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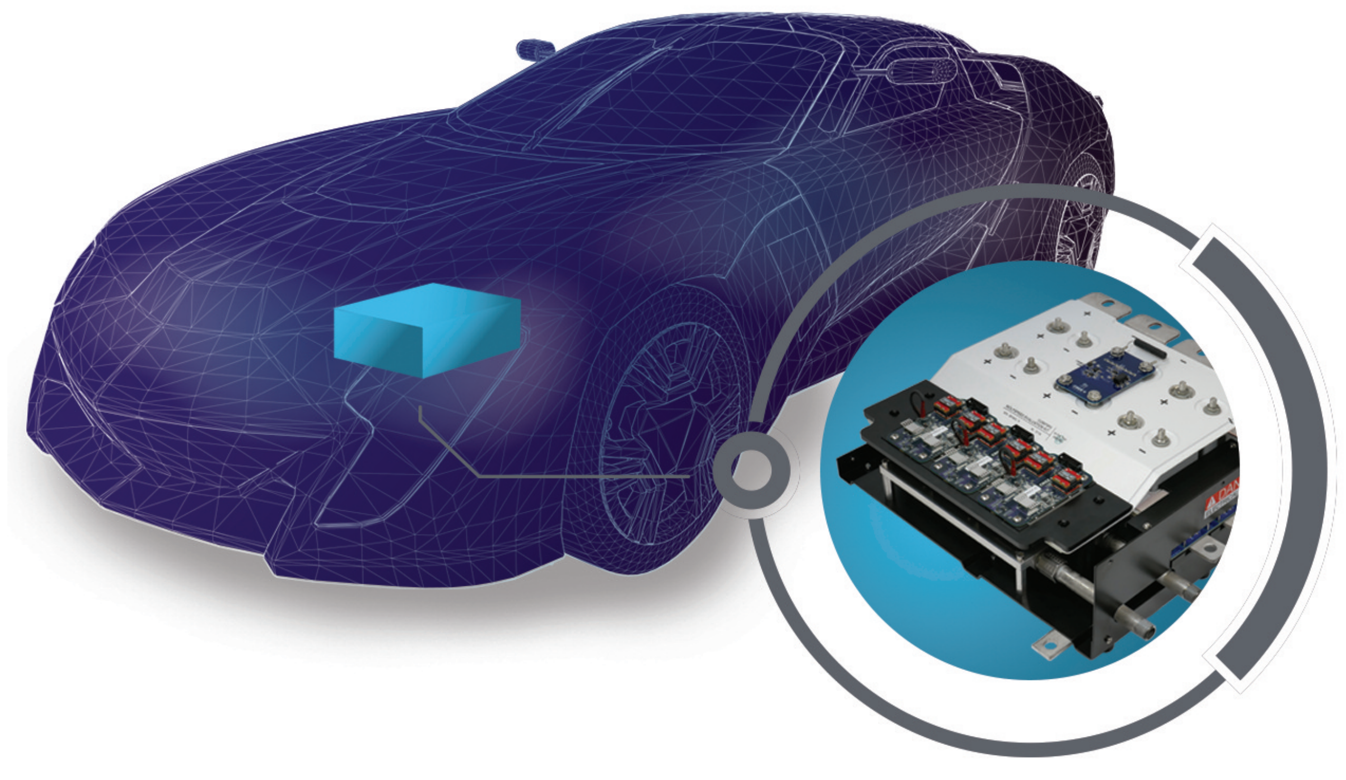
ISSUE 3 – May/June 2018 www.power-mag.com

SIC POWER

DC Bus Switching Performance as Determined by Commutation Loop Parasitics and Switching Dynamics



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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.

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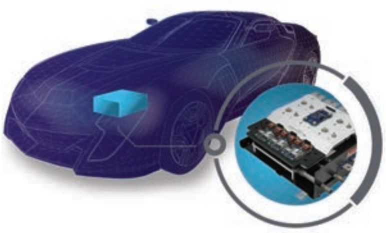
Printed by: Garnett Dickinson.

ISSN 1748-3530

COVER STORY



DC Bus Switching Performance as Determined by Commutation Loop Parasitics and Switching Dynamics

In this article a 250 kW all-SiC inverter evaluation kit designed around low-inductance, high-speed power modules is used to demonstrate the DC bus switching performance resulting from the interaction among commutation loop parasitics and the switching dynamics. SiC power module designers must pay special attention to module and system parasitic inductance, as these parameters determine the power module current and voltage utilization with respect to the module rating. The gate drivers, capable of switching at hundreds of kHz, must provide high noise immunity to large dv/dt, di/dt, and common-mode disturbances. Even though fast switching devices promise lower switching losses, EMI-related issues become more pronounced and can impact system behavior. The interplay among the DC bus structure parasitics and near-RF switching dynamics can be quantified in both the time and frequency domains. The gate driver external turn-on and turn-off gate resistor selections in the gate-source signal path directly impact the system response – and whether it is critically damped or underdamped. The parasitic ESR and ESL of the DC bus film capacitors, laminated bussing, high-frequency (HF) ceramic decoupling capacitors, and power module-DC bussing interconnects contribute to bus switching degradation due to fast SiC MOSFET switching dynamics. The key takeaway is to optimize the DC bus structure rather than trying to compensate for a poor design. Full article on page 26.

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Wide Bandgap Enters Automotive

In 2017, 1.2 million BEV and PHEV were sold, a 52 % increase compared to 2016. Full and mild HEV sales accounted for 2.8 million units last year, a 22 % year-to-year increase. Several European car manufacturers also launched their 48 V mild hybrid models in 2017. This cost-effective solution, which electrifies vehicle auxiliary systems and at the same time reduces CO2 emissions, will proliferate in 2018-2019 among all European carmakers, followed by the Chinese ones. Yole forecast a 50 % CAGR for the 2017-2023 period, for mild hybrids, because these low cost electrified vehicle models are attractive. Their approach can be easily implemented in any car, from city cars to higher end luxury models.

Pushed by aggressive legislation, car manufactures select the best way of electrification. The full HEV segment will drive the IGBT power module market, with IGBT modules used for EV/HEV. The market for IGBTs in the EV/HEV sector is expected to be worth almost $2.3 billion by 2023. At the IGBT power module level, a shift in design has happened in recent years. Modules have changed from classical packaging technologies, with a plastic casing, silicone gel encapsulation and a ceramic substrate. Now they are more compact, transfer-molded epoxy modules with organic isolation, although this has been a big step for traction inverter IGBT modules. These compact and flexible designs help integrate power converters better. As part of this, double-sided cooling modules have spread throughout the EV/HEV industry. The first double-sided cooling modules were in Lexus cars, but now we have the well-known fourth generation Toyota Prius PowerCards and the latest Bosch, Infineon or Dynex modules. This has built a pathway towards power electronics and cooling system integration and optimized thermal management systems. Some early adopters have already started using SiC, such as Chinese carmaker BYD in its onboard chargers, or US EV icon Tesla for its Model 3 inverter. Nevertheless, SiC is still used in only small volumes, requiring a back-up solution with Silicon IGBTs. Other carmakers are even more conservative and do not see enough system-level benefits to adopt SiC MOSFETs.

But, where Silicon plateaus in terms of performance, SiC presents a highly efficient alternative also in automotive applications, according to Infineon's Principal Engineer Laurent Beaurenaut in his feature "SiC-Based Power Modules Cut Costs for Battery-Powered Vehicles". SiC components have been on the market for about two decades. However, their use in vehicles was limited for cost and partly for quality reasons. To date, wafer dimensions for SiC have generally been much smaller than for Silicon. The availability of high-quality 150 mm (6-inch) SiC wafers increases productivity in manufacturing SiC chips. Initially dominated by smaller, specialized companies, leading semiconductor companies now process SiC components on standard equipment with high outputs and high reliability. This results in promising cost developments for SiC. The latest generation of SiC trench MOSFETs also exhibits advances in gate oxide reliability, making them ideal for automotive applications. The fundamental advantages not only make SiC MOSFETs ideal for operation at higher frequencies such as on-board charging circuits and DC/DC converters, but also for inverter applications, where switching frequencies below 20 kHz are typical. Here, the efficiency is determined to a very large extent by operation with low loads. Using SiC MOSFETs, it is possible, for example, to reduce the losses in inverters by up to two thirds under low or medium load. Extremely compact and highly efficient inverters can be realised with SiC MOSFETs. Under comparable conditions, SiC MOSFETs significantly reduced the chip area compared to IGBT-based inverters. Thanks to the reduced chip losses, the efficiency has been improved for various driving scenarios, especially in city traffic with many acceleration phases.

In order to make the best possible use of the performance of the SiC chips, a correspondingly optimized packaging technology for the power modules is also required. SiC facilitates better energy efficiency. However, this not only requires improved packaging materials, but also the consideration of higher thermal resistances for smaller chips. Smaller chips also cause higher current densities and a greater risk of thermo-mechanical deformation. To fully exploit the performance of the SiC MOSFETs, packaging with the lowest possible leakage inductance is required. Consequently, new innovative packaging concepts for power modules are required. Examples include the optimized modules of the HybridPACK Drive family and packaging concepts with double-sided cooling, such as HybridPACK DSC modules. This makes it possible to develop inverter designs with very high power density.

In our cover story a 250 kW all-SiC inverter evaluation kit designed around low-inductance, high-speed power modules is used to demonstrate the DC bus switching performance resulting from the interaction among commutation loop parasitics and the switching dynamics. SiC power module designers must pay special attention to module and system parasitic inductance, as these parameters determine the power module current and voltage utilization with respect to the module rating. The gate drivers, capable of switching at hundreds of kHz, must provide high noise immunity to large dv/dt, di/dt, and common-mode disturbances. Even though fast switching devices promise lower switching losses, EMI-related issues become more pronounced and can impact system behaviour. The inverter stack-up with the new bussing design showed ultra-low overshoot and clean switching three-phase output inverter waveforms.

Yole also analyzes the potential of GaN power devices, but they're not yet mature enough to be implemented in electric cars in the short term. Nevertheless, EPC announced AEC Q101 qualification of two eGaN devices recently, opening a range of applications in automotive and other harsh environments. And beyond SiC and GaN Diamond is on the horizon, promising even better performance.

We will keep you informed!

Achim Scharf
PEE Editor

GaN On the Rise

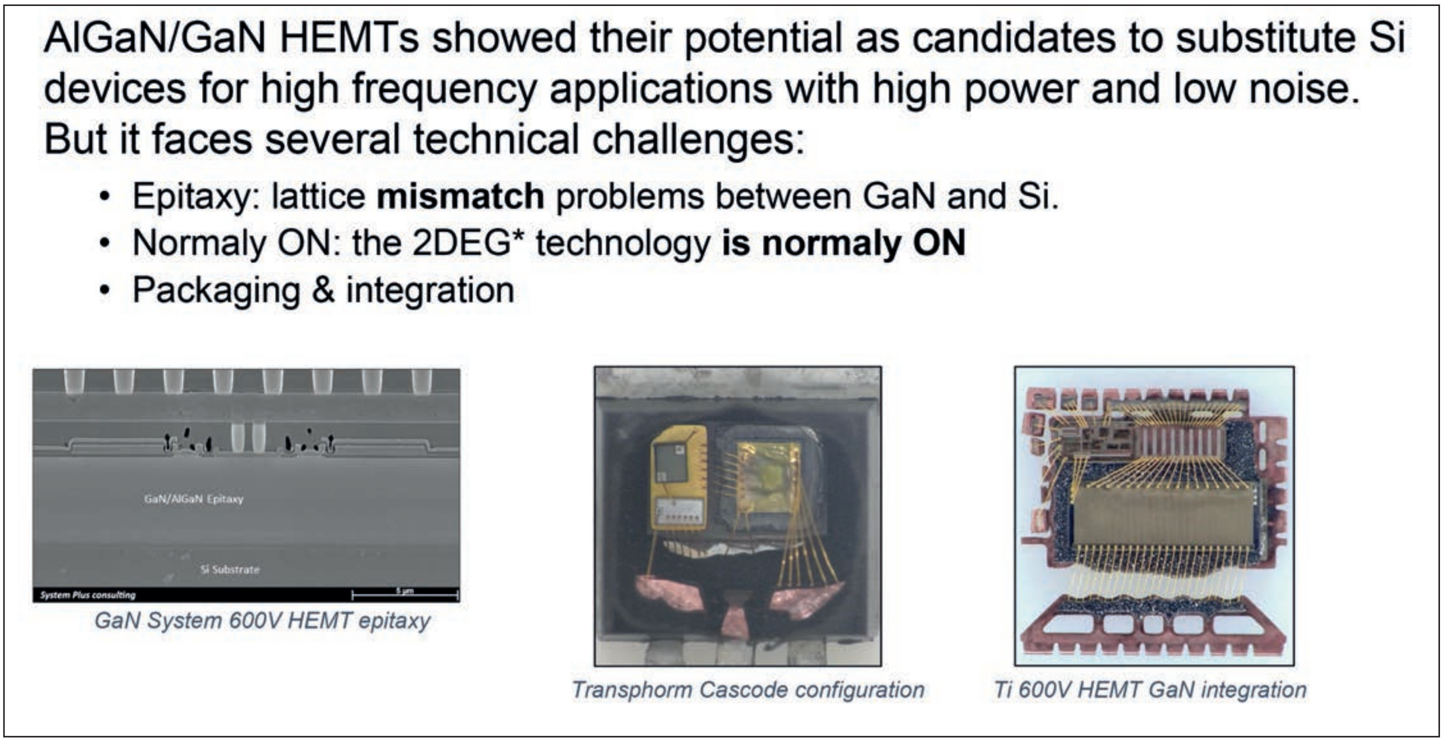
The GaN power business was worth about $12 million in 2016, but Yole analysts project that the market will reach US$460 million by 2022, with an impressive 79 % annual growth rate (CAGR). Amongst the numerous applications, the market research company mentions Lidar, wireless power and envelope tracking. They are high-end low/medium voltage applications. Today GaN technology is the only existing solution to meet their specific requirements."The GaN power market remains small compared to the $30 billion Silicon power semiconductor market", asserts Hong Lin, Technology & Market Analyst. "However, it has an enormous potential in the short term due to its suitability for high performance and high frequency solutions."

Although today only a few players are showing commercial GaN activities, many firms have GaN activities. Therefore, the power GaN supply chain prepares for production. During the 2016-2017 period, Yole's analysts identified lot of investments that are clearly supporting development and implementation of GaN devices. Yole differentiates GaN power supply chain into two main models: IDM (integrated device manufacturers) and foundry. Both models will co-exist while there are different needs on the market, for example in consumer and industrial applications. "The business model is directly linked to the final product/application," explains Ana Villamor, Technology & Market Analyst Yole. "Today, many questions related to the chip's integration and to the system's interface are still pending. And they condition the business relationship between the GaN companies".

"The current GaN device market is mainly dominated by devices <200 V. 600 V devices are expected to take off and keep growing. But the <200 V market share will increase again when GaN begins to replace MOSFETs in different applications and enables new applications," comments Elena Barbarini, Project Manager at System Plus Consulting. "GaN-on-Silicon has been a promising solution since the very beginning as its potential of CMOS compatibility and reduced cost".

GaN manufacturers continue developing new products and provide samples to costumers, as is the case with EPC (**www.epc-co.com**) and its wireless charging line. Indeed EPC is still the current market leader today. Other players including GaN systems (**www.gansystems.com**) selling high and also low voltage GaN transistors. System Plus Consulting, part of Yole Group of Companies, reveals a detailed comparison of GaN-on-Silicon transistors in its new report, "GaN-on-Silicon Transistor Comparison". This overview highlights the differences between the design and manufacturing processes, the impacts at epitaxy, device and packaging level and related production costs. Devices analyzed by System Plus Consulting have been developed by the leading companies EPC, Texas Instruments, Panasonic, GaN Systems and Transphorm.

http://www.systemplus.fr/reverse-costing-reports/gan-on-silicon-transistor-comparison-2018/



H(EV) Adoption Accelerates Power Module Market

In 2016, Yole Développement (Yole) already pointed out the impressive growth of the EV/HEV industry and its huge impact on the power electronics industry with numerous technical issues. Two years later, cards have been handling, the playground is ready and the game should reveal some surprises. In a dynamic context showing a 28 % CAGR between 2017 and 2023, Chinese car manufacturers become today major players in the EV/HEV industry while European companies, strongly involved in the development of power modules and components announce their leadership with innovative technologies.

EV/HEV sales continue to surge. In 2017, 1.2 million BEV and PHEV were sold, a 52 % increase compared to 2016. Full and mild HEV sales accounted for 2.8 million units last year, a 22 % year-to-year increase. Several European car manufacturers also launched their 48 V mild hybrid models in 2017. This cost-effective solution, which electrifies vehicle auxiliary systems and at the same time reduces CO2 emissions, will proliferate in 2018-2019 among all European carmakers, followed by the Chinese ones. "48V system will rapidly boost the market", explains Mattin Grao Txapartegi, Technology & Market Analyst. "We forecast a 50 % CAGR for the 2017-2023 period, for mild hybrids, because these low cost electrified vehicle models are attractive. Their approach can be easily implemented in any car, from city cars to higher end luxury models."

China today is strongly focused on BEV and PHEV segments. Last year China accounted for 50 % of global sales in these categories. Looking at the evolution of the giant Asian country, it seems that this predominance will continue in the future. Countries like Japan or the USA are more focused on full HEV than these full EV models. It's also interesting to highlight that even if China represents a huge market for EV/HEV, local companies are involved in car manufacturing, but much less at tier-1 component or power module supplier level. At these stages European, American and Japanese companies are predominant, even in the Chinese supply chain. Yole expects double-digit CAGR between 2018 and 2023. This means some 10 million EV/HEVs will be sold by around 2020, and up to 18 million by 2023, across all categories.

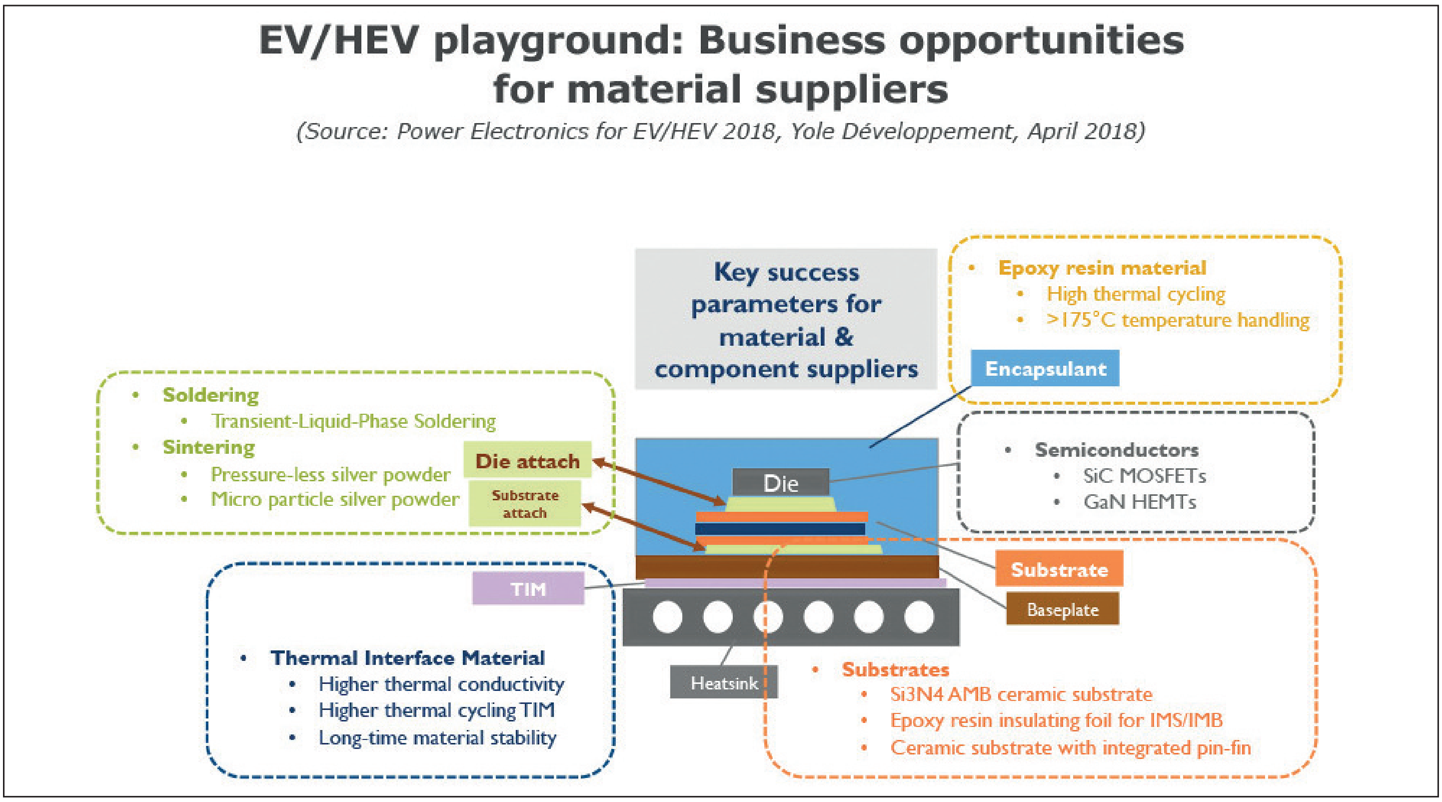
Pushed by aggressive legislation, car manufactures select the best way of electrification. The full HEV segment will drive the IGBT power module market, with IGBT modules used for EV/HEV. The market for IGBTs in the EV/HEV sector is expected to be worth almost $2.3 billion by 2023.

