that the solution may lie in SiC technology. The article content uses an essential part of UPS and charger systems, the active front end (AFE), to explore improvements in size and power density, power losses and efficiency, and bill of materials (BOM) costs. It aims to turn that general awareness of SiC benefits into a clearer understanding, clearing a path through an entrenched less-efficient technology toward greater SiC-based design experience.

The challenge in AFE design can be broadly expressed as a wish list of changes an engineer would want:

1. Lower switching and conduction losses in the semiconductor devices
2. Smaller and lighter cooling system
3. Smaller and lighter passives – capacitors and inductors
4. All of the above with reduction in operational cost as well as BOM cost

Any technology that resolves all of these challenges – simultaneously – can indeed have a significant impact on product competitiveness as well as the environment.

Why Silicon Carbide?

Silicon Carbide enables engineers to check items on the list above by virtue of material and resulting device properties.

Compared with the traditional Si technology, SiC devices offer a 2-3X lower on-state voltage drop than Si, thus lowering conduction losses in SiC switches. Since SiC devices are majority carriers, they offer much higher edge rates (di/dt) than possible with Si. Their 10X higher breakdown field than Si allows SiC devices to withstand higher voltage in the same package.

A higher thermal conductivity of 3.3-4.5 W/cmK versus Si's 1.5 W/cmK enables SiC devices to conduct heat away much more quickly, helping to reduce cooling requirements in the system. Moreover, SiC chip temperatures can reach 250-300°C (versus Si's 125°C) and junction temperatures in Wolfspeed devices can go up to 175°C before affecting reliability. This means that the devices can run hotter and with a smaller cooling rig.

Wolfspeed's SiC power modules offer the following advantages over Si versions:

- They are application-targeted with module selections offered in a variety of voltage and current ratings, and form factors, as well as with switching and conduction optimization
- They have lower $R_{DS(ON)}$ compared with IGBT modules
- They offer faster switching speeds
- They have lower switching losses

Application advantages of the AFE topology

The AFE is applicable to almost all grid-tied converters. Two prominent topologies in today's emerging markets are shown in Figure 1. The double-conversion UPS architecture comprises an AFE or rectifier, a DC/DC converter and an inverter. In normal power flow, a small current goes into the DC/DC converter that maintains the battery charge. Most of the power is sent through the DC link into the inverter where it feeds the load.

Under a power fault, the AFE stops switching and the DC/DC converter sends power from the battery into the inverter to feed the load. Some applications may use the battery also to compensate for poor

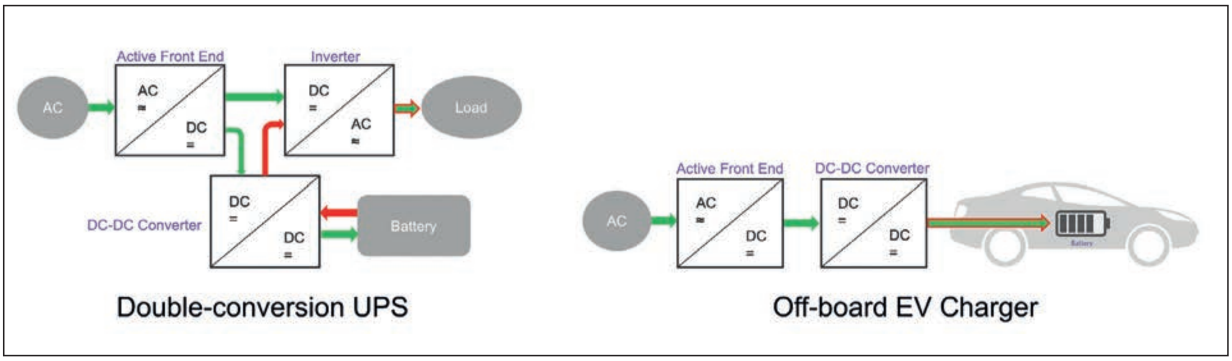


Figure 1: **The AFE ties both applications – the double conversion UPS (left) and the EV off-board fast charger (right) – to the grid, rectifying AC input to DC**

load or grid-side power quality. In the off-board DC fast charger as well, the AFE connects the converter to the grid. It rectifies the grid voltage into a stable DC link voltage, which then can be used to charge the batteries. The off-board charger topology is simpler with the AFE interfacing directly with just the DC/DC converter to quickly charge the EV. In both applications, the AFE uses three half-bridge power modules – one for each phase.

