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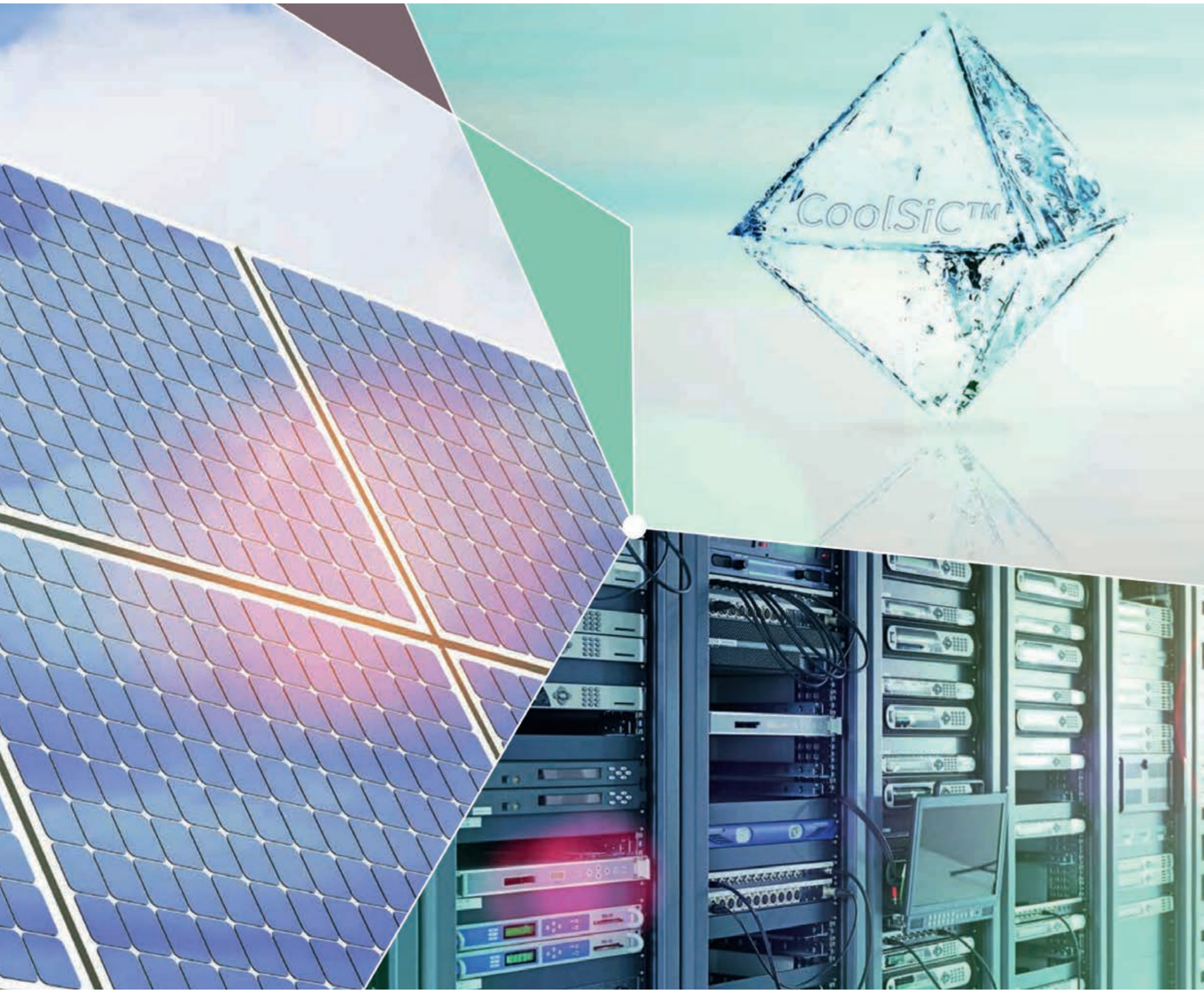
POWER SiC