"In a compact car the maximum power of the motor is 60 kW, while the hybrid systems used in medium and large vehicles have inverter power exceeding 160 kW," explains Elena Barbarini, Project Manager at System Plus Consulting. "However, when converting an existing petrol vehicle to a hybrid version, the available space in the engine compartment is often so limited that it is difficult to accommodate a PCU . Thus, it is necessary that the PCU, which controls the traction motors of HEVs, get smaller, with higher power density. To achieve these targets, manufacturers have developed different solutions, such as reducing wire bonding or using a double-sided cooling structure to efficiently cool the power semiconductor chips." Infineon Technology, after its acquisition of International Rectifier in 2014, is showing a strong leadership the power electronics industry. The HybridPACK Double Sided Cooled power module is the first DSC IGBT module from Infineon Technology. The module drives 700 A and uses a molded structure optimized for cooling, thus improving its thermal cycling capability and extending the lifetime of the power module.

At the IGBT power module level, a shift in design has happened in recent years. Modules have changed from classical packaging technologies, with a plastic casing, silicone gel encapsulation and a ceramic substrate. Now they are more compact, transfer-molded epoxy modules with organic isolation, although this has been a big step for traction inverter IGBT modules. These compact and flexible designs help integrate power converters better. As part of this, double-sided cooling modules have spread throughout the EV/HEV industry. The first double-sided cooling modules were in Lexus cars, but now we have the well-known fourth generation Toyota Prius PowerCards and the latest Bosch, Infineon or Dynex modules. This has built a pathway towards power electronics and cooling system integration and optimized thermal management systems.

Another important aspect is the arrival of organic insulator foils that avoid expensive and rigid ceramic substrates. Surprisingly, the isolation layer itself shows lower thermal conductivity of up to 10 W/mK, compared to 24 W/mK for Alumina and up to 90 W/mK for Silicon Nitride. However, it offers design flexibility, with thicker insulated-metal substrate type structures with copper layers on top and bottom, which can optimize the thermal paths for each custom design. This new business will obviously threaten the ceramic substrate suppliers, who therefore need to counterattack with new, better adapted ceramic propositions. Integrated ceramic and baseplate substrate solutions, which can be found in Mitsubishi Electric modules, go in that direction.

Lstly, the report discusses the penetration of SiC MOSFETs in vehicle converters extensively. Some early adopters have already started using SiC, such as Chinese carmaker BYD in its onboard chargers, or US EV icon Tesla



for its Model 3 inverter. Nevertheless, SiC is still used in only small volumes, requiring a back-up solution with Silicon IGBTs. Other carmakers are even more conservative and do not see enough system-level benefits to adopt SiC MOSFETs. Yole also analyzes the potential of GaN power devices, but they're not yet mature enough to be implemented in electric cars in the short term.

Entitled "Automotive Power Modules, Design Changes and Technology Innovations to Come?" Yole Développement will held its Power Electronics Market Briefing on June 6, 2018 in the Industry Forum Area of PCIM Europe from 10:00 to 11:30 am.

www.yole.fr

Global Trends In Renewable Energies

The world installed a record number of new solar power projects in 2017, more than net additions of coal, gas and nuclear plants put together, according to a new study of Bloomberg/Frankfurt School-UNEP Centre. China has been the leading destination for renewable energy investment, accounting for 45 % of the global total last year. The country initiated 13 off-shore wind projects which, in addition to reducing emissions, will generate jobs in all stages of construction and operation. This demonstrates the potential for renewable energy to fight climate change and boost economic growth. Fossil fuel-rich countries are also showing strong progress, with the United Arab Emirates for example recording an astounding 29-fold increase in renewable energy investment in 2017.

The key findings of the study:

- A record 157 GW of renewable power were commissioned in 2017, up from 143 GW in 2016 and far out-stripping the 70 GW of net fossil fuel generating capacity added last year. Solar alone accounted for 98 GW, or 38 % of the net new power capacity coming on stream during 2017.
- The proportion of world electricity generated by wind, solar, biomass and waste-to-energy, geothermal, marine and small hydro rose from 11 % in 2016 to 12.1 % in 2017. This corresponds to approximately 1.8 gigatonnes of carbon dioxide emissions avoided.
- Global investment in renewable energy edged up 2 % in 2017 to $279.8 billion, taking cumulative investment since 2010 to $2.2 trillion, and since 2004 to $2.9 trillion. The latest rise in capital outlays took place in a context of further falls in the costs of wind and solar that made it possible to buy megawatts of equipment more cheaply than ever before.

The leading location by far for renewable energy investment in 2017 was China, which accounted for $126.6 billion, its highest figure ever and no less than 45 % of the global total. There was an extraordinary solar boom in that country in 2017, with some 53 GW installed (more than the whole world market as recently as 2014), and solar investment of $86.5 billion, up 58 %.

Renewable energy investment in the U.S. was far below China, at $40.5 billion, down 6 %. It was relatively resilient in the face of policy uncertainties, although changing business strategies affected small-scale solar.

Europe suffered a bigger decline, of 36 % to $40.9 billion. The biggest reason was a fall of 65 % in U.K. Investment to $7.6 billion, reflecting an end to subsidies for onshore wind and utility-scale solar, and a big gap between auctions for offshore wind projects. Germany also saw a drop in investment, of 35 % to $10.4 billion, on lower costs per MW for offshore wind, and uncertainty over a shift to auctions for onshore wind. The latter change was also one reason, along with grid connection issues, for a fall in Japanese outlays of 28 % to $13.4 billion.

All in all, costs continued to fall for solar, in particular. The benchmark levelized cost of electricity for a utility-scale photovoltaic project dropped to $86 per megawatt-hour, down 15 % on a year earlier and 72 % since 2009. Some of this was due to a fall in capital costs, some to improvements in efficiency. "The extraordinary surge in solar investment, around the world, shows how much can be achieved when we commit to growth without harming the environment," said Head of UN Environment Erik Solheim. "The world added more solar capacity than coal, gas, and nuclear plants combined," added Nils Stieglitz, President of Frankfurt School of Finance & Management. "This shows where we are heading, although the fact that renewables altogether are still far from providing the majority of electricity means that we still have a long way to go."

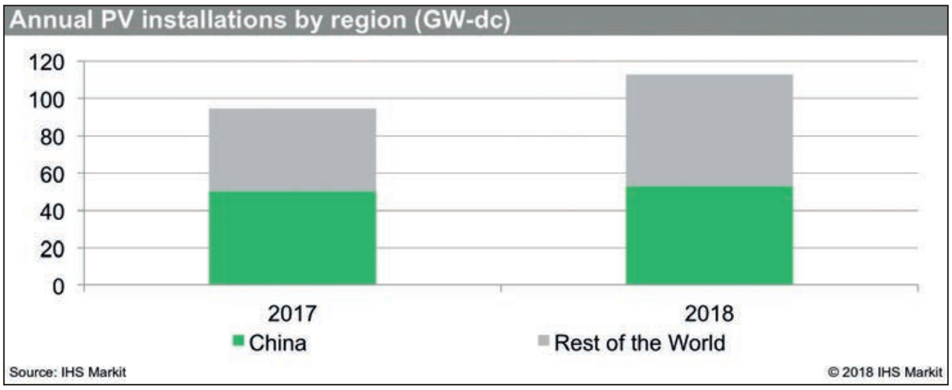
www.fs-unep-centre.org

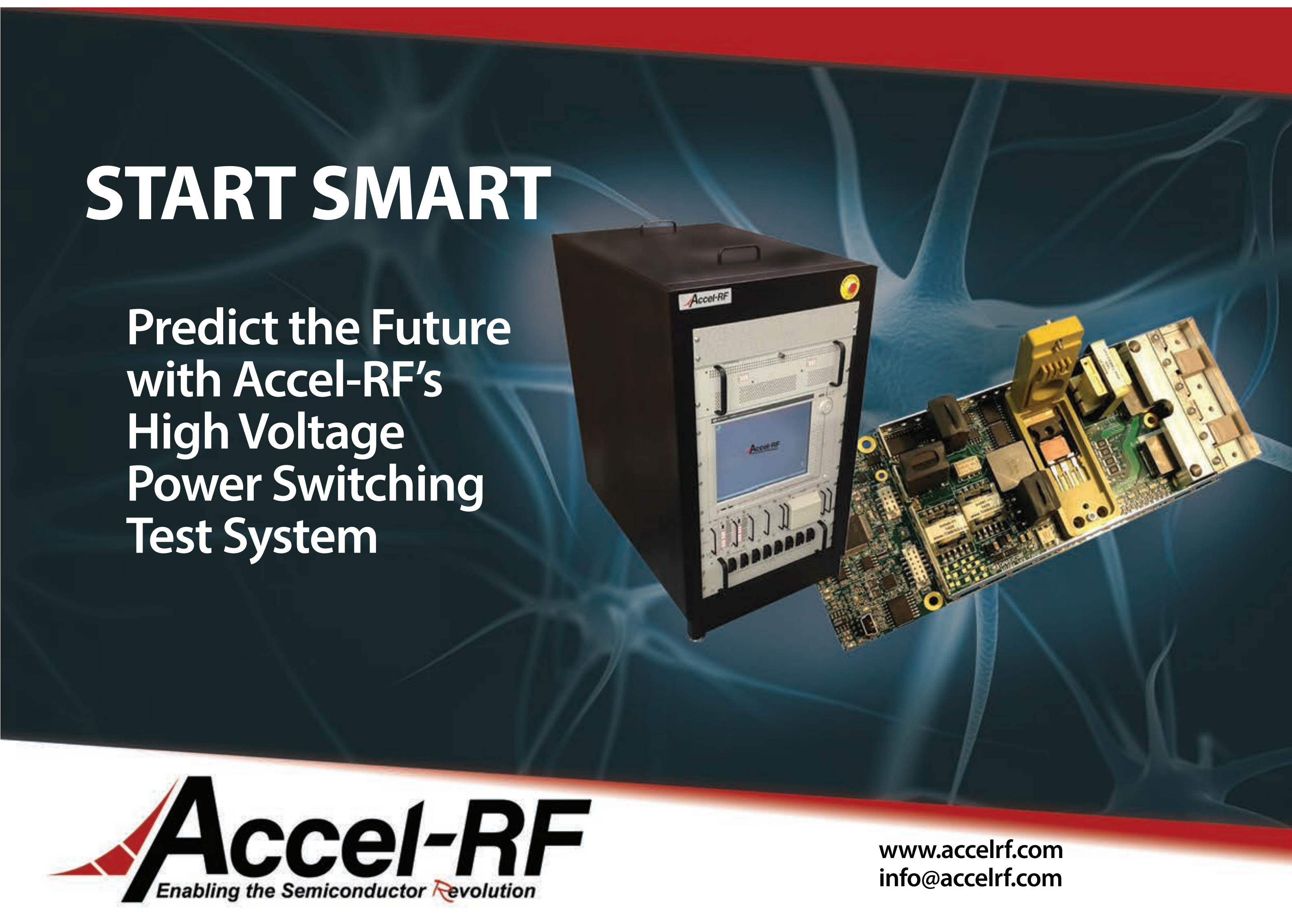
Global Solar PV Demand to Reach Record

Global solar photovoltaic (PV) demand is forecast to hit another annual record of 113 GW in 2018, propelled by strong demand anticipated in China. According to business information provider IHS Markit, burgeoning demand from the Chinese market is expected to persevere on the back of continuing policy support, a successful transition from a market that had been dominated by large ground-mount projects and strong momentum in the distributed-PV (DPV) sector. In particular, the fourth quarter of 2018 – with 34 GW of new PV installations – will be the largest quarter in history.

According to the latest edition of the new PV Installations Tracker, global solar installations will grow by 19 % in 2018, similar to the 20 % year-over-year growth in 2017. At this rate of installation, module availability will once again be the limiting factor, and prices may limit investment returns on solar projects already under contract to sell electricity at low prices. Stable module prices are expected throughout the year, which is a direct result of continued high demand. "This latest forecast is close to the global polysilicon limit manufacturers can supply," said Edurne Zoco, research and analysis director. "Tight supply and stable prices will continue throughout the year. Our forecast assumes manufacturers can further ramp up production, to meet demand, in the second half of the year. Demand is not only picking up in China, but also in India, where developers want to secure modules before any additional tariffs are introduced," Zoco said. "The United States continues to import modules, despite the latest import tariffs. In emerging markets, countries like Egypt, Brazil and Mexico have large PV projects requiring modules in 2018. Several projects that were postponed in 2017, due to high module prices, will need to be installed this year."

China will once again dominate global PV demand, reaching 53 GW with an upside potential of 60 GW in 2018, and comprising almost half (47 %) of the total market. "Demand in China will once again shape the global PV market. This year China will have feed-in tariff deadlines in the second and fourth quarters, which will create two sharp installation peaks,"Zoco said. Outside of China, India is forecast to overtake the United States





as the second largest PV market. Even if project profitability remains highly sensitive to module pricing, the fear of possible future import tariffs is likely to drive developers to complete installations in 2018. Emerging solar markets Mexico and Egypt will make up 1.8 % and 1.3 % of the solar market, respectively, replacing South Korea and the United Kingdom in the ranking of the 10 largest PV markets, in terms of annual PV installations.

www.ihsmarkit.com

Global Battery Energy Storage Reaches 10.4 GW Record

2017 was a record year for deployment of grid-connected battery energy storage. The Asia-Pacific region exhibited the strongest growth, led by South Korea, Japan and Australia. The three largest markets in 2017, accounting for over half of all installations globally, were South Korea, the United States and Japan.

This continued market growth was backed by an impressive project pipeline for grid-connected energy storage. While the geographic location of planned project activity is diversifying, the largest current pipelines are located in Australia, the United Kingdom, the United States and China.

Following are the four major battery energy storage pipeline global trends to watch in the coming year, according to IHS Markit analyst Julian Jansen: Solar-plus-storage co-location projects currently account for more than 40 % of the total utility-side-of-meter pipeline, highlighting the future potential of this market. The behind-the-meter segment will comprise more than half of annual installations, from 2023 onward. South Korea and Canada emerged as new key markets for commercial and industrial storage systems in 2017. Battery energy storage is challenging gas-fired peaker plants to meet California's capacity needs, leading to a significant increase in the outlook for large-scale energy storage in that state. New energy storage deployment targets, and the inclusion of storage in integrated resource planning across the United States, will drive future market growth across multiple states.

The global battery energy storage market gained significant momentum in early 2018. Emerging business models, such as gas-peaker replacement and renewable firming, have been successfully demonstrated, leading to a strong uptick in the global pipeline. This strong industry growth follows a highly active first quarter, with the following encouraging policy developments presaging a bright future for storage: FERC Order No. 841 will remove key regulatory barriers for electricity storage to participate in wholesale markets across the United States, creating a level playing field for storage to access new revenue streams. Irish grid operator EirGrid has published its consultation on the DS3 program, outlining potential six-year contracts that provide frequency response and reserve services to be launched in September 2018. New York State set a target to deploy 1,500 megawatts (MW) by 2025, supported by more than $260 million in funding to accelerate industry growth. Austria launched a federal subsidy program for small-scale solar plus storage, while several states in Germany announced the introduction of support programs for residential battery storage.

Thus more than 3 GW of battery energy storage is forecast to be deployed in 2018, but uncertainty over supply constraints – and potential cost increases for Li-ion batteries – may create unexpected challenges.

www.ihsmarkit.com

Global energy storage installations by country in 2017 (MW)

Source: IHS Markit

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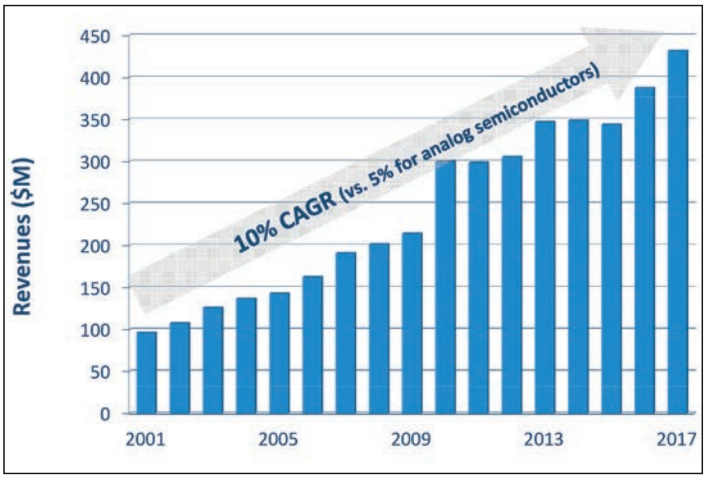
Power Integrations Reports Strong Growth

Power Integrations announced financial results for the quarter ended March 31, 2018. Net revenues were $103 million, a decrease of five percent from the prior quarter and a decrease of two percent from the first quarter of 2017.

"First-quarter revenues were consistent with our expectations, while gross margins exceeded our projections due mainly to a favorable end-market mix. Bookings strengthened compared with the prior quarter, and we expect healthy sequential revenue growth in the second quarter," commented Balu Balakrishnan, president and CEO.

In the just released Annual Report 2017 he stated: Our 2017 financial results featured double-digit revenue growth and strong cash flow, demonstrating the continued strength of our product portfolio, market positioning and financial model. We are capitalizing on global trends such as energy efficiency, clean power, faster charging for mobile devices, smart homes and the internet of things (IoT), the switch to battery power in areas such as tools and transportation, and the mass adoption of convenience and comfort appliances in developing markets. These trends are creating an ever-greater need for energy-efficient power-conversion technology.

PI's total revenues grew 11 % in 2017, led by the industrial and consumer



markets, which together accounted for more than 70 % of sales. Industrial revenues grew 20 %, driven by a broad range of vertical markets, some of which have only recently emerged and should have many years of growth ahead. Strong growth was in the home-and-building automation, or smart-home, category, which includes IoT applications such as smart lighting control, networked smoke alarms and occupancy sensors, smart plugs and USB wall outlets. Since many of these devices are permanently connected to the power grid and spend most of their lifetimes in standby mode, they require exceptionally low standby power consumption. And because they are often located in cramped, difficult-to-reach locations such as behind the wall or on the ceiling, reliability and compact footprints are also extremely important.

High-power gate-driver products also contributed significant growth in the industrial category, growing more than 20 % driven by renewable-energy applications and by the installation of high-voltage DC transmission infrastructure in China, which has embarked on a multi-year project to install a DC transmission grid capable of transporting power more efficiently over long distances than traditional AC infrastructure. Unlike AC transmission, which uses magnetic transformers, DC transmission facilities require highly sophisticated power-conversion electronics including high-voltage IGBT modules, each paired with a gate driver whose role is to ensure safe, reliable operation. With voltages running as high as a million volts, and with many millions of utility customers dependent on this infrastructure, reliability and safety are of the utmost importance in this application. "The fact that our SCALE-2 drivers have been chosen for this application is a testament to the strength of our gate-driver technology", Balakrishnan commented.

www.power.com

"The fact that our SCALE-2 drivers have been chosen for the HV DC transmission infrastructure in China is a testament to the strength of our gate-driver technology", PI's Balu Balakrishnan said

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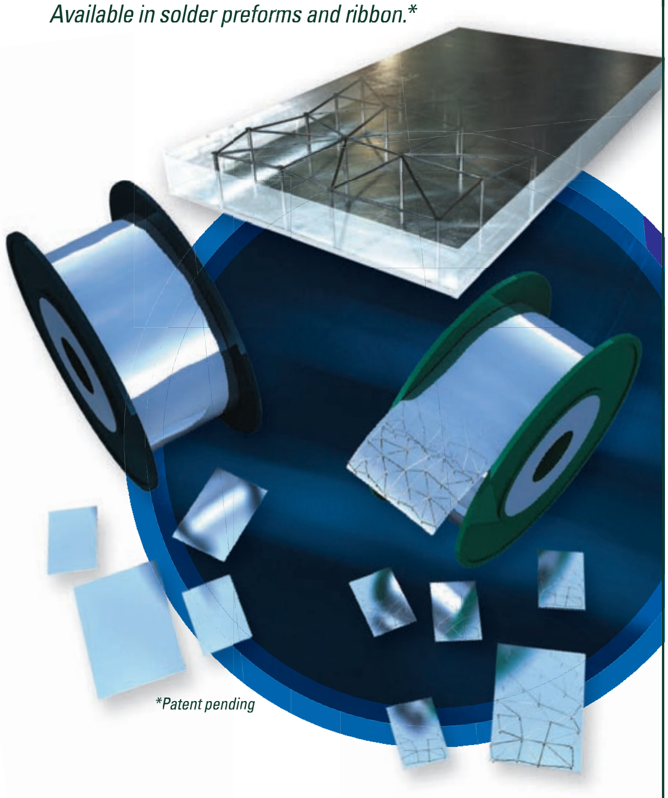
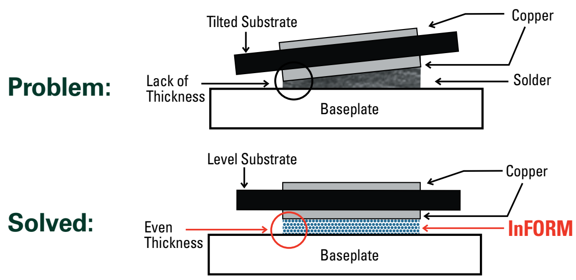
Reinforced Matrixed Solder Composite

*Available in solder preforms and ribbon.**



Uneven bondline thickness causes concentrated stress, which impacts reliability.