Defining the problem and design goals

A key issue with IGBT-based AFEs is that they are large and inefficient. They have high switching losses and, because they are also significant heat sources, engineers have the option to either use bulky cooling systems or take a performance hit in order to lower the heat generated. But, although demands vary slightly, all customers want to pay for a high efficiency system, not a heater.

The AFE design goals, therefore, can be defined as:

- Regulate the DC link voltage under normal operation by controlling the input current magnitude
- Minimize power quality issues by sourcing very low THD (<5%) current with very high-power factor
- Minimize BOM component costs
- Shrink system volume to enable more compact systems
- Maximize efficiency

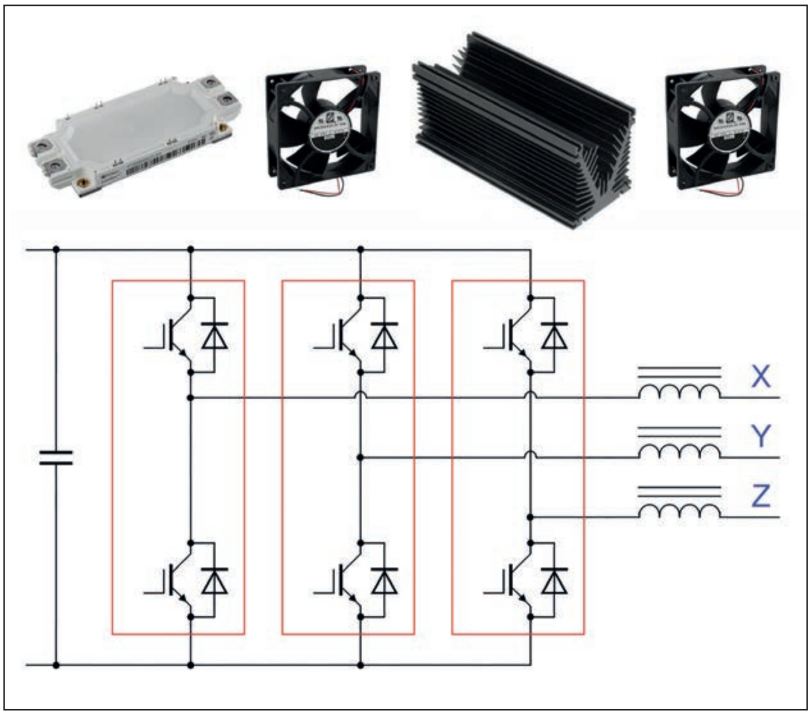
With this in mind, IGBT and SiC variants of an AFE system were designed to output 200 kW of high-quality rectified power with a well-regulated DC bus.

IGBT- versus SiC-based designs

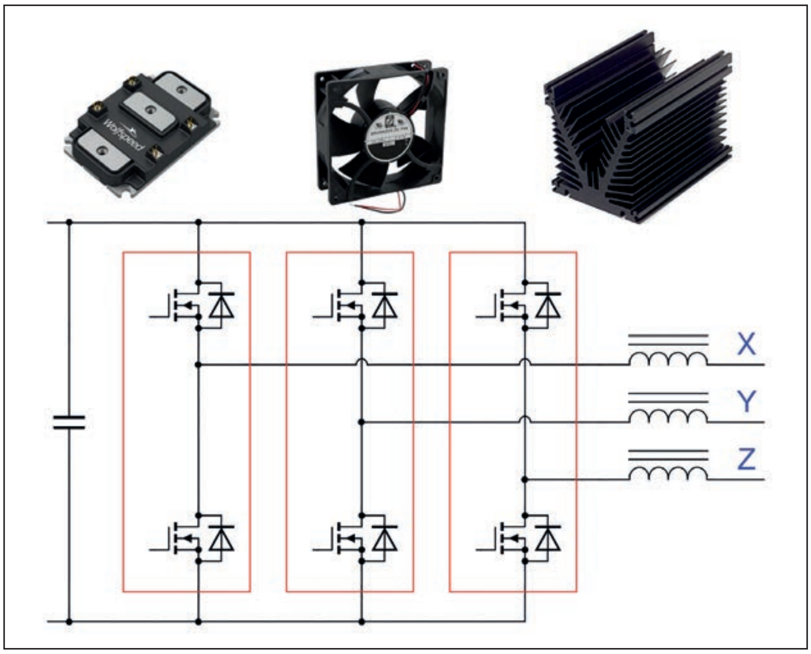
The IGBT- and SiC-based systems are presented broadly before delving deeper with a side-by-side comparison of the component sizes and losses.