SiC MOSFETs for Bridge Topologies in Three-Phase Power Conversion



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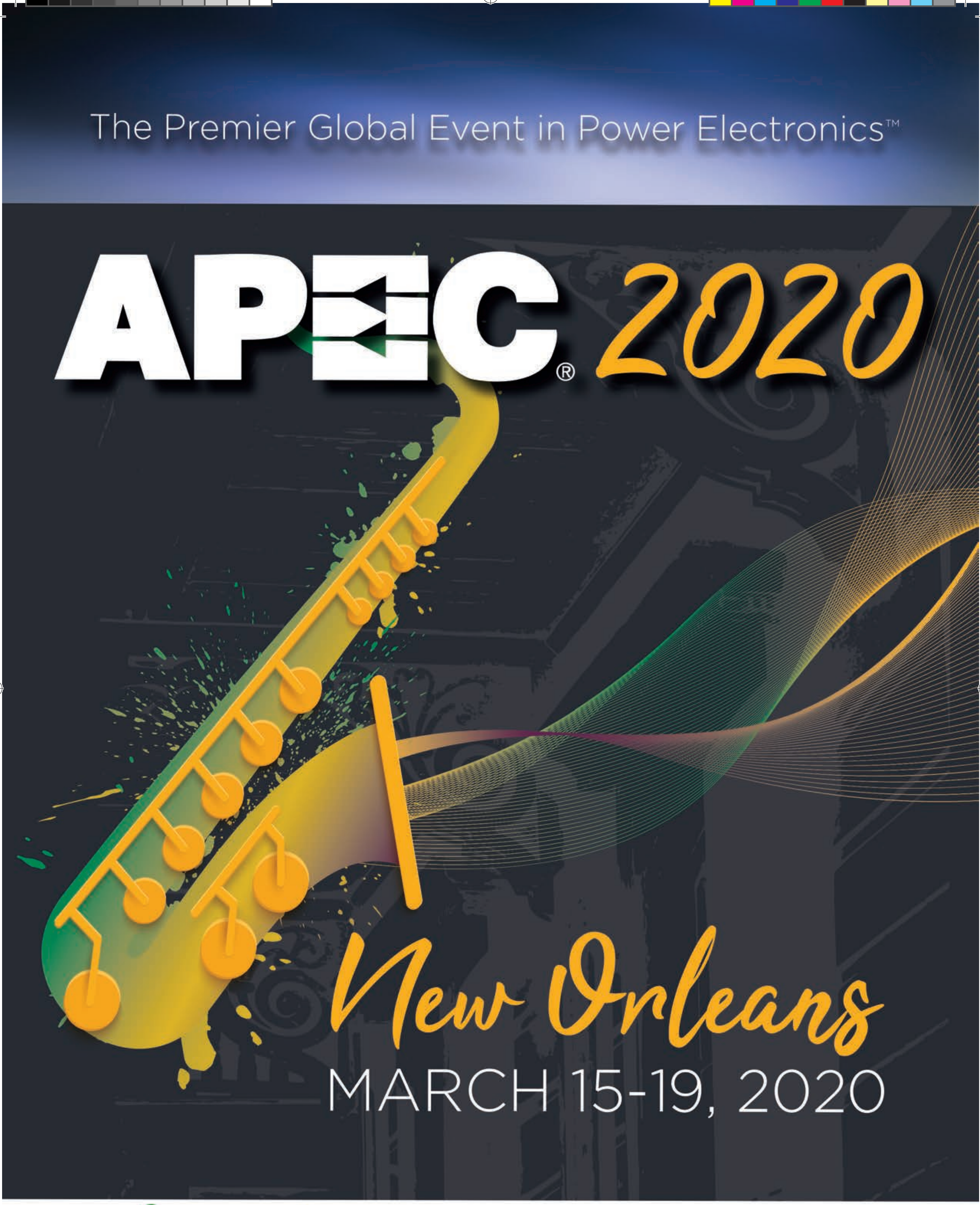
COVER STORY