InFORMS® can help solve this challenge.



Common InFORM stand-offs:

Solder Preform Requirements			
Description	Stand-Off (Microns)	Part Dimensions (x and y) (Millimeters)	Part Dimensions (z) (Microns)
LM04	100	>10 per side	>150
LM06	150	>10 per side	>200
LM08	200	>10 per side	>250
SM04	100	2.5–10 per side	>150
ESM03	75	.75–2.5 per side	>125

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LF xx10
Current transducers
Pushing Hall effect to new limits

To save energy, you first need to measure it! To maximise energy savings, you need to measure the current used accurately!
By using the most advanced materials available, LEM's new LF xx10 transducer range breaks new ground in accuracy for Closed Loop Hall effect transducer performance.
LEM ASIC technology brings Closed Loop Hall effect transducer performance to the level of Fluxgate transducers and provides better control and increased system efficiency, but at a significantly lower price.
Available in 5 different sizes to work with nominal currents from 100 A to 2000 A, the LF xx10 range provides up to 5 times better global accuracy over their operating temperature range compared to the previous generation of Closed Loop Hall effect current transducers.
Quite simply, the LF xx10 range goes beyond what were previously thought of as the limits of Hall effect technology.

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- 5 compact sizes in a variety of mounting topologies (flat or vertical)
- Immunity from external fields for your compact design
- 100 % fully compatible vs LEM previous generation
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CTO of Würth Elektronik appointed to PSMA Board of Directors

Alexander Gerfer, CTO of Würth Elektronik eiSos Group, has been appointed to the Board of Directors of the Power Sources Manufacturers Association PSMA. The international association for power electronics has set itself the goal of increasing and propagating knowledge about technologies and developments in the context of energy sources and the transformation of energy.

"It is a great honor for me to join the board of directors of this prestigious organization. The PSMA has rendered outstanding service globally in the dissemination of knowledge in the electronics industry. I wish to help intensify these activities through my work," said Alexander Gerfer. "From my experience in application and design consultancy, I know as an engineer, you never stop learning. Particularly the new generation of SiC and GaN high power switches which has special challenges for us as a manufacturer of inductive components. Besides the transfer of practical knowledge, new core materials and package types are also important with a requirement for improved specification data. New topologies are also called for here in order to achieve maximum efficiency. I would like to support bridge building between university research and technical expertise in industry."

PSMA is a non-profit professional organization with the two-fold objective of enhancing the stature and reputation of its members and their products, and improving their technological power sources knowledge. Its aim is to educate the electronics industry, academia, government and industry communities as to the applications and importance of all types of power sources and conversion devices.

www.psma.com

PE Innovation Award 2018

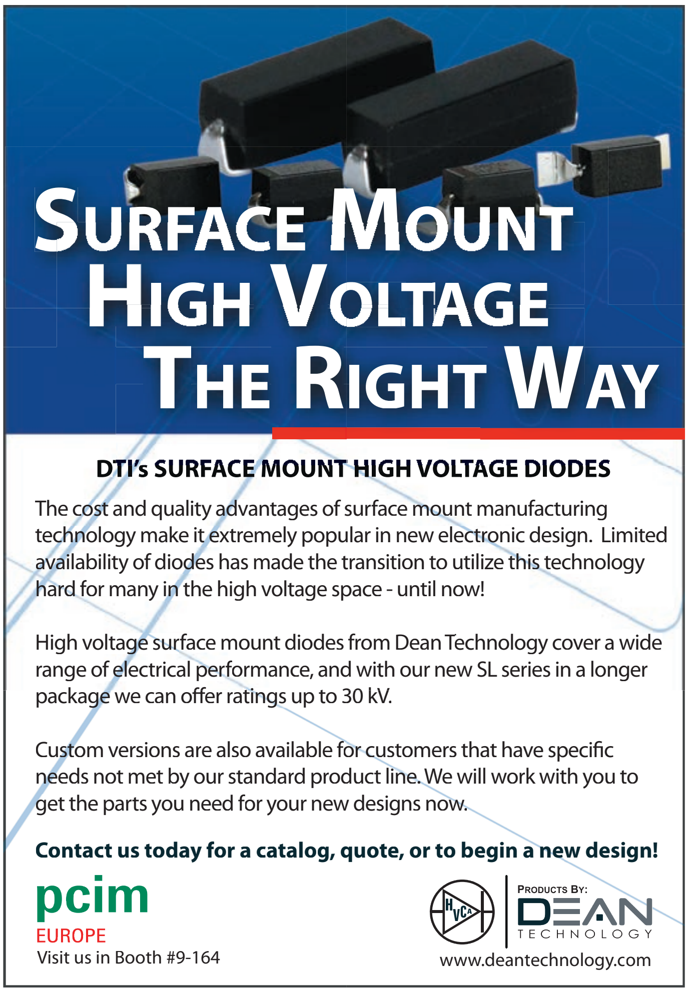
SEMIKRON Foundation and ECPE honored Stefan Matlok with the with the Innovation Award 2018 and Diogo Varajão for his work with the Young Engineer Award at CIPS 2018.

Ther Innovation Award 2018 to Stefan Matlok from Fraunhofer IISB in Erlangen, Germany honors his outstanding work on 'Zero Overvoltage Switching "ZOS". In power electronics turning off an electrical path is causing trouble by parasitic inductance leading to oscillations and voltage overshoot. The novel ZOS method offers the possibility to unleash unlimited switching speed in real-world applications without over-voltage on the semiconductors. Moreover, in best case, it is even avoiding any subsequent parasitic oscillation. The idea is to use the intrinsic parasitic inductances and parasitic capacities to build up a resonant circuit. The turn off event excites the resonant circuit and the free-wheeling diode stops it automatically after half a period, e.g. after a view nanoseconds. These resonant parasitic elements are thereby utilized to switch off a fixed current in a nearly lossless, over-voltage- and EMI compliant way. By designing the circuit and parasitics properly, there is no extra component necessary as parasitic inductance is now functional part of the topology.

The Young Engineer Award 2018 was given to Diogo Varajão from AddVolt AS in Porto, Portugal for his contributions on 'ACDC CUBE: Single-stage Bidirectional and Isolated AC-DC Matrix Converter for Battery Energy Storage Systems'. The ACDC CUBE technology consists in a new modulation and control strategy for the high-frequency link matrix converter. The matrix converter is a key element of the system, since it performs a direct AC to AC conversion between the grid and the power transformer, dispensing the traditional DC-link capacitors. Hence, the circuit volume and weight are reduced and a longer service life is expected when compared with the existing technical solutions. The innovation was validated through a prototype tested in the laboratory. Experimental results demonstrate the capability to control the grid currents in the synchronous reference frame in order to provide services for the grid operator. Additionally, the battery current is well regulated with small ripple which makes this converter appropriate for battery charging of EVs and energy storage applications.

www.semikron-stiftung.com

Innovation Awardees Stefan Matlok (left) and Diogo Varajão



High Performance p-GaN HEMTs on CTE-matched Substrates

Belgium-based imec and fabless Qromis have announced the development of high performance enhancement mode p-GaN power devices on 200 mm CTE-matched substrates, processed in imec's Silicon pilot line and offered by Qromis as commercial 200mm QST® substrates.

Today, GaN-on-Si technology is the industry standard platform for commercial GaN power switching devices for wafer diameters up to 150 mm/6 inch. Imec has developed GaN-on-Si power technology for 200 mm/8 inch wafers and qualified enhancement mode HEMT and Schottky diode power devices for 100 V, 200 V and 650 V operating voltage ranges, paving the way to high volume manufacturing applications.

However, for applications beyond 650 V such as electric cars and renewable energy, it has become difficult to further increase the buffer thickness on 200 mm wafers to the levels required for higher breakdown and low leakage levels, because of the mismatch in coefficient of thermal expansion (CTE) between the GaN/AlGaN epitaxial layers and the Silicon substrate. One can envisage to use thicker Si substrates to keep wafer warp and bow under control for 900 V and 1200 V applications, but practice has learned that for these higher voltage ranges, the mechanical strength is a concern in high volume manufacturing, and the ever thicker wafers can cause compatibility issues in wafer handling in some processing tools.

Towards vertical GaN on Silicon

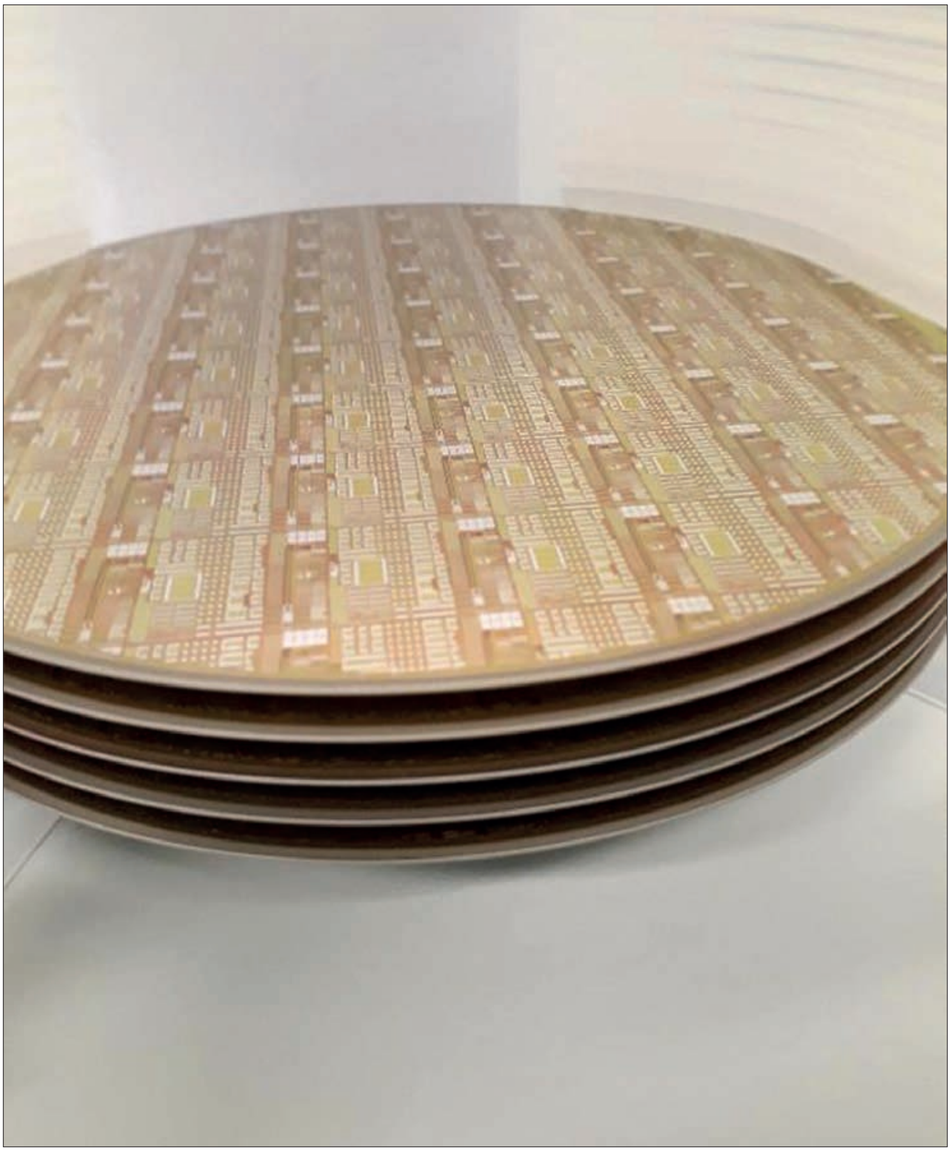
Carefully engineered and CMOS fab-friendly QST substrates with a CTE-matched core having a thermal expansion that very closely matches the thermal expansion of the GaN/AlGaN epitaxial layers, are paving the way to 900 - 1200 V buffers and beyond, on a standard semi-spec thickness 200 mm substrate. Moreover, these substrates open perspectives for very thick GaN buffers, including realization of free-standing and very low dislocation density GaN substrates by >100 micron thick fast-growth epitaxial layers. These unique features will enable long awaited commercial vertical GaN power switches and rectifiers suitable for high voltage and high current applications presently dominated by Si IGBTs and SiC power FETs and diodes.

"QST is revolutionizing GaN technologies and businesses for 200 mm and 300 mm platforms", stated Cem Basceri, President and CEO of Qromis. "I am very pleased to see the successful demonstration of high performance GaN power devices by stacking leading edge technologies from Qromis, imec and AIXTRON."

In this specific collaboration, imec and Qromis developed enhancement mode p-GaN power device specific GaN epitaxial layers on 200 mm QST substrates, with buffers grown in AIXTRON's G5+ C 200 mm high volume manufacturing MOCVD system. Qromis, Inc., established in March 2015 and located in Silicon Valley, California, is a privately held fabless technology innovator focusing on energy efficient and high performance wide bandgap (WBG) semiconductor materials and device solutions.

Imec then ported its p-GaN enhancement mode power device technology to the 200 mm GaN-on- QST substrates in their Silicon pilotline and demonstrated high performance power devices with threshold voltage of 2.8 V. "The engineered substrates facilitated a seamless porting of our process of reference from thick GaN-on-Si substrates to standard thickness GaN-on- QST substrates using the AIX G5+ C system, in a joint effort of imec, Qromis and AIXTRON," stated Stefaan Decoutere, program director for GaN power technology at imec. The careful selection of the material for the core of the substrates, and the development of the light-blocking wrapping layers resulted in fab-compatible standard thickness substrates and first-time-right processing of the power devices.

www.imec.be, www.qromis.com



200 mm QST substrates having a thermal expansion that very closely matches the thermal expansion of the GaN/AlGaN epitaxial layers
Source: imec/Qromis

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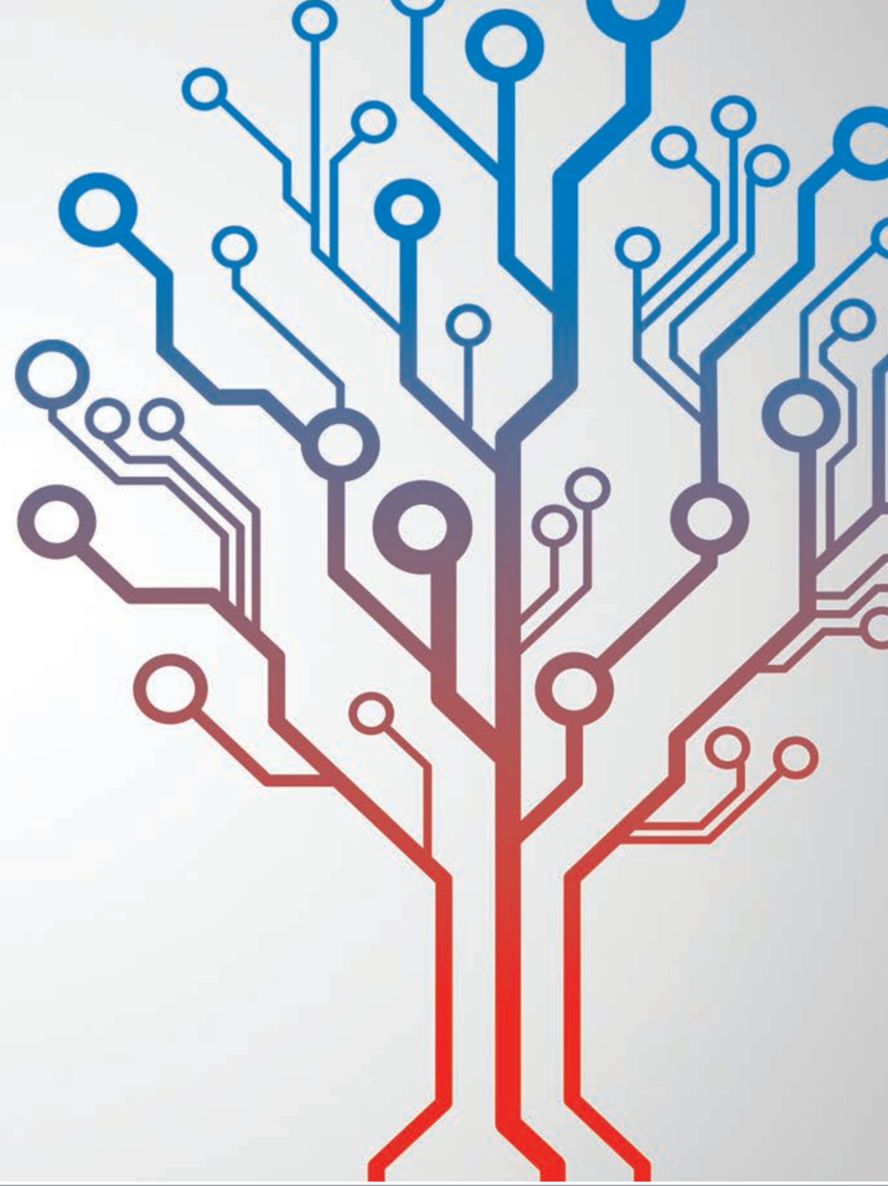

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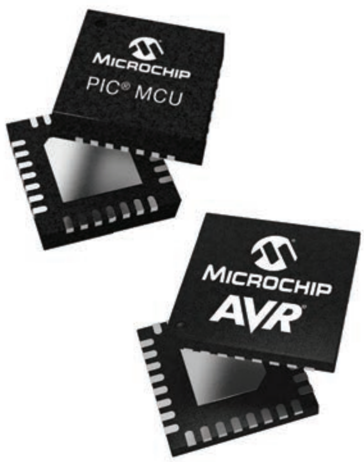

Key Features

- Autonomous peripherals
- Low-power performance
- Industry-leading robustness
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pcim
EUROPE
Nuremberg, 5 – 7 June 2018

The Power Of PCIM 2018

The PCIM Conference & Exhibition from 5 - 7 June 2018 in Nuremberg again is expected to hit previous numbers. The list of exhibitors already includes over 470 companies, 51 % of them are from abroad. In 2017 the exhibition counted a total of 465 exhibitors. The focus of products will be on power semiconductors and passive components which are offered by 36 % of exhibitors; this is followed by power converters / power supply and thermal management (25 % respectively) as well as coils and magnetic materials (20 %).

The international conference connects the worlds of research and industry with over 300 papers (Power Electronics 74, Intelligent Motion 24, Renewable Energy and Energy Mgmt. 13, 187 Poster Papers on the Tuesday and Wednesday afternoon with free entry for the exhibition visitors), making it the meeting point for experts in power electronics and users. On every day of the conference, a renowned keynote speaker will provide insights into the future of selected power electronics topics.

Seminars and tutorials

Already on the Sunday, June 3, six seminars will be held in the Arvena Park Hotel. Topics include Basics of Electromagnetic Compatibility (EMC) of Power Systems; Diagnosing and Locating Sources of EMI in Switchmode Power Converters; Wide Band Gap (WBG) Power Devices, Characterisation, Simulation and Testing; Modern Magnetic Technologies for High Efficiency and High Power Density; Functional Safety - an Introduction for Inverter and Servo Drive Developers; and Design of Magnetic Components for High Power Converters.

Nine Tutorials will be held also in the Arvena Park on the Monday, June 4. Subjects include Modern Soft Switching Technologies; Design of Multilevel Converter Systems; Electromagnetic Design of High Frequency Converters and Drives; High Performance Control of Power Converters; Advanced System Design with Ultra-Fast Si/SiC/GaN Power Semiconductor Devices;

From June 5 - 7 again PCIM Conference & Exhibition in Nuremberg calls for exhibitors, visitors and conference delegates

Switchmode Printed Circuit Board Design and Layout for Low EMI; Reliability of Si and SiC Power Devices and Packages: Reliability Engineering in Power Electronic Systems; and Magnetic Components - The Key to Future Power Electronic Circuits.