Si-based high-power designs, like the AFE example, typically use IGBTs. Shown in Figure 2 is the circuit diagram with the power module and its physical cooling requirements. To use a best-in-class component, a module was chosen from among the dominant IGBT modules today that come in EconoDUAL® package. The topology requires three such power modules – each red box shown in the figure includes a single power module, a heatsink, and two fans.

The system could be optimized to switch at a frequency as high as 8 kHz while needing a 100 µH inductor. For a 40°C ambient temperature, the IGBT



LEFT Figure 2: Each red box in the circuit comprises the EconoDUAL® power module and the associated cooling system shown above



ABOVE Figure 3: Each red box in the SiC-based circuit design uses the smaller XM3, a smaller heat sink and a single cooling fan

	Type of Loss	IGBT Module (W)	XM3 Module (W)
IGBT/MOSFET	Conduction	16	132
	Turn-on switching	66	96
	Turn-off switching	211	91
	Reverse recovery	N/A	12
	IGBT/MOSFET total	293	331
Diode	Forward conduction	140	N/A
	Reverse recovery	122	N/A
	Diode total	262	N/A
	Module total	**555 x 2 = 1110**	**331 x 2 = 662**

Table 1: The loss comparison demonstrates a per module loss reduction by SiC of 40 % over IGBT

junction temperature (Tj) reaches 130°C and the separate diode chip junction temperature reaching 140°C. This required a large heat sink and two fans per module even after limiting the switching frequency to 8 kHz.

The SiC-based system used a Wolfspeed XM3 power module, the XAB400M12XM3. The system can switch at a much higher 25 kHz, and uses a 30 µH inductor. For the same 40°C ambient temperature, the MOSFET junction temperature reaches 164°C. Again, each red box shown in Figure 3 comprises the module and it's much lower cooling requirements.

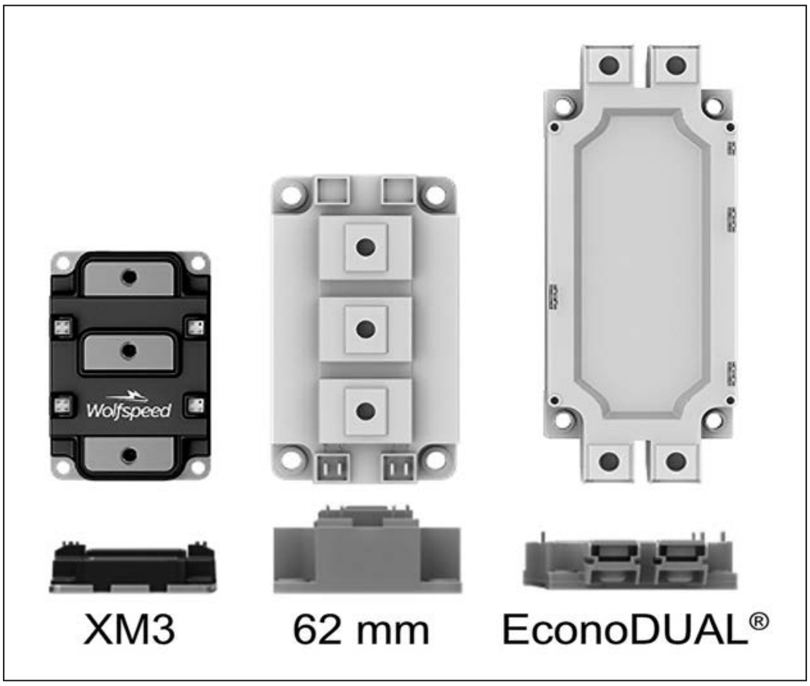
Power modules compared

Wolfspeed's XM3 power module platform occupies 60% less volume and 55% less area than an equivalently rated 62-mm module. Compared with a similarly rated EconoDUAL® IGBT module, the reduction in size, volume, as well as weight is significantly more.