SiC MOSFETs for Bridge Topologies in Three-Phase Power Conversion

Efficiency, productivity and legislation are main market drivers in power applications today. Making more out of less energy, and saving energy costs is putting a greater focus on better conversion efficiency and smaller, lighter systems. Here, power semiconductors provide new potential along the entire electrical energy supply chain, whether it be the growing share of renewables as part of the energy mix in generation, transmission or consumption of electricity in power converters. Although the latest generation of Si-MOSFETs and IGBTs are still good solutions in many cases, transistor functionality in the wide bandgap materials SiC and GaN offers a new degree of design flexibility for achieving new target requirements. Thus the use of SiC MOSFETs to improve power conversion performance or implement system innovation is nowadays a popular scenario for many system designers. In this article, Infineon takes the reader through SiC MOSFET design-in guidelines in bridge topologies, used for example in battery charging and servo drive applications.
More details on page 22.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Silicon Carbide Drives Electric Cars

Whether in airbags, belt tensioners, cruise control systems, rain sensors, or powertrains, there is scarcely a domain in modern automotive technology that does not rely on microchips. In 2018, the value of the chips in an average car was around €337. While this amount is growing by 1 to 2 % annually for applications not relating to infotainment, connectivity, automation, and electrification, on average an electric vehicle has additional semiconductor chips worth €410 on board. This figure will increase again by around $1,000 (€910) as a result of automated driving. This makes the automotive market one of the growth drivers in the semiconductor sector.

Market researchers expect a double digit compound annual growth rate with almost 30 million electric cars sales by 2024. Many companies from different segments are actively working to develop products for EV/HEV, as it is a very demanding application: high power density, low system losses, enhanced thermal management, system downsizing, or cost reduction. All this together means that the OEMs need to find optimized solutions going from the battery design and battery management system improvement, to system design, packaging techniques for good thermal dissipation and reliability, or new semiconductors enabling higher power density and lower conversion losses. By 2024 EV/HEV will become the biggest power module market, representing a market value of almost $2.5 billion. Thus, major technological choices in these segments can rapidly impact the overall power module packaging market. For example, the market share for silver sintering as a die-attach is increasing, driven especially by EV/HEV. This technology is pricier than more conventional soldering materials. In parallel, the introduction of Silicon Carbide (SiC) technology is also pushing the development of new power packaging solutions, since SiC devices can work at higher junction temperatures and higher switching frequencies with smaller die sizes.

And the automotive industry is moving towards SiC. A recent study by IHS projects annual SiC revenues will reach $10 billion by 2027, with hybrid and electric vehicles making up the vast majority of sales. A separate forecast from Cree also predicts EVs will present a tremendous growth opportunity for WBG materials, particularly SiC. To date, automakers have announced plans to spend $150 billion in the EV market. Cree estimates that even modest EV adoption - approximately 10 % of total vehicles sales by 2027 - could result in SiC revenues of $6 billion. In May the company announced it will invest up to $1 billion in the expansion of its Silicon Carbide capacity with the development of a state-of-the-art, automated 200 mm fabrication facility and a materials mega factory at its campus headquarters in Durham, N.C., the company's largest investment to date in fueling Silicon Carbide and GaN on Silicon Carbide business. Upon completion in 2024, the facilities will substantially increase materials capability and wafer fabrication capacity. Right after this announcement Cree signed a SiC cooperation agreement with Volkswagen in Germany. So far power modules control the electric drive in Volkswagen's modular electric drive matrix MEB, which is the industry's largest electrification platform. Most of coming EVs will be based on the MEB, including the new ID. family from the Volkswagen brand, as well as models from Audi, Seat and Skoda. The Volkswagen Group has committed to launch almost 70 new electric models in the next ten years, which is up from a pledge of 50 and increases the projected number of vehicles to be built on the Group's electric platforms from 15 million to 22 million in that timeframe. Now a similar agreement with tier-1 automotive supplier ZF Friedrichshafen has been signed. Cree's technology will initially be used to fulfill orders that ZF has already received for SiC based electric drives from several leading global automakers. Through the partnership, ZF expects to make SiC electric drivelines available to the market by 2022.