Keynotes on current trends

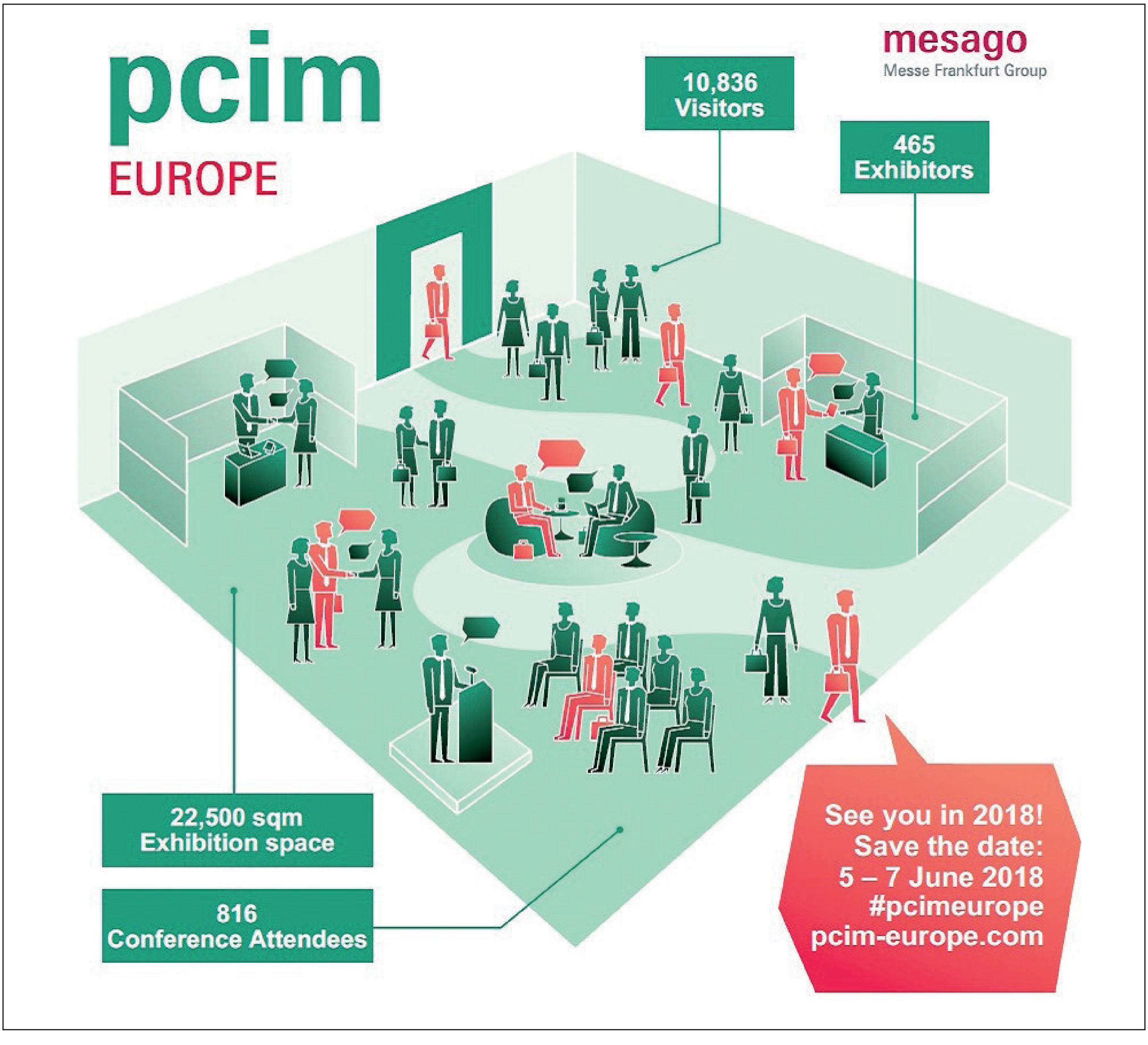
On the Tuesday (June 5) "Electric Vehicles Charging - An Ultrafast Overview" will be by Drazen Dujic, Power Electronics Laboratory, EPFL, CH. Electric vehicles charging infrastructure, its costs, availability and performances represent very important factors that will directly impact smoothness of mobility transition and is wider deployment. There are varieties of the electrical vehicles charging technologies, standards, requirements, different technological approaches and different charging levels (both in power and time). The keynote will cover the broad topic of electric vehicles charging and provide an overview of the past and present developments as well as future trends in this field.

On the Wednesday the important subject "New Passive Devices in Power Conversion - Nice to Have or a MUST", will be presented by Petar J. Grbovic, Huawei Technologies, D. Power electronics play significant role in industrial applications, power generation, home appliance, transportation, etc., etc. Until today, significant research effort has been made in the field of power semiconductors and control circuitry. However, somehow minor research effort has been made in the field of passive devices. The Key Note will address the need to invest more in Passive Devices: Magnetic material for medium, high and very high frequencies, capacitors for very high current applications, system integration, passive current sensors and PCB integration.

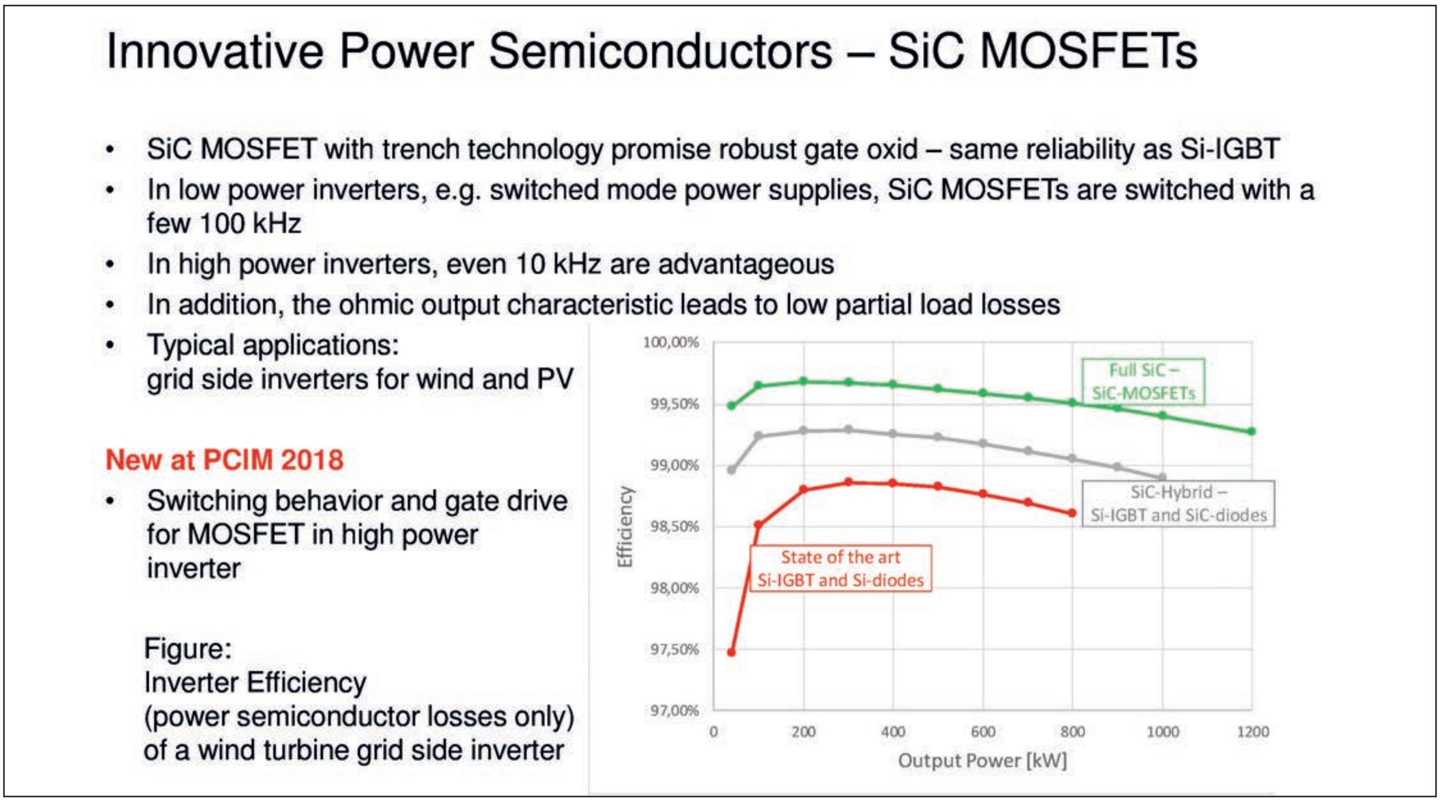
On the Thursday "Modular Multilevel Submodules for Converters, from the State of the Art to Future Trends", will be introduced by Markus Billmann, Fraunhofer Institute IISB, D. Modular Multi Level Converters have become a mature and proven technology. This paper describes the need for a next step which should be standardization for the submodules of an MMC converter. A submodule that will combine recent topology improvements with latest available semiconductors is described. As it is difficult to pick one of the actual global players to set one new standard, an option to solve such political challenges is also identified.

Special sessions

A Special Session "Advanced Solutions for Charging of Electric Vehicles" on



Facts & figures of PCIM 2017

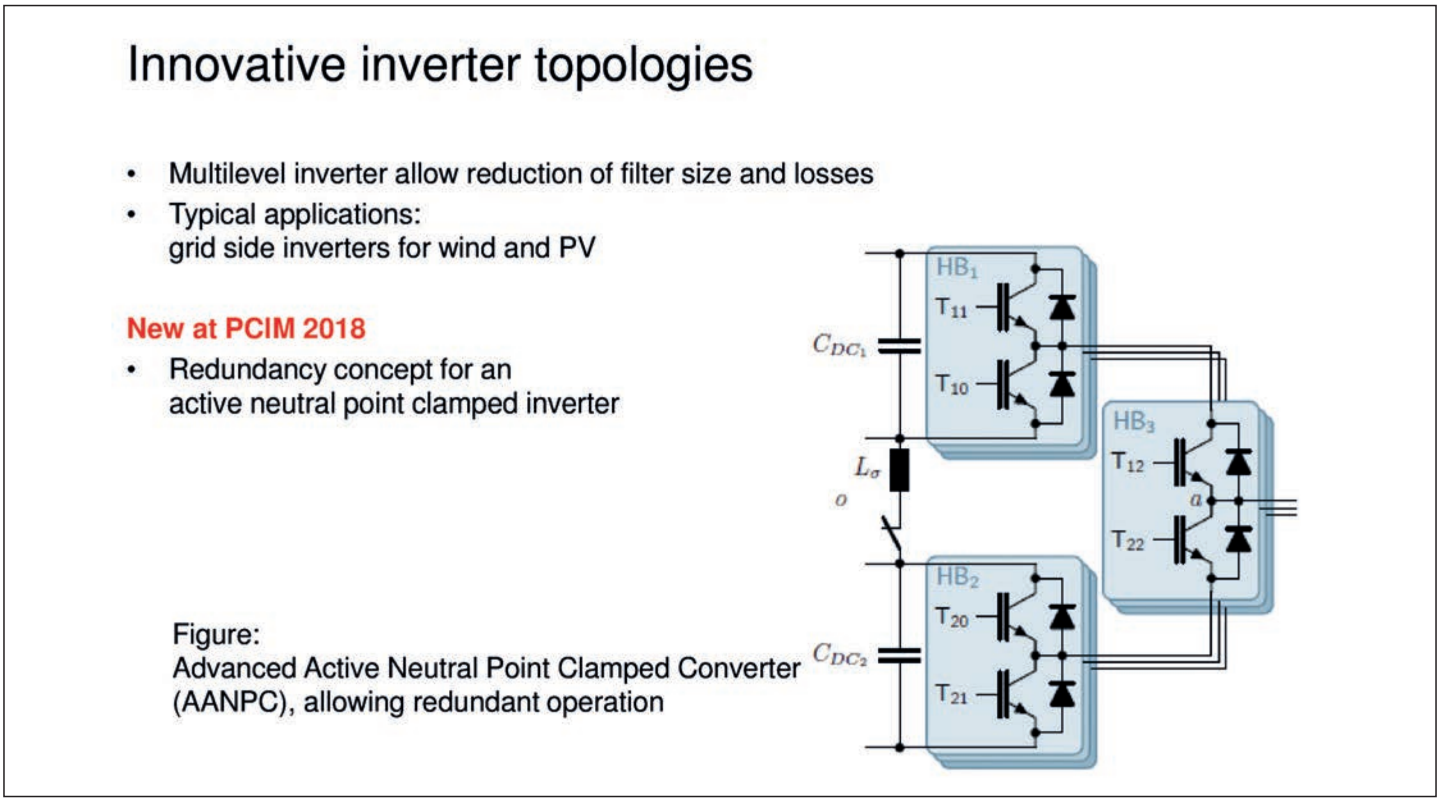


SiC MOSFETs and its applications will play an important role at PCIM 2018 **(Source: Institut für Elektrische Energietechnik, Prof. Eckel)**

the Tuesday morning follows the subject of the first keynote comprising three papers. “85 kHz Band Wireless Charging System for EV or Electric Bus” by Akihisa Matsushita, Toshiba, JP. The company have developed a 44 kW wireless charging system for electric buses, which achieves a reduction in radiated electromagnetic emissions by devising structure alignment. The receive output power of 44 kW or more was confirmed by test verification. And system efficiency exceeds 85 %. Tests have verified that these wireless charging systems offer enhanced convenience and achieve the targeted power transmission efficiency. “Advanced Vehicle Charging Solutions Using SiC and GaN Power Devices” will be introduced by Bernd Eckardt, Fraunhofer Institute IISB, Erlangen D. Very compact and highly efficient charging solutions for plug-in hybrid and full electric vehicles are mandatory for the break trough of electric mobility. Therefore designs for uni- and bidirectional chargers using SiC and GaN devices are presented. In the very challenging field of inductive charging, a small, lightweight solution is shown and the benefits of SiC MOSFETs compared to Si devices are evaluated. “System Architectures for Multiple Ports, Bidirectional and Buffered Charging Unit for EVs” will be covered by Alfred Rufer, EPFL, CH. Bidirectional buffered units for Multi-port charging of EVs allowing to charge with high power even if the line current capability is limited. The systems are also dedicated to operate as reactive power compensators, or to provide grid system services as V2G operation or other power smoothing functions.

A parallel Special Session entitled “Materials for Packaging and Thermal Management” deals in four papers with the extended temperature range of power modules, crucial for Silicon Carbide applications. The “Development of High Temperature Silicone Gels” will be illustrated by Makoto Ohara, Shin-Etsu Silicones, Wiesbaden, D. Market requirements to packaging material (Silicone Gel), what happens when it’s exposed high temperature, how to overcome these failure modes and introduction of the latest high temperature gels and future targets are the subjects. “Silicone Gels for Continuous Operation up to 200°C in Power Modules” will be introduced by Thomas Seldrum, Dow Chemical, Seneffe, B. A Silicone Gel with high temperature resistance (up to 215°C for more than 2000 hours) has been developed. The mechanical softness and high elongation at break, together with the electrical performances have been preserved via formulation engineering and use of additives that can prevent the oxidative degradation mechanisms. “High Temperature Encapsulation for Smart Power Devices” is the title of a paper given by Karl-Friedrich Becker, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration IZM, Berlin, D. It contains a detailed description of the high temperature suitability of encapsulants for power electronics encapsulation, additionally an extended test methodology is described to facilitate future material evaluation for HT or harsh environment use of polymeric materials as encapsulants or base materials. “Next-Generation PPS Grades for Power Module Applications” will be described by Christian Schirmer, Toray Resins Europe GmbH, Neu-Isenburg, D. Greater toughness is sought in PPS (Polyphenylene Sulfide) electrical housings to enable simplified assembly procedures. The development uses proprietary Nanoalloy compounding technology to enhance the mechanical properties of the PPS compounds. This effort seeks to balance trade-offs in formulation to maintain comparative tracking performance (CTI 600V) while increasing toughness.

The third Special Session on “Passive Components” will take place on the Wednesday morning comprising five papers. The “Design and Optimization Method of PCB-Integrated Inductors for High-Frequency Converters” describes Ammar Chafi, University of Lille, F. Power electronics converters require energy storage components. The DC/DC converters need the magnetic storage components which take a large volume. The new power GaN transistors allow to increase the operating frequency of the power converter. The consequence is a reduction of the values and the dimensions of the passive components - mainly the inductors. A design method for PCB-integrated inductors is proposed, based on the optimization approach of inductors volume. “Simulating the Parasitic Capacitance of Inductive Components” will be introduced by Stefan Schefler, EPCOS, Heidenheim, D. A simulation based method for calculating the parasitic capacitance of inductive devices is presented. The method allows the consideration of the influence of the magnetic material which is very important for practical applications. Additionally, different winding techniques can be taken into account in the calculations. With an example how the winding technique affects the overall parasitic capacitance will be shown. “Future Winding for Next Power Electronic Generation” is the title of the paper given by Dennis Kampen, BLOCK Transformatoren-Elektronik, Verden, D. In this paper a new winding technique is presented. The new design offers significant



New Neutral Point Clamped Converter topologies allows for redundant operation **(Source: Institut für Elektrische Energietechnik, Prof. Eckel)**

advantages in life time, losses, potential control, cooling, current density and cost. "Ripple Current Determination for Inductors in a DC/DC Converter Both With and Without Magnetic Bias" will be described by Tobias Appel, Spezial-Transformatoren-Stockach, D. A study of inductor models applicable in a DC/DC converter is presented. The main focus is to determine the optimum ripple current with respect to given boundary conditions e.g. a saturation flux density with and without magnetic bias. It becomes clear that different flux densities require different ripple current determination. It is a guideline for determination optimal ripple currents for different inductor designs. Finally, "Development of Accelerated Testing of Thermal Degradation in Metallized Ceramic Substrates for SiC Power Modules" will be discussed by Hiroyuki Miyazaki, AIST, Nagoya, JP. In order to shorten the testing time of thermal cycling for metallized ceramic substrates, a new accelerated fatigue test was developed. Maximum tensile stress in the ceramics during thermal cycle was estimated by FEM analysis. The stress swing in the ceramic substrates during the thermal cycling was simulated by 4-point bending the test piece repeatedly at a constant temperature. The time to failure by repeated loading for some ceramic substrates was about 1/100 of the time to delamination of the copper plate by the thermal cycling.

SiC based power modules and devices

The session on the Tuesday morning cover in four papers the ongoing transition from IGBT to SiC MOSFET power modules in demanding applications.

A "New SiC 1200V Power MOSFET & Compact Power Module for Industrial Applications" will be introduced by Jeffrey Casady, Wolfspeed, Durham, USA. For the first time, a new SiC chip & module combination is designed and characterized for optimal performance and cost. The chip is a 1200 V, 13 mΩ SiC MOSFET designed for a half-bridge power module with no need for individual RG inside the module, improved shoot-through immunity, low R_{DSON} of 23 mΩ at 175°C, and low C_{RSS} of 12 pF. The compact 41 mm module allows up to four MOSFETs per switch, I_{DS} rating of 340 A (~ 7x higher than Si baseline modules) and lower R_{DSON} (3.25 mΩ) than commercial SiC modules over twice its size. A "Wire-bond-less 10 kV SiC MOSFET Power Module with Reduced Common-mode Noise and Electric Field" is the paper entitled presented by Christina DiMarino, CPES, Viriginia Tech, Blacksburg, USA. While wide-bandgap devices offer many benefits, they also bring new challenges. The new 10 kV SiC MOSFETs can switch higher voltages faster and with lower losses than Silicon devices while also being smaller in size. In order to fully utilize the benefits of these unique devices, this work proposes a module package with high power density (18 W/mm^3), increased partial discharge inception voltage (67 %), low thermal resistance (0.38 K/W junction-to-ambient), small inductance (4 nH), fast switching (200 V/ns), and reduced common-mode noise (50 %). "Enhanced Breakdown Voltage and High Current of All-SiC Modules with 1st Generation Trench Gate SiC MOSFETs" will be introduced by Motohito Hori, Fuji Electric, Matsumoto, Nagano, JP. In order to expand the application range of Silicone Carbide, SiC modules with 1st generation trench gate SiC MOSFETs from small capacity to large capacity were developed. This paper presents the package technologies of enhanced breakdown voltage and high current for All-SiC modules. Finally, "Highly Integrated SiC-power Modules for Ultra-Fast Lithium Ion Battery Chargers in LLC-Topology" will be described by Thomas Blank, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, D. A compact version of a SiC LLC converter for ultra-fast-charging of lithium-ion batteries is presented. The module can deliver a power of 40 kW, paralleled up to 350 kW. The system has been designed for highest reliability in a 24h/7d scenario. An Aurix processor controls the system. The SiC power devices are integrated in an Econopack 2, utilizing Si3N4 substrates, silver sinter die attach and CuCoreAl bonding technology. The LLC resonant tank is immersion cooled. Hence, a reliable, highly integrated ultra-fast charging system is realized.