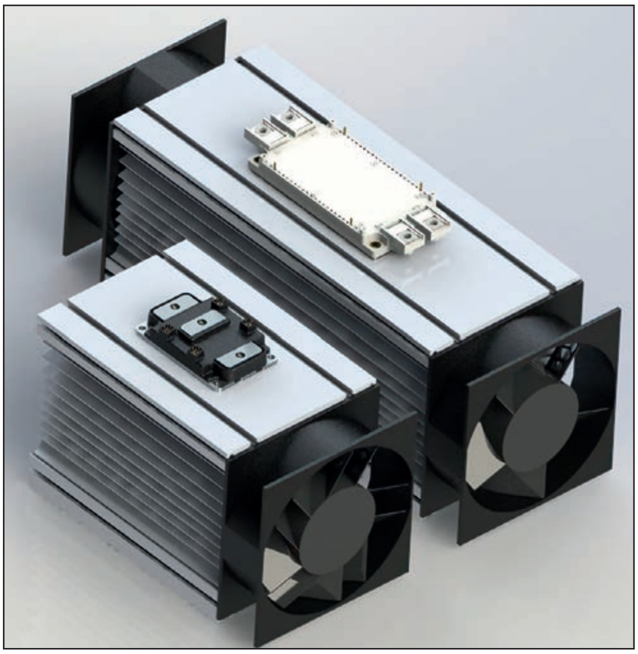
The XM3 platform's key features include:

- A high power density of up to 32 kW/l
- Junction temperature of up to 175°C
- Low inductance (6.7 nH)
- >5X lower switching losses
- Low conduction losses without intrinsic knee-voltage
- High reliability Silicon Nitride power substrate for enhanced power cycling capability

In the AFE under consideration, Table 1 compares the IGBT power module losses against the XAB400M12XM3. As shown, using Wolfspeed SiC technology helps overcome the first broad design challenge by reducing the total switching and conduction losses, which enables the remaining broad challenges to be addressed.



ABOVE Figure 4: The XM3 platform represents a drastic reduction in area and volume over the EconoDUAL®



LEFT Figure 5: The XM3 lowers cooling system volume by 42 % and cost by 70 %

Smaller and lighter cooling

The high MOSFET junction temperature allowed by SiC technology and the XM3's low losses have an immediate effect on the cooling requirements.

With a loss per module of 1.11 kW, every EconoDUAL® needs to be mounted on a large heatsink with a pusher and puller fan each to achieve sufficient airflow for cooling efficiency. The cooling system volume is 6.4 l/module.

Given the 40% lower losses, the XM3 needs a smaller heatsink and just one fan to achieve the same result (@40°C). The cooling system volume is just 3.7 l. This 42 % reduction in cooling system volume is accompanied by yet another advantage – a 70 % reduction in the AFE system thermal solution cost.

The impact on passives

By enabling an increase in the switching frequency by a factor of three, from 8 kHz to 25 kHz, the SiC-based AFE needs smaller passives (Figure 6).

As mentioned earlier, the required inductance can also be reduced by a factor of three, from the IGBT design's 100 µH to 30 µH. The resulting reduction in the physical size is about 37%. Moreover, I2R losses in the inductor are also reduced by close to 20%.

For the power levels required by the AFE example, the cost of the magnetics, including the core and the copper windings, is lower in the XM3 design by 75% over the IGBT-based AFE.

The effect on the required DC link capacitance is similar due to the increased switching frequency. While for the IGBT variant 1800 µF are required, the SiC MOSFET-based design only needs 550 µF capacitance. The side-by-side comparison in Figure 6 illustrates the reduction in the volume of the needed capacitance by 54 %.

AFE system-level comparison

At the system level, the 3X increase in switching enabled by SiC translates to a 3X improvement in control bandwidth that in turn means faster response time to dynamic conditions. The easing up of the demand on passives, including the cooling system, results in a 37 % reduction in the BOM costs toward those components put together.