Also automotive tier-1 supplier Bosch now invests heavily in SiC power semiconductors by expanding its Reutlingen plant, 25 miles south of Stuttgart. At this plant, the company has been turning out several million microchips every day for decades. The company will be using the SiC semiconductors in its own power electronics in the future. Silicon Carbide semiconductors bring more power to electric motors. For motorists, this means a 6 % increase in range at a single battery charge. Alternatively, car manufacturers can make the battery smaller for a given range. This reduces the cost of an electric car's most expensive component, which in turn reduces the vehicle's price. Thus Silicon Carbide semiconductors will transform e-mobility, Bosch is convinced.

And the wide bandgap semiconductor technology progresses, as outlined in our sections research, market news and features. Enjoy reading!

Achim Scharf
PEE Editor

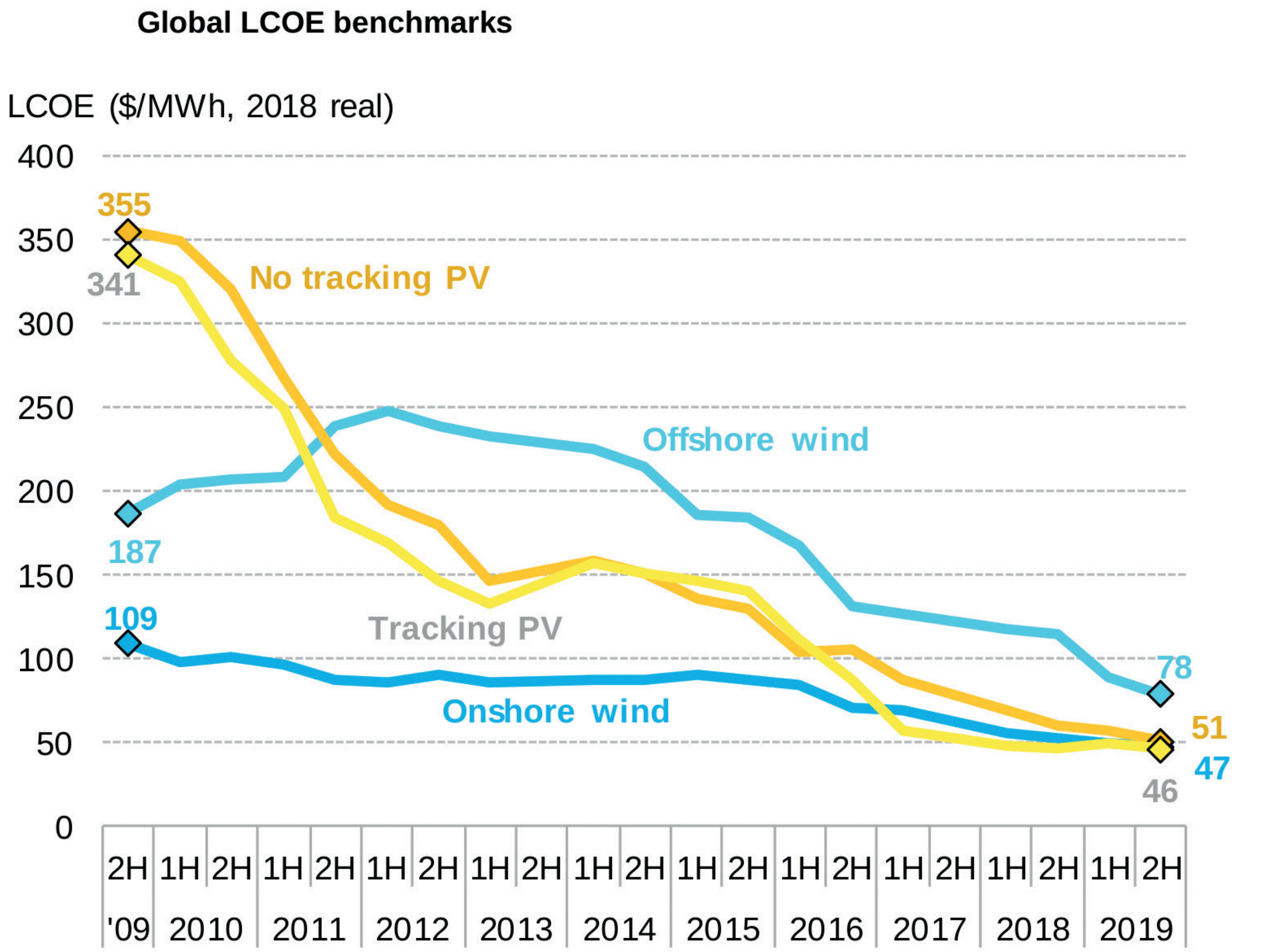
Solar and Wind Reach Parity with Power Prices