The oral session "SiC Devices I" on the Tuesday afternoon (14:00 – 15:15) covers three papers. A "3.3 kV/800 A Ultra-High Power Density SiC Power Module" will be introduced by Takashi Ishigaki, Hitachi Power Semiconductor Device, Ibaraki, JP. The SiC power module adopts the next High Power Density Dual (nHPD2) package. The ultra-high power density value of 37.7 kVA/cm? was realized by constituting the module with only SiC-MOSFETs. Furthermore, as a countermeasure for "bipolar degradation" issues of body diodes in SiC-MOSFET, also new high-throughput screening process technology was deployed. The low-loss and high reliability characteristics of the module are demonstrated. "Efficiency Investigation of

Full-SiC versus Si-based Automotive Inverter Power Modules at Equal Commutation Speed" is the title of the paper given by Ajay Poonjal Pai, Infineon Technologies, Neubiberg, D.This paper investigates the mission profile efficiency performance of a 1200 V full-SiC Module based on Automotive CoolSiC technology, suitable for traction inverter applications. This module is compared against a full-Silicon module with Si Insulated Gate Bipolar Transistors (IGBTs)/diodes, and a hybrid SiC module with Si IGBTs and SiC diodes. "Applying the 2D-Short Circuit Detection Method to SiC MOSFETs Including an Advanced Soft Turn Off" will be demonstrated by Patrick Hofstetter, University of Bayreuth, D. To address the problem of small short circuit withstand times of SiC MOSFETs, this paper presents a short circuit protection, which detects the fault close to the earliest time possible and turns off the device safely. For the detection, the 2D-short circuit detection method was adapted to SiC MOSFETs. As SiC MOSFETs have to be turned off softly, a turn off strategy is shown which is able to turn-off the device during a short circuit type 1 and a short circuit type 2 in an optimized way.

The oral session "SiC Devices II" on the Wednesday afternoon also consists of three papers. The paper "Beyond the Datasheet: Commercialization of 700 V - 1.7 kV SiC Devices with Exceptional Ruggedness for Automotive & Industrial Applications" by Avinash Kashyap, Microsemi, Bend, USA, will discuss (a) Microsemi's approach to create widespread adoption of SiC devices via rapid commercialization, and (b) key ruggedness metrics based on industry feedback that is not commonly presented in either datasheets or qual standards, but can potentially unearth underlying device and package weaknesses undermining reliable long-term operation. A "6.5-kV Full-SiC Power Module (HV100) with SBD-embedded SiC-MOSFETs" will be introduced by Junichi Nakashima, Mitsubishi Electric, Hyogo, JP. The company has developed a 6.5 kV Full SiC power module with HV100 standardized package. The devices are the SBD-embedded SiC-MOSFETs. Embedding SBDs within the SiC-MOSFET can suppress bipolar degradation and reduce recovery current of the body diode in the MOSFET. "Is an Antiparallel SiC-Schottky Diode Necessary? Calorimetric Analysis of SiC-MOSFETs Switching Behavior", this question will be raised by Otto Kreutzer, Fraunhofer Institute IISB, Erlangen, D. Within this paper the switching losses of a Wolfspeed bare die SiC-MOSFET are measured in a hard switching 800 V DC/DC-converter with five different commutation partners. A small and a large SiC Schottky diode, a SiC-MOSFET body diode and a combination of body and Schottky diode are compared at different switching speeds and switching currents. The results show quite well the reverse recovery charge dependence of SiC-MOSFET?s body diode on switching speed.

Gate drivers

The oral session "Gate Driver" on the Wednesday morning covers in five presentations the important aspects of safely driving devices and modules. "IGBT Power Stage Delay Calibration is Minimizing Current Imbalance in Large Power Modules with Isolated Multiply Segmented Paralleled Half Bridges" is the paper entitled from Sven Teuber, SEMIKRON Elektronik, Nürnberg, D. The paper comprises an overview about the utilized IGBT driver methods to drive multiply paralleled power stages like IGBT modules. Typical drawbacks of the approaches found in practice and the logical conclusion to propose a totally delay matched and low jitter configuration that allows clustering of up to 12 individual power blades by individually digitally tuned gate drivers. The measurement of existing standard solutions and the results of the described totally matched approach is shown and the corresponding topologies and experimental switching test results are presented in this paper. A"Performance Comparison Between Voltage Source and Current Source Gate Drive Systems" will be presented by Wolfgang Frank, Infineon Technologies, Neubiberg, D. This paper presents the comparison of two gate driver boards, which are operated with the same power module. One solution is realized using a gate current control driver IC, while the other solution uses a conventional gate driver IC with external buffer. The power module is a 1200 A / 1200 V module designed for high power applications. The functionality of both boards is analysed and the switching performance is compared. "High-Side Driver Supply With Reduced Coupling Capacitance" will be introduced by Jens Friebe, Leibniz University Hannover, D. The capacitive coupling of high-side driver circuits is in the range of the output capacitance of new semiconductors. To reduce the negative impact of the capacitive coupling, in particular common mode currents into the heatsink, a new gate drive supply circuitry is presented, discussed and verified with laboratory measurements. Moreover, the impact on the inductor design is being discussed, including a description of further optimization potentials. "An Isolated Voltage-Source Integrated SiC Gate Driver IC with a Slew Rate Adjusting for Gate-Resistance-Free" will be discussed by Yasufumi Kawai, Panasonic Corporation, Moriguchi City, JP. This work presents a novel galvanic isolated gate driver IC, which drives a SiC power device by itself without any isolated voltage source, buffer ICs and gate resistances due to its internal wireless signal power transmission and slew rate adjusting function. The fabricated compact gate driver with a 5 V power supply successfully drives a 120 A SiC power device stably up to 30 kHz. This demonstrates a new technique to drive a SiC power device without negative gate bias at off-state by eliminating the gate inductance. "A Gate Driver Approach using Inductive Feedback to Decrease the Turn-on Losses of Power Transistors" will be presented by Michael Ebli, Technical University Dortmund, D. A novel gate driver approach for power transistors is introduced, allowing to decrease the turn-on losses of power transistors. The decrease in turn-on switching losses is possible through a transformer, which couples energy from the power current path to the control current path. Measurements of a 650 V SJ MOSFET show a turn-on energy reduction of up to 30 %.

GaN session

The oral session "GaN Devices" on the Thursday (June7), 14:00 – 15:15, also covers three papers. The work "High Power Nanosecond Pulse Laser Driver Using an eGaN®FET" by John Glaser, Efficient Power Conversion, El Segundo, USA, describes a laser driver using commercial GaN FETs to achieve a high power, high speed pulse laser driver capable of operating from an 80 V bus, and can generate current pulses into a laser diode of 60 A peak current with a 5 ns duration. Thw work "Towards Highly-Integrated High-Voltage Multi-MHz GaN-on-Si Power ICs and Modules" by Stefan Moench, Fraunhofer IAF, Freiburg, D, discusses integration and packaging approaches using 600 V GaN-on-Si technology. The influence of a common conductive Si substrate on circuit performance is investigated. A 300 V DC/DC converter (97 % efficiency) is built to compare separately source-connected and common semi-floating substrate terminations of the high-/low-side circuits. Operation of a GaN-based half-bridge with integrated gate-driver on a common substrate is demonstrated, emulating a fully-integrated solution. Finally, a "6.78 MHz Multi Amplifier and Transmit Coil eGaN® FET based Class-E Wireless Power System" using multiple high Zout class E amplifiers driving partially overlapped coils is presented by Michael de Rooij, Efficient Power Conversion, El Segundo. Experimentation shows that high Zout amplifiers inherently isolate from each to balance load sharing for receivers that straddle across two or more coils. Only eGaN FET based class E amplifiers can simultaneously achieve high efficiency and high output impedance making them ideal for this application.

Other oral sessions feature Traction Inverters; Intelligent Motion; Advanced Packaging Technologies I; Power Electronics Topologies; Multi-Level Converters; Energy Storage; High Power IGBT Devices; Converter Design and Integration; Control in Power Electronics; High Power IGBT System Applications; Advanced Packaging Technologies II; HVDC Transmission Systems; Software Tools and Applications; Reliability SiC Devices; Power Modules & Smart Driver; Reverse Conducting IGBTs; High Frequency Converters; System Reliability; Power Converters; and Advanced Sensors.

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SiC-Based Power Modules Cut Costs for Battery-Powered Vehicles

Demand for plug-in hybrid and all-electric vehicles is growing significantly, driven by, amongst other things, stricter emission regulations. However, current and future requirements call for further advances in efficiency and power density. Where Silicon plateaus in terms of performance, Silicon Carbide (SiC) presents a highly efficient alternative. **Laurent Beaurenaut, Principal Engineer, Infineon Technologies, Germany**

These vehicles are packed full of power electronics – most of which to date have usually been based on Silicon (Figure 1). In xEV drive trains, SiC circuits facilitate smaller chip dimensions with the same performance data offering advantages such as reduced switching losses and thus higher switching frequencies. Corresponding packaging technology renders more efficient, lighter and more compact power modules and discrete solutions possible compared to previous systems. Typical applications that benefit from SiC chips and optimised power modules include the main inverter, on-board charging electronics, boosters and DC/DC converters.

SiC components have been on the market for about two decades. However, their use in vehicles was limited for cost and partly for quality reasons. To date, wafer dimensions for SiC have generally been much smaller than for Silicon. The availability of high-quality 150 mm (6-inch) SiC wafers increases productivity in manufacturing SiC chips (Figure 2). Initially dominated by smaller, specialized companies, leading semiconductor companies now process SiC components on standard equipment with high outputs and high reliability. This results in promising cost developments for SiC. The latest generation of SiC trench MOSFETs also exhibits advances in gate oxide reliability, making them ideal for automotive applications.

Comparison of Silicon and Silicon Carbide

Compared to conventional Silicon-based high-voltage IGBTs or MOSFETs (> 600 V), SiC MOSFETs offer several advantages. For example, Infineon's 1200V SiC MOSFETs (CoolSiC) have lower gate charge and capacitance values than IGBTs, as well as minimal body diode reverse recovery losses. This results in switching losses, which are significantly lower compared to Silicon and also independent of the temperature (Figure 3). In addition, MOSFETs exhibit a resistance-like output characteristic, while in IGBTs this is similar to a diode. The threshold-free on-state characteristic results in smaller leakage losses in the part-load range.

The fundamental advantages not only make SiC MOSFETs ideal for operation at higher frequencies such as on-board charging circuits and DC/DC converters,

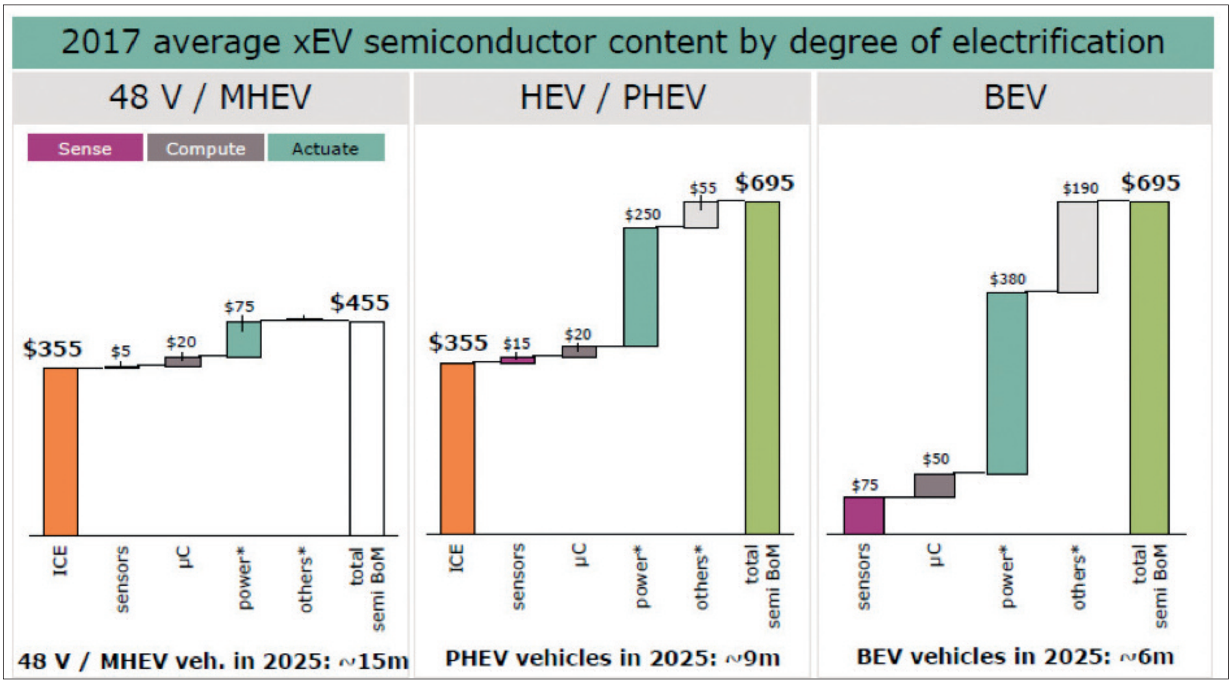

Figure 1: **Average proportion of semiconductors in xEV applications depending on the degree of electrification**

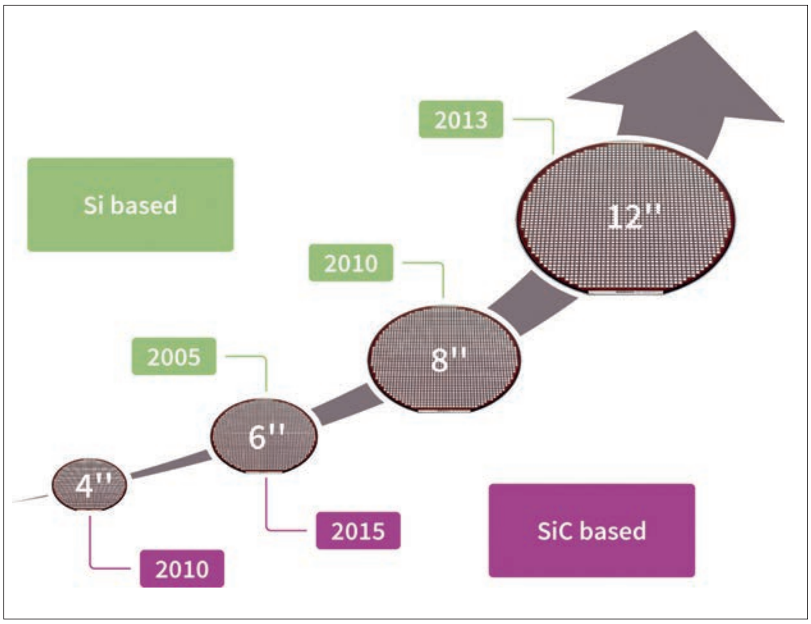

Figure 2: **Larger wafers and improved processes reduce costs and increase reliability for SiC chips**

but also for inverter applications, where switching frequencies below 20 kHz are typical. Here, the efficiency is determined to a very large extent by operation with low loads. Using SiC MOSFETs, it is possible, for example, to reduce the losses in inverters by up to two thirds under low or medium load.

Extremely compact and highly efficient inverters can be realised with SiC MOSFETs. Under comparable conditions, SiC MOSFETs significantly reduced the chip area compared to IGBT-based inverters. Thanks to the reduced chip losses, the efficiency has been improved for various driving scenarios, especially in city traffic with many acceleration phases.

In connection with the inverter efficiency, it is necessary to consider that the energy basically flows in two directions – from the battery to the wheel during the generation of the torque and back from the wheel to the battery during energy recovery (recuperation). Consequently, the efficiency of the inverter is very important for battery-powered electric vehicles (BEVs), because it has a direct impact on the range or the use of a smaller battery with the same range. Since the battery is an important cost factor, a 5 to 10 % reduction in battery cells can result in a significant cost reduction of over $800 in systems with more than 40 kWh of battery power.

Silicon does not support breakdown field strengths as high as SiC. As a result, a standard 1200 V IGBT exhibits significantly more losses than its counterpart in the 600 V class. On the other hand, a 1200V SiC MOSFET allows very efficient operation at higher battery voltage in the range of 850 V. SiC is therefore ideally suited for architectures that also enable fast-charging applications. With the infrastructure currently under development, an 80 kWh battery can be charged to 80 % in just 15 minutes. An important aspect for the implementation of electromobility and ensuring customer satisfaction.

Optimized power modules

In order to make the best possible use of the performance of the SiC chips, a correspondingly optimized packaging technology for the power modules is also required. SiC facilitates better energy efficiency. However, this not only requires

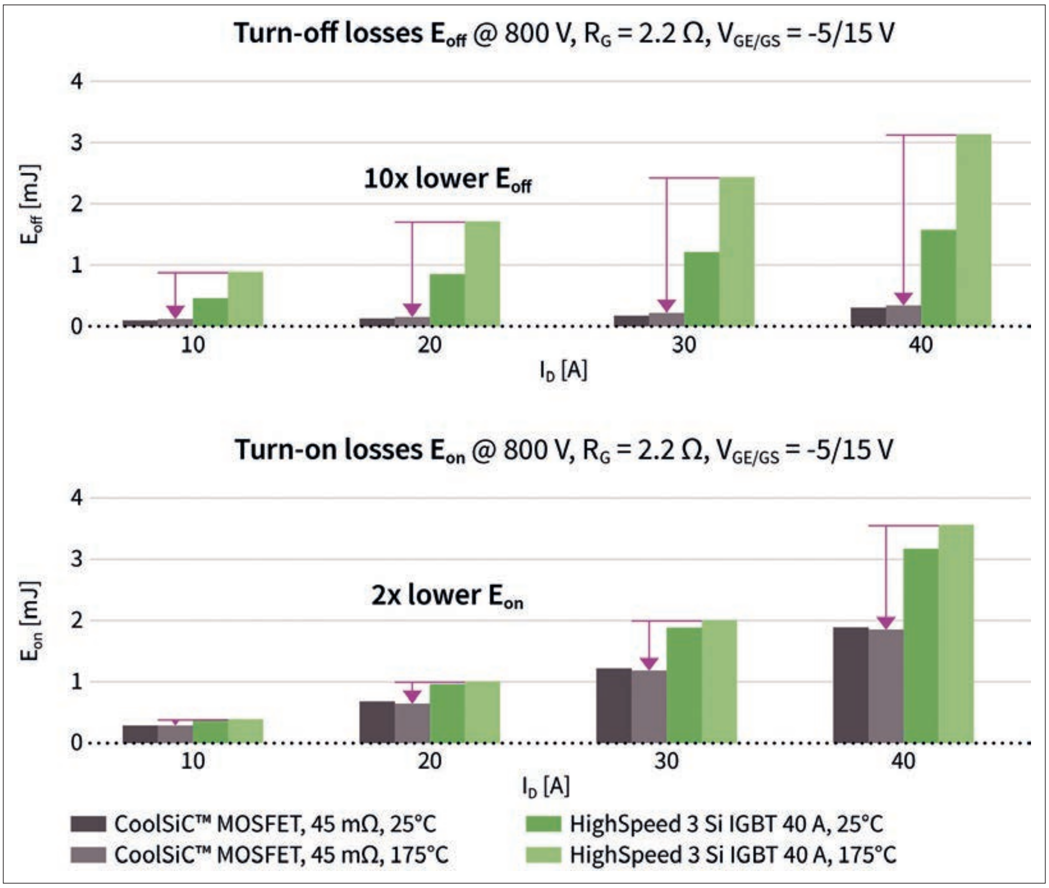

Figure 3: **Comparison of switching losses between CoolSiC MOSFETs and silicon IGBTs**

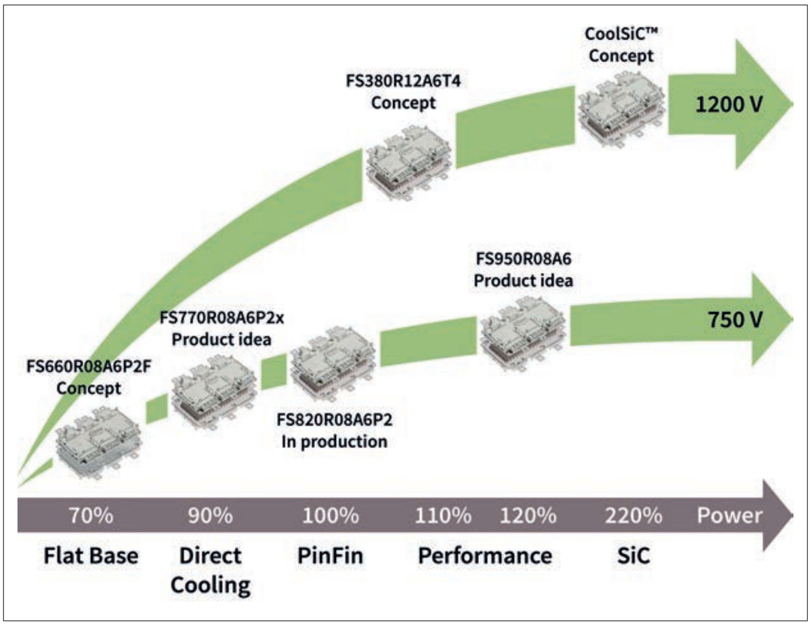

Figure 4: **The HybridPACK Drive power module has a modular design and can be easily scaled**

improved packaging materials, but also the consideration of higher thermal resistances for smaller chips. Smaller chips also cause higher current densities and a greater risk of thermo-mechanical deformation. To fully exploit the performance of the SiC MOSFETs, packaging with the lowest possible leakage inductance is required. Consequently, new innovative packaging concepts for power modules are required. Examples include the optimized modules of the HybridPACK Drive family and packaging concepts with double-sided cooling, such as HybridPACK DSC modules. This makes it possible to develop inverter designs with very high power density.