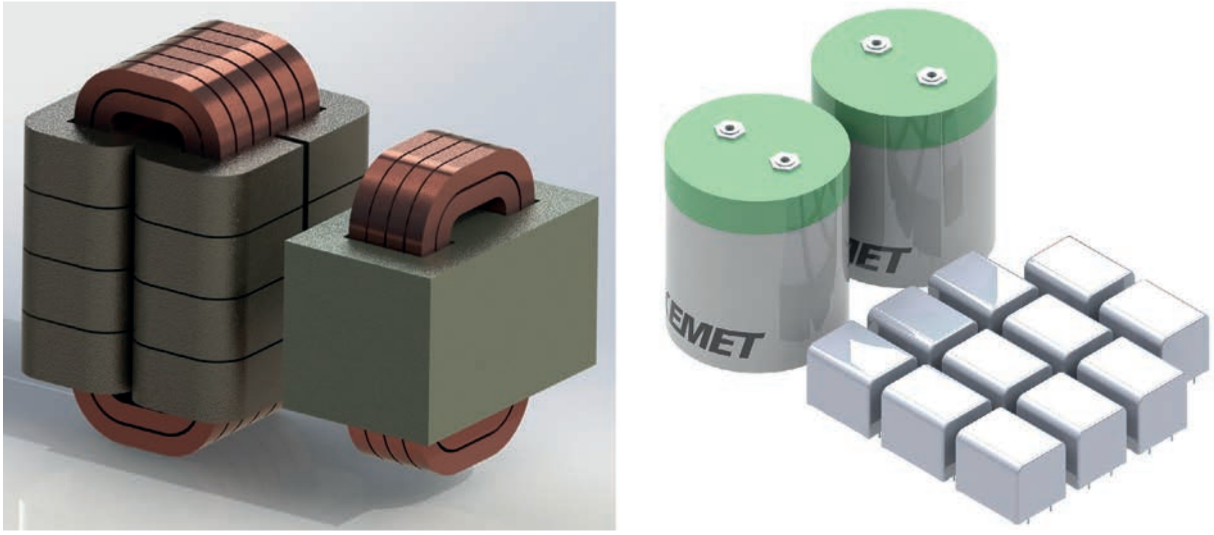


Figure 6: **The SiC-based AFE uses inductors (left) and capacitors (right) that are much smaller than those needed by the IGBT-based design**

The SiC-based AFE also has 40 % lower losses than the IGBT-based system. For a system that runs continuously — 24 hours a day, 7 days a week — this leads to 26 MWh in annual energy savings. Beyond the green credentials, at a cost of $0.10/kWh, SiC can lower the annual operational cost by $2,591.

Looking beyond performance, passive BOM costs, and operational costs, the SiC-based system is much smaller in size and weight. It effects a system volume reduction of 42 % over the IGBT version (Figure 7).

Conclusion

A side-by-side comparison of best-in-class IGBT EconoDUAL® and Wolfspeed XAB400M12XM3 SiC-MOSFET power modules in similarly rated AFE systems reveals that SiC technology makes the aforementioned designer's wish list come true. Wolfspeed's XM3 platform helps significantly increase efficiency throughout the system, boost overall system response and performance, cut the system-wide volume to achieve much higher power density, and increase competitiveness by shaving off overall passive BOM costs.

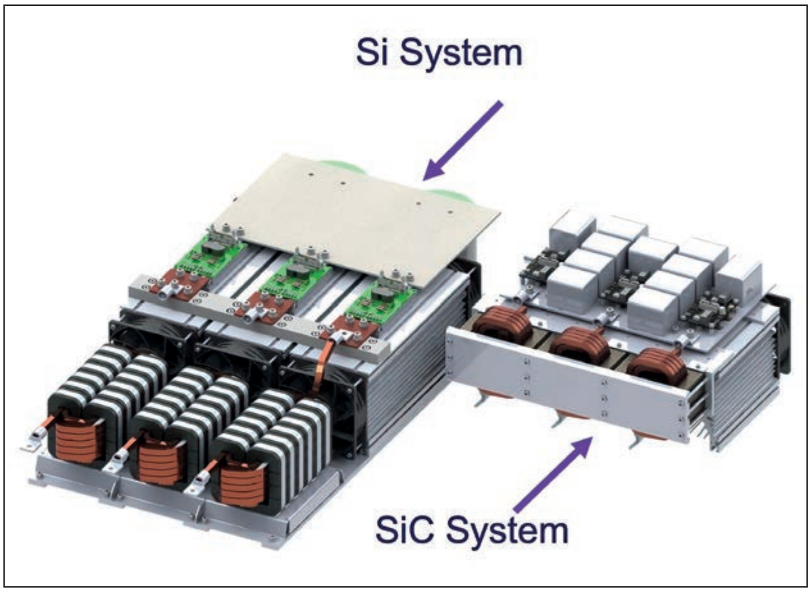


Figure 7: **A side-by-side AFE system comparison shows the SiC system's fractional size compared with IGBT**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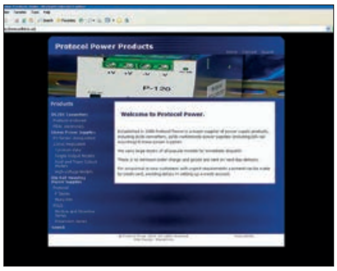

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