Every half year, BloombergNEF runs its Levelized Cost of Electricity (LCOE) Update, a worldwide assessment of the cost-competitiveness of different power generating and energy storage technologies – excluding subsidies. New solar and onshore wind power plants have now reached parity with average wholesale prices in California and parts of Europe. In China, their levelized costs are now below the average regulated coal power price, the reference price tag in the country.

BNEF's global benchmark levelized cost figures for onshore wind and PV projects financed in the last six months are at $47 and $51/MWh, down 6 % and 11 % respectively compared to the first half of 2019. For wind this is mainly due the fall in the price of wind turbines, 7 % lower on average globally compared to the end of 2018. In China, the world's largest solar market, the capex of utility-scale PV plants has dropped 11 % in the last six months, reaching $0.57 million per MW. Weak demand for new plants in China has left developers and engineering, procurement and construction firms eager for business, and this has put pressure on capex.

Some of the cheapest PV projects financed recently will be able to achieve an LCOE of $27-36/MWh, assuming competitive returns for their equity investors. Those can be found in India, Chile and Australia. Best-in-class onshore wind farms in Brazil, India, Mexico and Texas can reach levelized costs as low as $26-31/MWh already. Offshore wind has seen the fastest cost declines, down 32 % from just a year ago and 12 % compared to the first half of 2019. Current global benchmark LCOE estimate is $78/MWh. New offshore wind projects throughout Europe now deploy turbines with power ratings up to 10 MW, unlocking capex and opex savings. In Denmark and the Netherlands, the most recent projects financed to achieve $53-64/MWh excluding transmission are expected. "This is a three-stage process. In phase 1, new solar and wind get cheaper than new coal and gas plants on a cost-of-energy basis. In phase 2, renewables reach parity with power prices. In phase 3, they become even cheaper than running existing thermal plants. Our analysis shows that phase one has now been reached for two-thirds of the global population. Phase 2 started with California, China and parts of Europe. We expect phase 3 to be reached on a global scale by 2030," said Tifenn Brandily, associate in BNEF's energy economics team and the report's author.

www.bloomberg.com



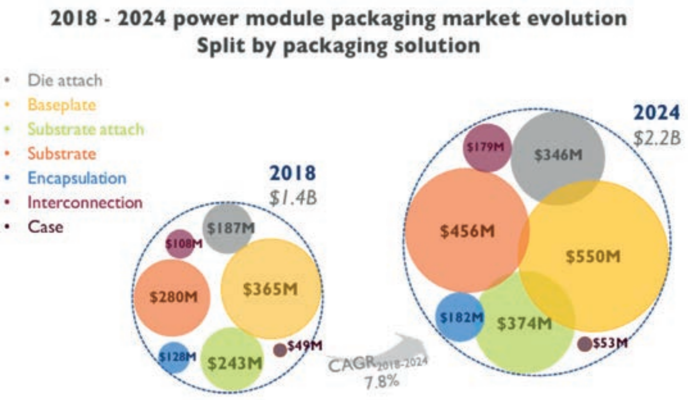
Source: BloombergNEF. Note: LCOEs exclude subsidies or tax credits. Global benchmarks are country weighed-averages using the latest annual capacity additions.