HybridPACK drive

When developing the HybridPACK Drive (HPDrive) power module for use in electric and hybrid vehicles, it was necessary to combine technical and application-related requirements. These include elements as diverse as optimized costs, high efficiency, power density, current carrying capacity for starting torques and service life due to thermal cycling. It has been shown how a fully integrated development approach allows all the individual components of a power module to be designed in such a way that the application requirements are met to optimum effect. The higher rated voltage of the chip and the lower inductance of the module allow operation at higher working voltages and switching edges. The higher temperature load capacity, the improved chip bonding technology and materials with lower losses allow a higher current carrying capacity and thus a higher starting torque of the drive motor. Altogether, the smaller module size with reduced chip area, lower losses and the use of the latest mass production techniques help to reduce system costs.

A HybridPACK Drive module with pressfit terminals and the latest IGBT technology for automotive (EDT2) is about 20 % smaller than the comparable equivalent of the HybridPACK2 family, with the same performance. The HybridPACK Drive product line is a scalable platform with various options for power connections, IGBT and MOSFET technologies, as well as the thermal stack. The family was modular from the outset. The modular concept begins with the terminal taps, which facilitate either a quick welding process or screw-bolt joint for the cable connection. A 'long tap' version is also available for implementing phase current sensors.

HybridPACK Drive modules are designed to minimize development effort for inverter manufacturers depending on the application. It is thus possible to either reduce or increase the output power by replacing the base plate or the thermal stacks, while the Silicon part remains unchanged. Various base plates (flat, direct cooling and pin-fin) as well as various ceramic substrates are available for this purpose. The performance can however also be scaled by retaining the electronics (driver board and DC link capacitor) and the inverter design, but adapting the cooling structure. If you take e.g. the FS820R08A6P2 module with 750 V IGBTs, pin-fin structure and standard ceramics as a 100 % reference, this produces a scaling bandwidth for performance of 70 to 120 % (Figure 4).

For even higher powers, 1200 V technologies are also available for the HybridPACK Drive. First of all with 1200 V IGBTs and improved ceramics and then in future also with SiC MOSFETs (CoolSiC). With the introduction of SiC or CoolSiC, not only can the performance of an inverter be virtually doubled, but it can also reduce system costs in terms of the battery and smaller components.

Combining SiC and HybridPACK drive

The first on-board charging systems with SiC diodes are now coming onto the market. However, the high-voltage battery will continue also in future to be the most expensive part for hybrid and electric drive systems, considering that vehicles that are solely battery powered (BEVs) need a battery capacity of up to 100 kWh for ranges of 400 km and more. In this case, a high-efficiency inverter with lower losses permits better battery utilization and thus longer range.

To compare the efficiency of silicon and SiC based inverters, different driving scenarios such as NEDC (New European Driving Cycle), WLTP (Worldwide Harmonized Light Vehicles Test Procedure) and realistic Artemis simulations were investigated (Figure 5). This showed that a

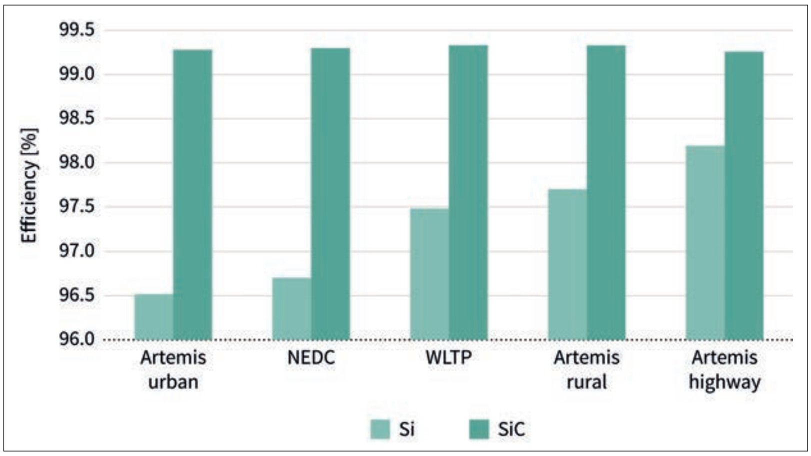

Figure 5: **Efficiency comparison for various inverter implementations based on a HybridPACK module (Si and SiC) and different driving profiles**

SiC-based inverter can achieve an efficiency of over 99 % and what's more for all scenarios. If the recovery is also taken into account, a SiC inverter can extend the range for BEVs by 5 to 10 %. This efficiency increase is based in particular on the faster switching of the SiC MOSFETs with up to 80 % lower switching losses compared to the IGBTs. Even if this potential cannot yet be fully exploited, due to EMC criteria and parasitic effects, the elimination of recovery losses and current-tail effects at shutdown alone will significantly reduce dynamic losses. In addition, SiC offers a resistance-like output characteristic. This makes these components ideal for low-load conditions that make up much of inverter operation. An inverter thus operates more than 80 % during active operation with loads of 20 % or less.

SiC-based inverters are expected to be used in premium BEV platforms that require more than 200 kW of power and 850 V system voltages to support fast charging. SiC technology offers decisive advantages precisely in this area. To facilitate the implementation of SiC inverters, Infineon is developing power modules based entirely on SiC on the basis of the scalable HybridPACK Drive package (Figure 6). These modules cover a power range up to 300 kW.

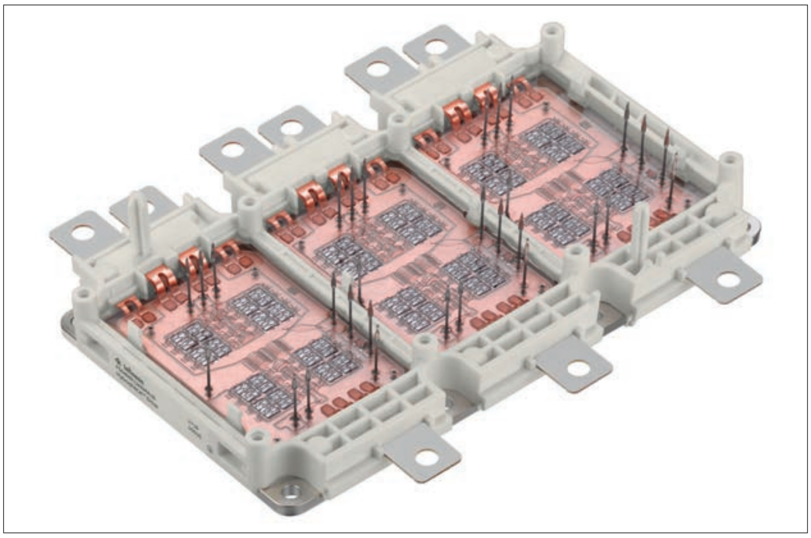

Figure 6: **HybridPACK Drive based on CoolSiC allows the performance to be doubled**

Conclusion

More and more OEMs and automakers are turning to SiC for future development. With 1200V CoolSiC MOSFETs, Infineon has demonstrated new capabilities in terms of efficiency and power density, coupled with innovative packaging technology, corresponding gate drivers and extensive automotive expertise. This means that in future xEV vehicles and other automotive applications will be able to take advantage of SiC. With the integration or combination of SiC MOSFETs and/or CoolSiC and the optimised, scalable HybridPACK power module package, inverter performance can be doubled compared to a corresponding module with 1200V Si IGBTs whilst reducing system cost.

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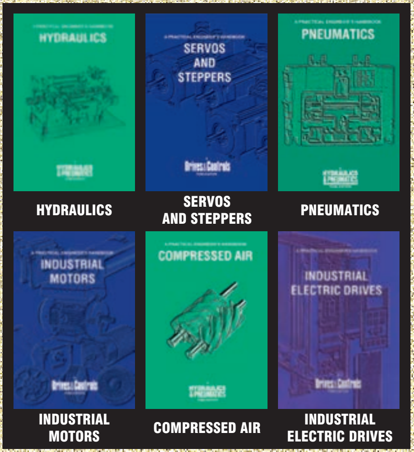

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DC Bus Switching Performance as Determined by Commutation Loop Parasitics and Switching Dynamics

In this article a 250 kW all-SiC inverter evaluation kit designed around low-inductance, high-speed power modules is used to demonstrate the DC bus switching performance resulting from the interaction among commutation loop parasitics and the switching dynamics. The interplay among the DC bus structure parasitics and near-RF switching dynamics can be quantified in both the time and frequency domains. The gate driver external turn-on and turn-off gate resistor selections in the gate-source signal path directly impact the system response – and whether it is critically damped or underdamped. The parasitic ESR and ESL of the DC bus film capacitors, laminated bussing, high-frequency (HF) ceramic decoupling capacitors, and power module-DC bussing interconnects contribute to bus switching degradation due to fast SiC MOSFET switching dynamics. The key takeaway is to optimize the DC bus structure rather than trying to compensate for a poor design. **Ty McNutt, Kraig Olejniczak, Daniel Martin and Guy Moxey; Wolfspeed, a Cree Company, USA**

SiC power module designers must pay special attention to module and system parasitic inductance, as these parameters determine the power module current and voltage utilization with respect to the module rating. The gate drivers, capable of switching at hundreds of kHz, must provide high noise immunity to large dv/dt, di/dt, and common-mode disturbances. Even though fast switching devices promise lower switching losses, EMI-related issues become more pronounced and can impact system behavior.

All-SiC power modules - working from the inside out

The high-performance power module of Figure 1 forms the coupling mechanism from the SiC die to the rest of the system beyond the modules' power terminals. An optimal system design begins by working from the inside out; it starts by using: high performance, low on-resistance/high current SiC power devices; a low ESL internal gate-source board to equalize paralleled die performance (up to 13 die); low impedance lead frames (i.e., < 0.1 mΩ parasitic module resistance and 5.5 nH of parasitic inductance); and, high-temperature module material capability in excess of 225°C. To fully capture the benefits of SiC power devices, one cannot be on a "mental holiday" when designing the external bussing; to do so may nullify the power module designer's design intent and optimization efforts within the all-SiC power module.

Gate driver design

Due to extremely high di/dt and dv/dt switching, it is critical that the gate driver have a minimal gate-loop stray inductance to reduce the gate oscillations that are so sensitive to SiC devices. How? Minimize the gate driver-module electrical interconnect length by placing the gate driver PCB on top of the module (i.e., within a few cm). The internal gate-source PCB design and internal gate resistor value selection are critical for achieving optimum module EMI and switching loss reductions.

The driver's external gate resistors control the speed at which the gate

Figure 1: The CAS325M12HM2 All-SiC power module with a 5.5 nH power-loop inductance uses a high-speed internal signal distribution board for equalized die performance

Figure 2: **An initial bussing design V1 (left), and optimized design V2 (middle), for a 3-phase inverter using the Wolfspeed CAS325M12HM2 power module. The magnetic flux Bx for the low-inductance (~ 3.5 nH) V2 bussing is shown (right)**

capacitance is charged and discharged and therefore determines the system switching losses. The lower the gate resistor value, the faster the switching time, and greater the overshoot. Minimizing the isolation capacitance of the gate driver is critical to improving the system noise immunity from switching the SiC power module. Wolfspeed's gate driver has an isolation capacitance of ~17 pF per channel. Utilizing differential signaling for control and feedback signals further improves system-level noise immunity by rejecting common-mode noise enacted upon the cabling or input pins of the gate driver.

DC bus structure

The commutation loop, which includes the laminated DC bussing and the DC-link capacitor bank, must have a minimal ESL as viewed from the modules' power terminals. The maximum continuous DC bus voltage is constrained by the voltage overshoot resulting from the energy stored in the parasitic inductances seen by the power module's drain and source power terminals. This parasitic inductance, L_σ, combined with higher di/dt, negatively impacts the power module voltage and current utilization. The first is the voltage overshoot, $\Delta V_{overshoot} = - L_\sigma$ di/dt, which adds to the DC bus voltage during turn-off. This constrains V_{bus} to an artificially low value since the peak value of $V_{bus} + vr_{ipple} + \Delta V_{Overshadow}$ + the safety margin must be less than the module DC rating.

Here, $v_{\rho\iota\pi\pi\lambda\epsilon}$ is the peak voltage ripple resulting from the AC current interacting with the capacitor bank's ESR. Note the three ways to minimize the voltage overshoot: minimize L_σ, decrease the load current, di, and/or increase the switching time dt. Decreasing the load current results in less power delivered to the load. Slowing down the device during turn-off will result in additional switching losses penalizing the device thermally and affecting the overall system efficiency. Limiting di/dt, by reducing the current or slowing down the power device during turn-off, will result in a reduction in power module current utilization. Thus, minimizing the parasitic inductance is paramount.

DC-link film capacitor selection

The one component which imposes a significant constraint to the overall system performance is the DC-link capacitor. In general, capacitors used in power electronics applications are usually either electrolytic, metallized polypropylene (MPP), or ceramic. The optimum DC-link capacitor selection is important due to the tension that exists among the following three concerns: cost, electro-thermal-mechanical performance at the system maximum ambient temperature, and capacitor reliability based on its maximum hot-spot temperature. The power electronics designer seeks to maximize voltage blocking capability as a function of temperature; capacitance stability as a function of temperature and voltage; RMS ripple current capability; insulation resistance; and reliability and life expectancy. Similarly, the power electronics designer seeks to concurrently minimize footprint, volume, weight, ESR, ESL, and thermal resistance from hot-spot to case.

DC laminated bus

The DC bussing is a multi-physical design problem in the electrical, thermal, and mechanical domains. Electrically, the DC bus needs to be a low ESR (i.e., high conductivity material, "large" cross-sectional conduction area) and ESL (i.e., thin and wide "planes") structure. The main DC bussing design parameters affecting ESR and ESL include: copper thickness (t), width (w), length (l), of the V+ and V- planes and separation distance (d), between the V+ and V- planes. Thermally, a low temperature rise (e.g., $<$ 80 K from room temperature) due to the maximum expected RMS current passing through the structure is required. Mechanically, a high level of robustness against normal shock and vibration during use is required.

The DC bussing that connects the DC-link capacitors to the SiC power module is shown in Figure 2 for two designs: Version 1 (V1), an early stage prototype with inexpensive laminated copper bussing to begin evaluating the module performance, and Version 2 (V2), a design iteration based on theoretical analysis of module/bussing/capacitor interactions. Note, the V1 bussing design does not carry the laminated structure to the module; but instead, shifts to thin "fingers" connecting to the module lead frames thus creating high inductance paths that must be compensated with HF capacitors (see 2 of 3 snubber PCBs installed in Figure 2, left). These HF capacitors, or snubber capacitors, are used to alter the frequency response of the DC bussing, and can result in a reduced turn-off voltage magnitude when placed across the DC bussing as close as physically possible to the module DC terminals.

On the contrary, Figure 2 (middle) shows the improved bussing design where laminated parallel planes are formed from the DC bulk capacitors all the way to the

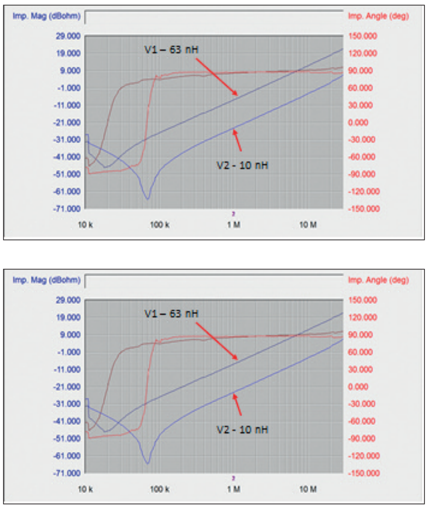

Figure 3: Frequency response of V1 and V2 bussing (top) and V2 bussing with and without snubber PCBs (bottom)

power module terminals. This design eliminates all finger-like bussing features and maintains the smallest current loop from the power module V+ to V- terminals as possible. Implementing this design approach, the DC bus and DC-link capacitor inductance was measured to be 10 nH. Figure 3 shows the magnitude and phase response of the V1 and V2 bussing, respectively, combined with the DC-link capacitor impedance from the SiC power module terminals. Clearly, the source impedance seen by the power module is a combination of the DC bus structure and the equivalent series inductance of the DC-link capacitors. To ensure the lowest source impedance, the designer must utilize either low-inductance capacitors, or parallel many capacitors to reduce the capacitors' effective parasitic inductance.

The snubber capacitor board reduces the effective inductance to 6.8 nH at HF but causes a resonance that can introduce current oscillations between the DC-link capacitors and snubber capacitors. If a snubber is still desirable for the designer, an RC snubber should be implemented to reduce the HF oscillations that can occur with a purely capacitive snubber arrangement. Due to V2 bus structure's low impedance, it was determined that low overshoot and ringing could be achieved with no added snubber circuit. Proper understanding of impedances allows high-speed switching, high efficiency, more bus voltage utilization, and safe utilization of high-speed SiC power modules. This results in an overall higher system power density.

System results

The V2 bussing design was implemented with three CAS325M12HM2 half-bridge power modules to form a three-phase inverter system. In addition to the power modules and DC bussing structures, this design used a liquid- cooled coldplate and three CGD15HB62LP half-bridge gate drivers optimized for SiC. Figure 4 shows clamped inductive load (left) and inverter operation (right) results of the optimized system. Using the V2 laminated bus, test data at a 900 VDC bus and high-speed SiC turn off at 304 A demonstrates an ultra-low overshoot (Figure 4, left). Clean inverter voltage and phase currents feeding a 250 kW three-phase are achieved with f_{sw} = 20 kHz and a 700 VDC bus (Figure 4, right).

Conclusion

A HF power module design philosophy has been extended to the DC bus structure and DC-link capacitors to enable increased DC bus voltage utilization of SiC high-performance power modules by greatly eliminating the overshoot voltage introduced by stray inductance. By optimizing the bus structure and DC-link capacitors the need for external HF snubber capacitors can be eliminated which can lower cost and increase power density. The optimization of bussing inductance, elimination of snubber capacitors, and maintaining current handling capability are concurrently satisfied through an iterative design approach. In addition, the 1200 V SiC power modules were implemented with the new bussing design to demonstrate a 250 kW inverter. The inverter stack-up with the new bussing design showed ultra-low overshoot and clean switching three-phase

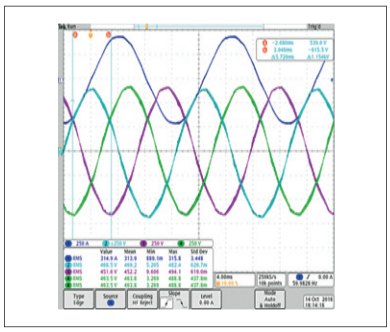

Figure 4: Using a single-phase of the V2 bussing, a 900 V DC bus and turn-off at 304 A demonstrates an ultra-low overshoot (left). A balanced three-phase set of line voltages and one phase current for 250 kW at f_{sw} = 20 kHz & 700 V DC bus (below)

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Silicon Carbide Gate Drivers – A Disruptive Technology In Power Electronics

Silicon-based power semiconductor switches have traditionally been and still are the primary choice for high-power application designers, who typically make this choice based on voltage and power ratings. Applications that require bus voltages greater than 400V – such as EVs, motor drives and string inverters require switches with voltage ratings greater than 650 V. Unfortunately, MOSFETs and IGBTs are approaching their theoretical limits. IGBTs currently used in high-voltage (>650V)/high-power applications are already being stretched to their absolute limit at voltages above 1 kV. SiC FETs have emerged as a disruptive material due to their superior properties. This article examines the value of SiC as a switch and its ecosystem – particularly the gate driver. **Nagarajan Sridhar, Strategic Marketing Manager – SiC and Smart Isolated Drivers, Texas Instruments, Dallas, USA**

SiC has a breakdown voltage 10 times higher than Silicon, resulting in a lower on resistance – and thus realizing high-voltage operation with low conduction losses. SiC has a bandgap energy three times higher than Silicon, enabling system operation at higher junction temperatures. Whereas Silicon-based power devices operate at a junction temperature (T_j) of 150°C, the higher T_j of SiC (greater than 200°C) means that systems can operate in environments that achieve ambient temperatures of 175°C or more. One example of such an environment would be power converters located under the hood of an HEV.

The high saturation velocity and electron mobility of SiC lowers switching losses and enables higher system operating frequencies. In turn, these benefits lead to a reduction in passive elements and therefore the size and the weight of the system. SiC has three times the thermal conductivity of Silicon, enabling systems with fewer cooling needs.

All of these characteristics result in an energy-efficient, robust and compact system. Figure 1 shows the value of the material properties of SiC and their corresponding system benefits. Going back to automotive applications, compact systems enable easier integration of power electronics into traction motors, resulting in an overall weight and size reduction in HEVs/Evs. This, along with increased efficiency and robust ranges and therefore bring more energy savings.

Gate drivers in the SiC ecosystem

At a system level, there are ideally three semiconductor components for high-power solutions like traction inverters, drives and solar inverters: the controller, gate driver and power semiconductor (SiC in this case). It is therefore important to understand how to drive SiC power devices. These switches turn on and off for efficient power transfer across the power-electronics circuit, as dictated by the controller. A key element that acts as an interface between the controller and power device is the gate driver. Think of it as an amplifier that takes the controller signal and amplifies it to drive the power device. Given the superior characteristics of SiC FETs, defining the requirements for gate drivers becomes very critical.

These requirements are:

- A high supply voltage of 25-30V, to realize high efficiency through low conduction losses

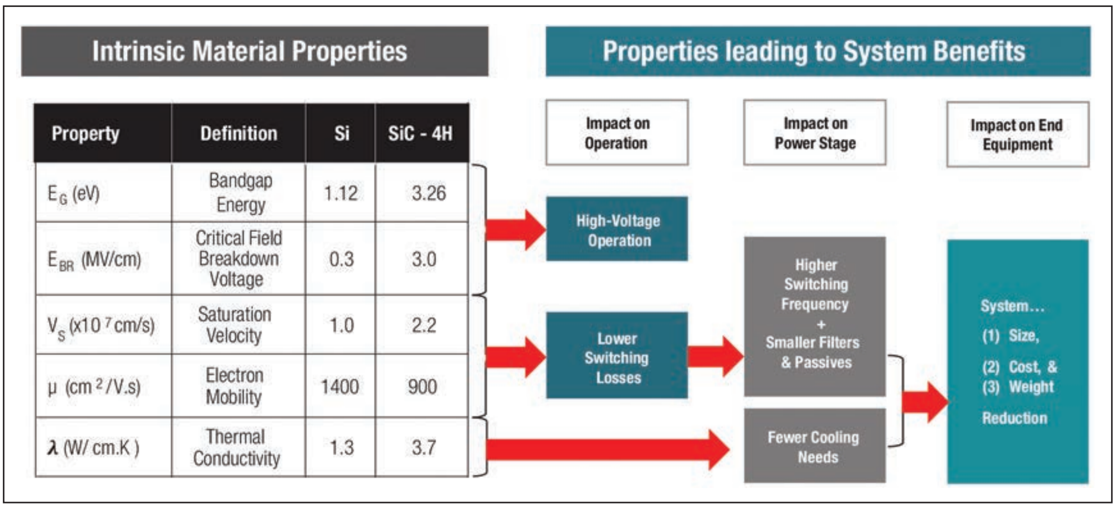

Figure 1: Material properties of SiC impacting system benefits

Power Switch	Si MOSFET	Si IGBT	SiC
Switching Frequencies	High (>20 kHz)	Low to Medium (5-20kHz)	High (>50 kHz)
Basic Protection	No	Yes – Desaturation, Miller Clamping	Yes – Current sense, Miller Clamping
Max.V_{DD} (power supply)	20V	30V	30V
V_{DD} Range	0-20V	-10 to 20V	-5 to 25V
Operating V_{DD}	10-12V	12-15V	15-18V
UVLO	8V	12V	12-15V
CMTI	50-100V/ns	<50V/ns	>100V/ns
Propagation Delay	Smaller the better (<50ns)	High(not critical)	Smaller the better (<50ns)
Rail Voltage	Up to 650V	>650V	>650V
Typical Applications	Power supplies – Server, datacom, telecom, factory automation, onboard and offboard chargers, solar u-inverters and string inverters (<3kW), 400-12V DC/DC – Auto	Motor drives (AC machines), UPS, solar central and string power inverters (>3kW), traction inverters for auto	PFC – Power supplies, solar inverters, DC/DC for EV/HEV and traction inverters for EV, motor drives, railways

Table 1: Comparing SiC to MOSFET and IGBT gate drivers

- A high drive strength (typically greater than 5 A), to realize low switching losses
- Fast short-circuit protection for fast responses
- Smaller propagation delay and variation, for high efficiency and fast system control
- High dv/dt immunity, for robust operation

These requirements are unique for SiC versus Silicon-based MOSFET and IGBT gate drivers, as shown in Table 1. One unique feature for a SiC gate driver is fast over-current protection, versus desaturation for an IGBT gate driver. For the same rated current and voltage, IGBT reaches the active region for significantly lower voltage between the collector and emitter (V_{CE}) at typically 9 V compared to a SiC MOSFET. IGBT self-limits the current increase. In the case of SiC, the drain current I_D continues to increase with an increase in the drain-to-source voltage difference (V_{DS}), eventually resulting in faster breakdown, as illustrated in Figure 2. It is therefore critical for a SiC gate driver to have fast protection and therefore fast fault reporting, typically 400 ns. The gate voltage must have a high dv/dt in order to accommodate the high switching speeds of SiC, thus necessitating a low-impedance driver for robust operation.

The need for digital isolation

Since SiC is used in high-voltage/high-power applications, and since there is a human machine interface (HMI) involved, almost all gate drivers for SiC are isolated.

Galvanic isolation is a technique that isolates functional sections of electrical systems to prevent the flow of direct current or uncontrolled transient current between them. Data and energy still need to pass through galvanic isolation barriers, however. This barrier is based on optical, magnetic or capacitive isolation technologies. Of these, capacitive and magnetic isolation are digital isolators where data transmits through the barrier digitally.

Like magnetic isolation, capacitive isolation has digital circuits for encoding and decoding incoming signals so that they can pass through the isolation barrier. Fundamentally, capacitors can only pass AC signals, not DC signals; plus, they are not susceptible to magnetic noise while maintaining high data rates and keeping power consumption low. This makes capacitive isolation the right choice for SiC gate drivers because of their high data rates and high noise immunity (with common-mode transient immunity above 150 V/ns).

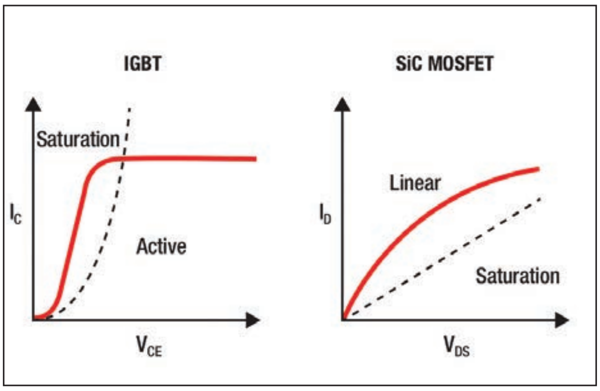

Figure 2: Differences in current-voltage (I-V) characteristics between a SiC MOSFET and IGBT

System-level advantages and challenges

SiC FETs can switch faster than IGBTs because of the absence of a tail current during SiC turn-off.

However, this tail current provides a method to dampen any ringing during turn-off, which is actually an advantage in IGBTs (especially in motor-drive applications) because any false turn-on and thus overshoot could damage the system. The challenge at the system level for SiC-based applications is to control ringing through gate resistors or snubbers.

Higher switching speeds imply smaller magnetic and capacitor filter sizes, thereby reducing system size and cost. As mentioned earlier, the system should also have fewer cooling needs given the high thermal conductivity.

Some system-solution suppliers still argue that reducing the system size and cost are not sufficient to negate SiC's high component cost. Since SiC-based system development is still at an early stage, the cost will be high for now. With more market adoption, however, it is only natural that SiC costs will come down due to economy of scale, thus realizing the cost benefits at the system level.

Conclusions

To achieve CO_2 emissions reduction mandates, high-power density, robust and compact solutions are becoming a trend in high-power applications such as traction inverters, onboard chargers, solar inverters and motor drives. SiC has emerged as a disruptive material that has superior properties compared to Silicon, including low on resistance, high thermal conductivity, high breakdown voltage and high saturation velocity. The uniqueness of the gate driver for SiC FETs is a key component in a SiC ecosystem, but given high voltages and high power levels, it is important to protect the HMI and intelligent systems. Therefore, isolated gate drivers are becoming the norm for SiC gate drivers. TI offers several SiC isolated gate drivers for power switches, including the UCC21521C, UCC53xx and ISO545x/585x families.

New IsolationTechnology Improves Reliability and Safety

To ensure safe and reliable operation for industrial and automotive electrical systems, isolation is required between the high voltage, high power elements in a circuit and the low voltage sensing, processing and control elements. Power Integrations' FluxLink™ magneto-inductive coupling technology uses a coreless transformer built-into the lead frame of the device. This unique technology not only affords complete galvanic isolation between the low voltage and high voltage sides of the device but also provides a high speed isolated two-way communications link. **Michael Hornkamp, Senior Director Marketing, Gate Drivers, Power Integrations GmbH, Ense, Germany**

Incorporating FluxLink into the lead frame ensures the mechanical tolerances can be maintained to a high level, providing a stable, low coupling capacitance, high speed, bi-directional link which can maintain its isolation integrity even after IC destruction. The low capacitive coupling between the primary side and secondary of the transformer and its reduced loop area improve primary side immunity to magnetic field interference and current and voltage transients developed on the secondary side to achieve reliable robust operation.

High isolation capability

FluxLink provides reinforced Isolation up to 1200 V, basic isolation to 1700 V, transient isolation voltage of 8 kV maximum for 1 minute and is certified to VDE0884-10. This internal reinforced isolation is supported by the external creepage and clearance distances of 9.5 mm provided by Power Integrations' eSOP™ package (Figure 1) which meets or exceeds TUV/IEC60950 requirements.

FluxLink provides the galvanic and reinforced isolation required to meet VDE0884-11 and IEC60747-17 requirements along with very high electromagnetic interference (EMI) and magnetic field immunity, allowing manufacturers to easily comply with IEC61000-4-8 and IEC61000-4-9 standards. All parts in the family operate up to 125°C and are 100 % tested during production using both hi-pot and partial discharge techniques along with functionality testing designed to ensure safe reliable operation throughout the device lifetime.

Additionally, FluxLink technology delivers full safety isolation in the event of a system failure on the high voltage side, caused for example, by an IGBT Collector Gate short. Alternative isolation technologies such as optocouplers offer similar voltage isolation but suffer from temperature stability and long-term reliability issues, thereby reducing system reliability and increasing maintenance costs. Other isolation techniques may not offer the safety isolation provided by FluxLink in the event of a failure on the high voltage secondary side, compromising protection and safety on the primary side.

Simplified power semiconductor drivers

FluxLink technology has been integrated into many products including AC/DC convertors and SCALE-iDriver IGBT / Power MOSFET drivers. The high speed, low latency, low jitter, of the FluxLink enables precise control and timing signals to be transferred from the low voltage primary interface and controller side to the high voltage secondary power switching side. The high voltage secondary side is also able to return feedback and fault information back to the primary interface and control side to ensure correct and safe

Figure 1: **FluxLink™ magneto-inductive coupling technology uses a coreless transformer built-into the lead frame of the device**

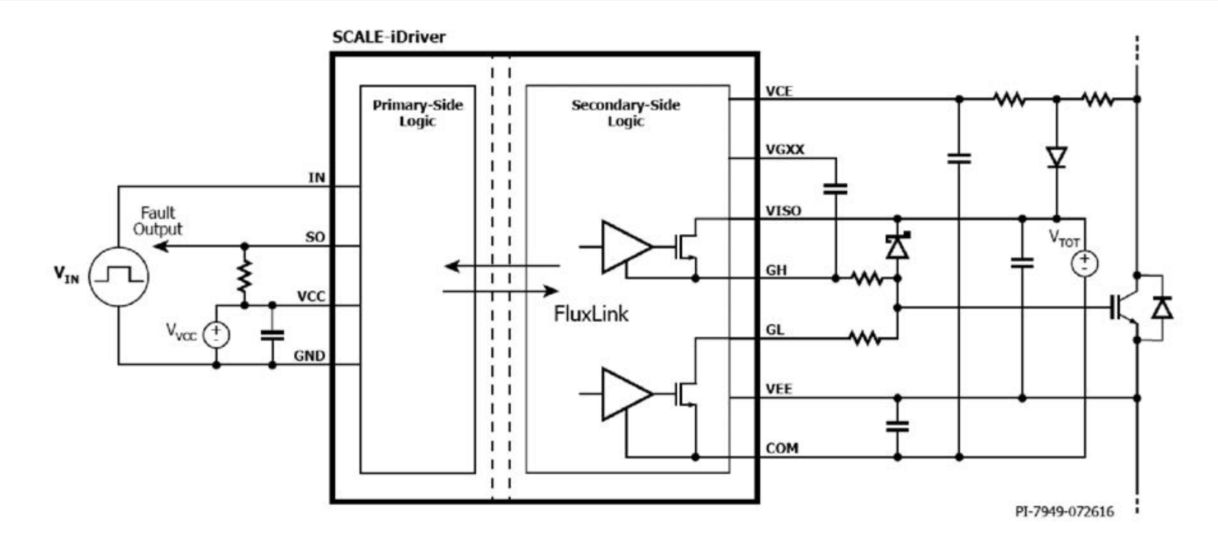

Figure 2: Typical single channel IGBT with SCALE-iDriver

operation of the power stage. Enhanced safety features, previously performed by additional external components, can now be integrated into the SCALE-iDriver IC, simplifying board design, reducing the bill of materials cost and improving reliability.

The SCALE-iDriver family has a working voltage of up to 900 V. Devices are available with four peak output-current ratings - 1 A (SID1112K) 2.5 A (SID1132K), 5.0 A (SID1152K) and 8.0 A (SID1182K), and three voltage ratings - 650 V, 1200 V and 1700 V. This high peak drive current allows the SCALE-iDriver to directly drive IGBTs with collector currents up to 800 A.

For gate drive requirements in excess of sink/source peak current of ±8.0 A, the SID1182K gate driver IC may be used with an external amplifier (current booster) to achieve 15 A or more with full safety functionality. Safety features include short-circuit detection (DESAT), Advanced Soft Shut Down (ASSD) to reduce turn off di/dt and limit turn-off overvoltage, primary side and secondary side Under Voltage Lockout (UVLO) and temperature compensated output impedance.

IGBT driver example

If we examine a typical SCALE-iDriver design, we can see how FluxLink is able to improve safety and reliability whilst reducing overall build cost. Figure 2 illustrates the number of external component required for a typical single channel IGBT SCALE-iDriver circuit.

The SCALE-iDriver power supply requirements have been simplified. Only two power rails are required, +5 V (VCC Pin) Vin to power the primary side, and a single unregulated +25 V (VISO Pin) to power the secondary side. The secondary side power supply should provide the same level of isolation that the SCALE-iDriver provides and have minimal capacitive coupling between primary and secondary or to any other secondary channel; typically this could be provided by a flyback converter with primary side regulation. Internal power supply monitoring and auxiliary power supply generation blocks on both the primary and secondary sides are integrated within the SCALE-iDriver. The secondary side +25 V supply is internally regulated to +15 V to generate the positive gate emitter voltage and then a negative -10 V rail is generated to provide the negative gate emitter voltage.

On the primary side the interface is designed to work with microcontrollers using 5 V I/O logic. Only two pins are required, the Input (IN Pin) and an open drain Fault Output (SO Pin). The input gate driver commands are transferred from the input across the FluxLink isolation barrier to the secondary side logic driving the Gate High (GH0 turn-on Pin and Gate Low (GL) turn-off pins.

During normal operation the SO output stays in the high impedance state, pulled high by an external pull up resistor. In the event of a fault condition, either on the primary side or secondary side, the SO output will be connected to ground and the input switching commands will be ignored. Primary and secondary fault detection and reporting enhances system reliability and safety. The primary side will indicate a fault when the V_{CC} supply drops below the primary side under voltage limit, UVLO V_{CC} and the SO output will remain grounded as long as V_{CC} stays below the threshold.

The secondary side features under voltage detection and output short circuit detection with advanced soft shut down. When a fault is detected the information is transferred back across the isolation barrier to drive the fault output low. During either of these conditions the fault output is driven low after a delay of typically 190 ns. To manage IGBT and SiC-MOSFET behavior, the ASSD can turn off the IGBT or SiC-MOSFET typically in 1.8 µs with a programmable delay time, the SO output SO fault signal has a period of 10 µs. Once the fault has been removed, the SCALE-iDriver IC will need a new 'turn-on' command transition on the input before the driver will enter the on-state again.

A short-circuit of the connected power device is detected using the semiconductor desaturation effect which then triggers the ASSD routine protecting the power switch by controlling the collector current slope, limiting the V_{CE} over voltage excursions which could damage the IGBT or MOSFET. The primary and secondary side under voltage detection also enables safe power on and power off even in the event of slow supply voltage ramp rate. The driver will also correct any short drive pulses, caused by input noise, by internally extending the duration of the output drive signals GH and GL.

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250 A Output Current DC/DC Modules Powering FPGAs and ASICs

The growing number of high-performance FPGA and ASIC applications that are driven by the increased bandwidth of wireless networks and data centers require power regulators with high power density, fast load transient response, and intelligent power-management features. The MPM3695 series of power modules with integrated inductors from Monolithic Power Systems (MPS) offers a versatile solution for powering FPGAs and ASICs by offering up to 60 % higher power density compared to discrete point-of-load (POL) solutions, simplified PCB layout and power stage design, minimal external components, and minimal expertise requirement for the power converter and compensation network design. **Heng Yang, Sr. Applications Engineer, Monolithic Power Systems, San Jose, California**

The trend of higher power density for FPGA and ASIC applications poses challenges to power module designs. A compact power module inherently requires both highly efficient operation and good thermal management. The MPM3695 series optimizes the package size and current-handling capability by adopting lead-frame packaging technology that enables direct and efficient heat dissipation from the power module to the PCB. With the monolithic structure of the power IC and customized integrated inductor design with advanced packaging technology, the MPM3695 series power modules achieve up to 40 % footprint reduction.

Achieving high power density

The MPM3695 series offers four power modules that are tailored for different output voltage and current ranges.

The MPM3695-25 is a step-down, 25 A power module with a 3.3 – 16 V input range and 0.5 - 5.5V output range. The output current is scalable for up to 250 A by stacking multiple modules. The top and bottom sides of the MPM3695-25 are shown in Figure 1. Residing in a 10 mm x 12 mm x4 mm QFN package, it integrates one monolithic buck converter and one inductor with up to 25 A of current-handling capability. The power density is 2.25 kW/inch? due by its highly efficient operation. The efficiency of the MPM3695-25 peaks at 94 % with a 3.3 V output voltage and above 80 % for the main operation range (Figure 2).

The MPM3695-10 is a thin, 10 A, step-down power module with output current scalable for up to 60 A. Its 1.6 mm height enables the power module to be placed on the bottom-side of a PCB, saving board space for high-density designs (Figure 3). The input voltage range is 3.3 – 14 V, and the output voltage range is 0.5 – 3.3 V. Residing in a compact 8 mm x 8 mm x 1.6 mm QFN package, the MPM3695-10 offers power density of 3.7kW/inch^3. Additionally, the MPM3695 series offers two enhanced-efficiency versions: the MPM3695A-25 and MPM3695A-10 with an output voltage range between 0.5 – 1.8 V

The dynamic load of FPGAs and ASICs inherently demands fast transient response from the power regulators to satisfy the voltage requirement of the core power. The output capacitors required to maintain the output voltage during a load transient occupy significant board area. The MPM3695 series

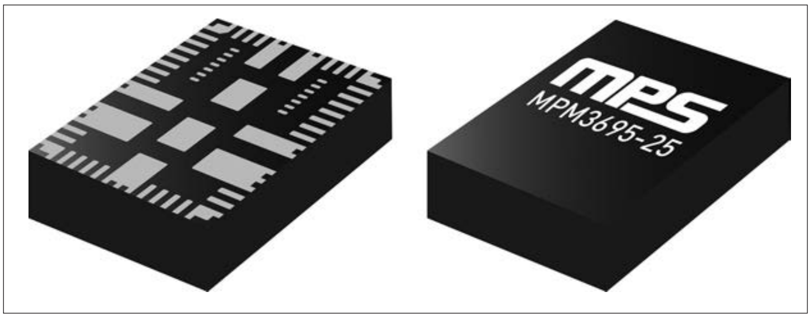


Figure 1: MPM3695-25, 25A power module

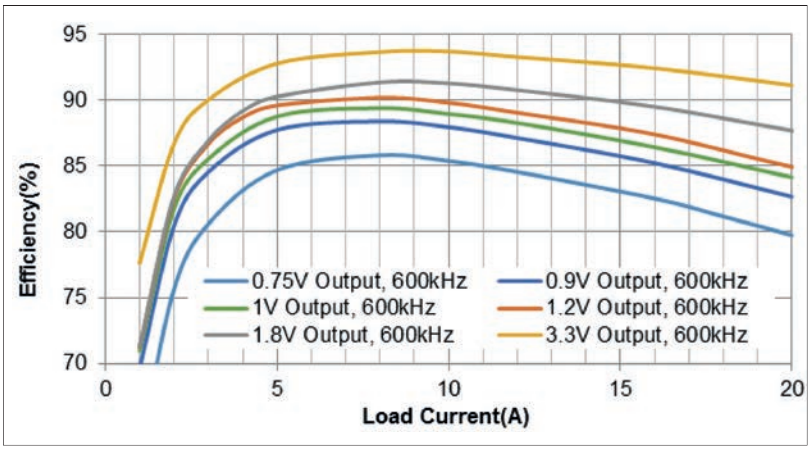


Figure 2: Efficiency curve of MPM3695-25 at 12 V input

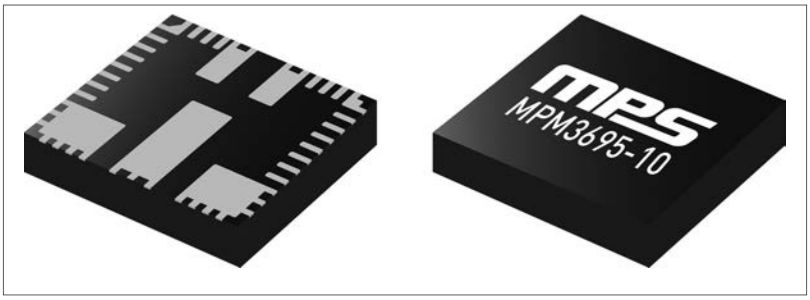


Figure 3: **Ultra-thin MPM3695-10 power module**

minimizes the output capacitor requirement by adapting the patented multiphase constant-on-time (MCOT) control scheme. MCOT control enables the power modules to adjust the switching frequency dynamically during a transient event, minimizing the energy demand from the output capacitors. Under steady-state operation, MCOT control guarantees interleaved operation for multi-phase configurations and leads to minimize input and output current ripple.

Additionally, the MCOT control scheme simplifies the converter design by eliminating the need for complex compensation networks used in traditional current- and voltage-mode control schemes. Figure 4 shows the experimental waveform of an MPM3695-10 module under a 25 % load current step at a 200 A/µs slew rate. The converter operates at an output voltage of 1.2 V. Two 47 µF output capacitors are installed on the evaluation board. As shown in the waveform results, only two 47µF output capacitors are required to maintain ±3 % or better output voltage deviation during a load current transient.

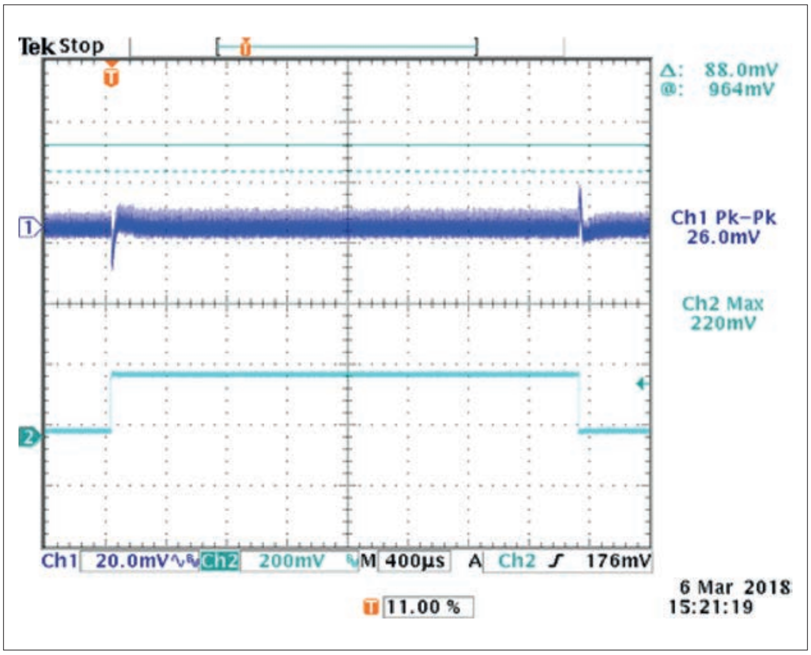
Scalable and smart power modules

The MPM3695 series adopts the concept of modular and scalable design, by which each module is a standalone power converter block with integrated inductors and can be easily stacked up to handle higher current. The parallel connection is conceptualized in Figure 5. The modular feature of the MPM3695 series simplifies PCB layout and power stage design, which leads to minimized development lead-time. A design engineer can easily copy and paste the same layout design for a variety of voltage rails with different current requirements. Additionally, the modular design minimizes the number of parts that must be maintained.

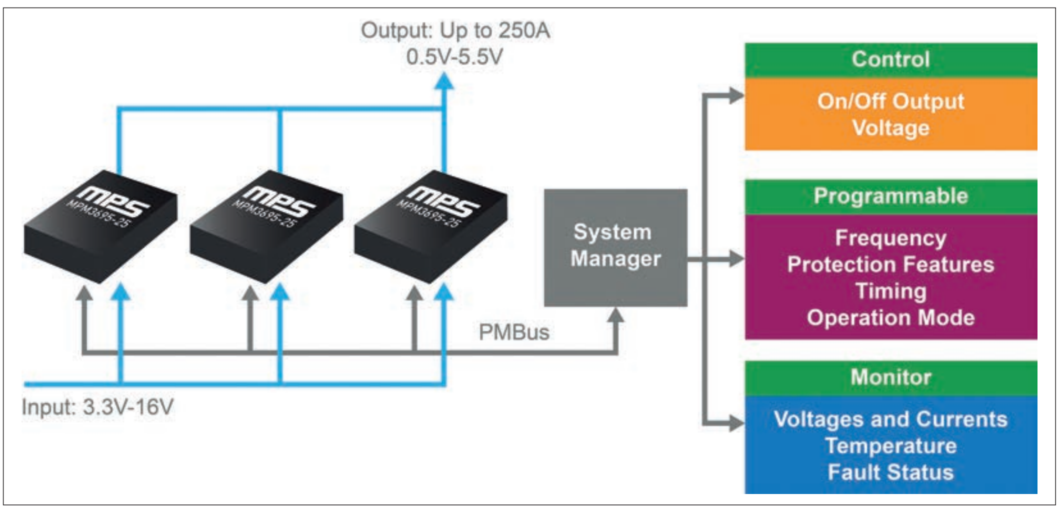
The smart features of the MPM3695 series enable the power modules to cooperate with intelligent power management systems. As shown in Figure 5, the series features PMBus 1.3, which allows the power module to report its operating condition and state of health (including voltages, currents, temperatures, and a variety of fault alerts) and to receive commands from a host. Programmability is offered over many important functions, such as faults threshold, switching frequency, timing, and conduction modes. The MPM3695 series also supports real-time on/off control and the output voltage setting. Paired with the graphical user interface (GUI) Virtual Bench Pro the series offers a customizable performance that fits the need for various applications.

Conclusion

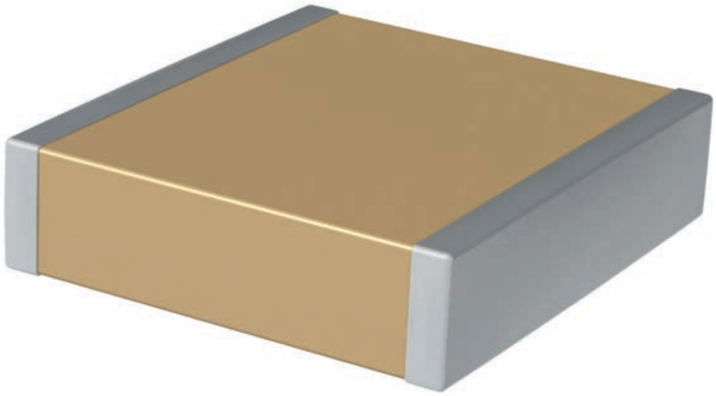
The MPM3695 series of power modules is the power solution for today's FPGA and telecom applications requiring a short time-to-market, high power density, and intelligent power management. The modular feature of the MPM3695 series minimizes schematic and layout design effort. The innovative MCOT control scheme eliminates the expertise required for designing complex compensation networks. The programmable and power management features enables the power modules to fit every application.



ABOVE Figure 4: **Experimental waveform of a 25 % load step on MPM3695-10 with 1.2 V output**



LEFT: Figure 5: **MPM3695 series offers scalability and programmability**



WBG Optimized Capacitors

Kemet's KC-INK surface mount capacitors are designed to meet the growing demand for fast-switching WBG semiconductors. Wide bandgap semiconductors have enabled power converters to operate at higher voltages, temperatures, and frequencies, allowing for much higher efficiencies and power densities. The capacitors can operate at very high ripple currents due to superior capacitance stability over temperature and voltage, rendering them for DC link, snubber and resonator applications. This is due to its robust and proprietary C0G/NPO base metal electrode (BME) dielectric system, which operates with very low effective series resistance (ESR) and thermal resistance. With an operating temperature of 150°C, these capacitors can be mounted close to fast-switching semiconductors in high power density applications which require minimal cooling. High mechanical robustness allows KC-LINK capacitors to be mounted without the use of lead frames. This provides extremely low effective series inductance (ESL), increasing the operating frequency range and allowing for further miniaturization. Available in both commercial and automotive grades with standard and flexible termination systems, this series is Pb-Free, RoHS and REACH compliant.

www.kemet.com/KC-LINK

3.0 V XT Supercapacitor

Eaton's XT supercapacitors are unique, ultra-high capacitance devices utilizing electrochemical double layer capacitor (EDLC) construction combined with new, high performance materials. This combination of advanced technologies allows Eaton to offer a wide variety of capacitor solutions tailored to specific applications that range from a few micro-amps use for several days to using several amps for just seconds. The XT series increases the energy density by 15 percent and power density by 20 percent, leading to longer operating life and/or lower cost systems. XT supercapacitors are designed for high-power, high-energy applications such as industrial systems backup, medical equipment and 48-volt automotive systems. Other applications include material handling systems such as robots and automated guided vehicles (AGVs).

www.eaton.com/supercapacitors

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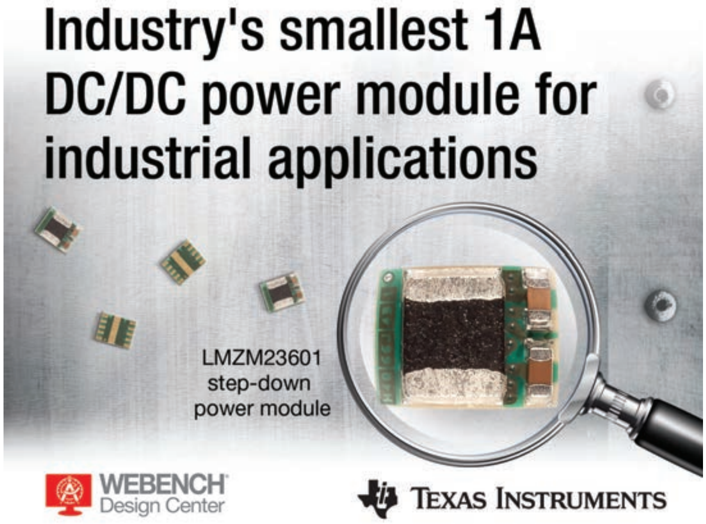
Miniature Step-Down Converters



Texas Instruments introduced two 4 V to 36 V power modules that measure 3.0 mm by 3.8 mm and require only two external components for operation. The 0.5-A LMZM23600 and 1-A LMZM23601 DC/DC step-down converters achieve up to 92 % efficiency, which minimizes energy loss, and feature tiny MicroSiP™ packaging that shrinks board space by up to 58 %. These converters address space-constrained communication and industrial designs, including field transmitters, ultrasound scanners and network security cameras. The modules are offered with either fixed 5 V or 3.3 V outputs, or with external synchronization and adjustable 2.5 V to 15 V output voltages. The LMZM23601 features a mode pin that allows flexibility to operate at a fixed frequency for low electromagnetic interference (EMI), or an automatic pulse frequency modulation control mode for high efficiency at light loads.

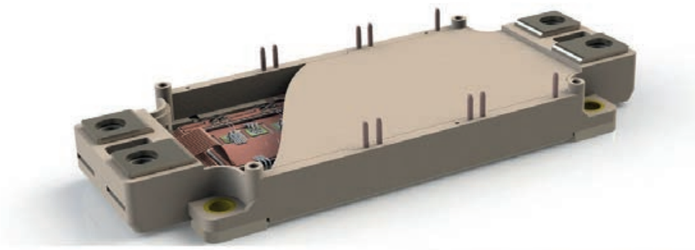
www.ti.com/lmzm23601

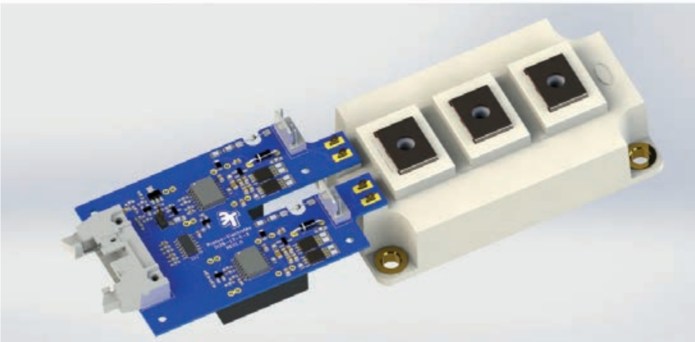
Gate Driver Board for Microsemi SiC Power Module

Analog Devices in collaboration with Microsemi introduced at APEC a high-power evaluation board for half-bridge SiC power modules with up to 1200 V and 50 A at 200 kHz switching frequency. The isolated board is engineered to improve design reliability while also reducing the need to create additional prototypes. The board can be used as the building block of more complex topologies, such as full-bridge or multi-level converters, for complete bench debugging of customer solutions. It can also function as a final evaluation platform or in converter-like configuration for full test and evaluation of Analog Devices' ADuM4135 isolated gate driver with iCoupler® digital isolation technology and LT3999 DC/DC driver in a high-power system. The high-power evaluation board enables Microsemi's SiC power modules to provide benefits such as a common test bench, higher power density for reduced size and cost, and isolated and conductive substrate and minimum parasitic capacitance for higher efficiency, performance, and thermal management. These attributes make the board suitable for applications including electric vehicle (EV) charging, hybrid EV (HEV)/EV onboard charging, or DC-DC converters.

www.analog.com/EVAL-MICROSEMI-SIC-MODULE

Proton-Electrotex to Present Press-pack IGBT and IGBT Drivers at PCIM Europe 2018





Proton-Electrotex is making final preparations for the largest exhibition in the industry of power electronics, PCIM Europe 2018, taking place on June 5-7th in Nuremberg, Germany. This year our company is proud to announce two important additions to our portfolio that will be presented at the expo.

- IGBT Driver DI28-17-E-1 is a dual channel IGBT plug&play driver designed specifically for 34 & 62 mm IGBT modules with voltage class up to 1.7 kV.
- Press-pack IGBT Module (MCDA) is a full-SiC 1200V 500A low inductance half-bridge / phase-leg module in industry-standard housing. Its compact design ensures flexibility, small size and cost reduction on the system level.

Meet us in Hall 9, Booth 115 on June 5-7th in Nuremberg Exhibition Center for more detailed information about these and many other brand new products to be launched in 2018. To plan a more detailed meeting please let us know by email to marketing@proton-electrotex.com.

High-Voltage Coupled Inductors

Coilcraft's new LPD8035V provides 1500 Vrms, one-minute isolation (hipot) between windings from a package that measures 7.92 X 6.4 X 3.5 mm, providing significant size and cost reductions over conventional bobbin-wound alternatives. It is ideal for Flyback, SEPIC and isolated-Buck converter designs. The LPD8035V Series is currently offered in six inductance values ranging from 4.7 to 150 µH. It provides peak current ratings up to 2.7 A, which represents a 40 % increase over previous generation products. It also has a tight coupling coefficient (≥0.97). LPD8035V coupled inductors are qualified to AEC-Q200 Grade 3 standards (-40° to +85°C ambient), making them suitable for automotive and other high-temperature applications. They feature RoHS compliant matte tin over silver-platinum-glass frit terminations and are halogen free.

www.coilcraft.com

Highly Integrated PoE ICs

Silicon Labs released at APEC two Power over Ethernet (PoE) Powered Device (PD) families (Si3406x and Si3404) for a wide range of Internet of Things (IoT) applications. The rapid expansion is boosting demand for PoE+ connectivity in IP cameras, smart lighting luminaires, feature-rich video IP phones, advanced 802.11 wireless access points and smart home appliances. These applications require higher wattage driving increased demand for PD devices that support the PoE+ standard. For example, the latest motor-positioned IP cameras with pan/tilt/zoom and heater elements create heavy loads on power supplies. PoE+ technology brings 30 W of power to support these demanding application tasks. Silicon Labs' Si3406x family is a PD interface solution for new classes of PoE+-enabled IoT products in residential, commercial and industrial environments. The Si3406x ICs integrate all power management and control functions required for a PoE+ PD application, converting the high voltage supplied over a 10/100/1000BASE-T Ethernet connection to a regulated, low-voltage output supply.

www.silabs.com

USB Type-C Protected Smart Load Switch

Alpha and Omega Semiconductor introduced at APEC a new Type-C Power Delivery compliant load switch with up to 28 V over-voltage protection. The AOZ1353 is a current-limited load switch with reverse current blocking capability intended for applications where internal circuitry requires protection from exposure to high voltages. This new device features 40 mΩ on-resistance in a thermally enhanced 3x3 mm DFN package. The new AOZ1353 operates from input voltages between 3.4 V and 5.5 V, output is rated at 28 V maximum. The internal current limiting circuit protects the supply from large load currents. The back-to-back switch configuration blocks any leakage when the device is disabled or when the device is enabled. The device is fully programmable with comprehensive protection features including soft start, short-circuit protection, thermal protection, over-current and over-voltage.

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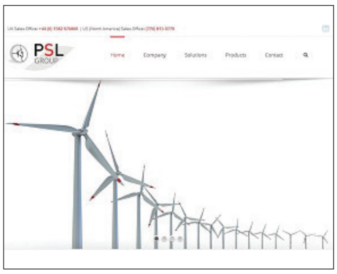

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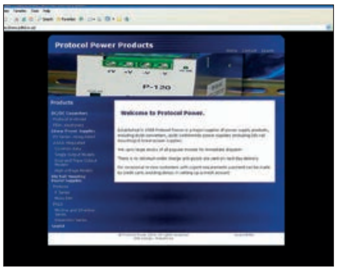

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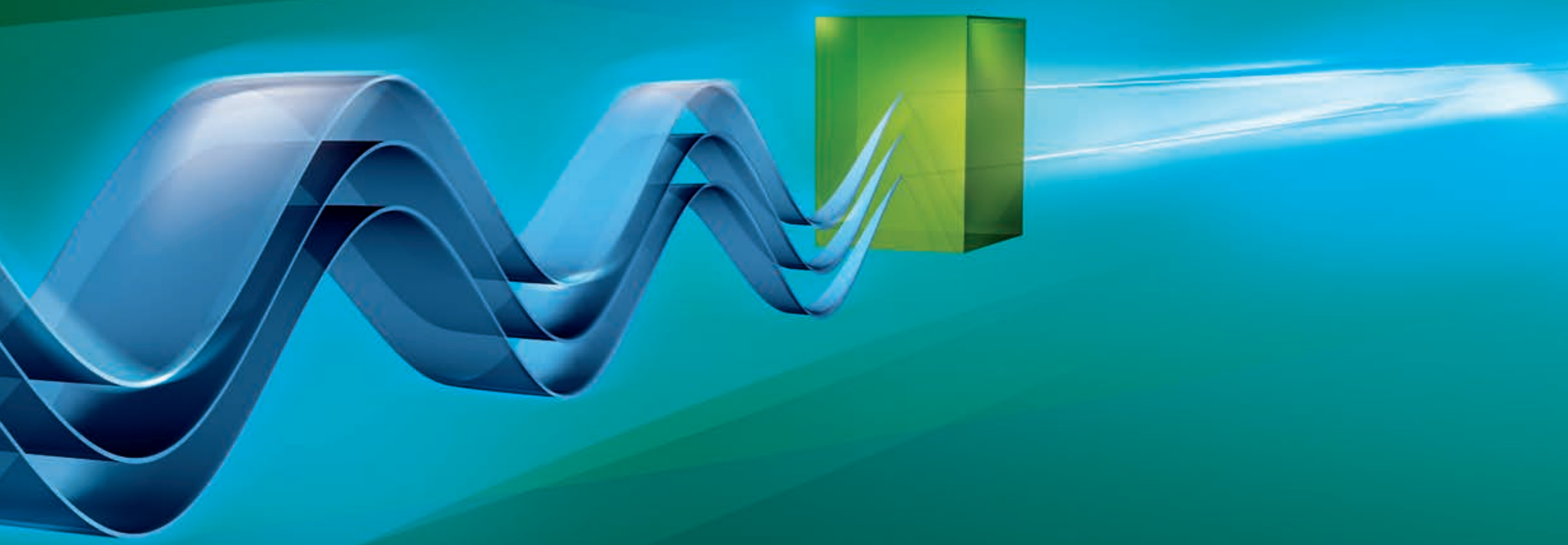

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