Electric Vehicles Drive SiC and Packaging Markets

The power module is one of the key elements in power converters and inverters, according to market researcher Yole Développement its market will reach $6 billion by 2024, with a 2018 – 2024 compound annual growth rate (CAGR) of 6.6 %.

In the past, packaging needs were driven by industrial applications, but today they are increasingly driven by electric and hybrid electric vehicles (EV/HEV). Yole expects a double digit CAGR with almost 30 million electric cars sales by 2024. Many companies from different segments are actively working to develop products for EV/HEV, as it is a very demanding application: high power density, low system losses, enhanced thermal management, system downsizing, or cost reduction. All this together means that the OEMs need to find optimized solutions going from the battery design and battery management system improvement, to system design, packaging techniques for good thermal dissipation and reliability, or new semiconductors enabling higher power density and lower conversion losses.

"In fact, by 2024 EV/HEV will become the biggest power module market,



(Yole Développement, October 2019)

(Yole Développement, October 2019)

representing a market value of almost $2.5 billio. This market's promising outlook is beneficial for the power module packaging material business. The power module packaging material market will achieve a 2018 - 2024 CAGR of 7.8 %, reaching the $2 billion business opportunity by 2024 and representing more than one-third of the power module market", said analyst Shalu Agarwal. In 2018 the largest packaging material segment was baseplates, followed by substrates. The other 32 % were represented by die-attach and substrate-attach materials. Thus, major technological choices in these segments can rapidly impact the overall power module packaging market. For example, the market share for silver sintering as a die-attach is increasing, driven especially by EV/HEV. This technology is pricier than more conventional soldering materials, and the 2018 - 2024 CAGR for the die-attach market is around 11 % - well higher than for other market segments. The second-highest growth is for interconnections (with a 2018 - 2024 CAGR of 8.7 %), followed by substrates, with a 2018 - 2024 CAGR of 8.5 %.

Although no major packaging technology breakthrough has been observed over the last several months, many technology trends from the past have been confirmed. EV/HEV applications are increasingly driving the technology trends in power module packaging, where high power density and highly reliable power module packages are needed. In parallel, the introduction of SiC technology is also pushing the development of new power packaging solutions, since SiC device can work at higher junction temperatures and higher switching frequencies with smaller die sizes.

Power module packaging solutions are moving towards high-performance materials and reduction of the number of layers, size, and interfaces, while conserving electrical, thermal, and mechanical characteristics. In terms of substrate, the most common choice for power module packaging is Al_2O_3 DBC (direct-bonded copper). The industry is moving towards materials offering better mechanical stability and higher thermal conductivity (i.e. AlN AMB (active metal brazed), Si_3N_4). Also, insulated metal substrate (IMS) is an alternative to ceramic substrate for low- and mid-power devices. In order to make the power module package more stable thermally, and to take advantage of SiC's properties, reliable and robust die attach is required. Therefore, the use of silver sintering is increasing.

Additionally, the interconnection technology is a key factor influencing the power module's strong performance. "Even though aluminium wire bonding remains the mainstream, copper wire bonding will also be widespread. Wire-free modules using flexible interconnections or top leadframes will also see considerable growth, especially in the EV/HEV industry. Double-side cooling with two substrates/leadframes will have a strong impact on the choice of packaging materials - however, single-side cooled power modules with a flat / pin-fin baseplate will also be preferred by many players," Agarwal pointed out.

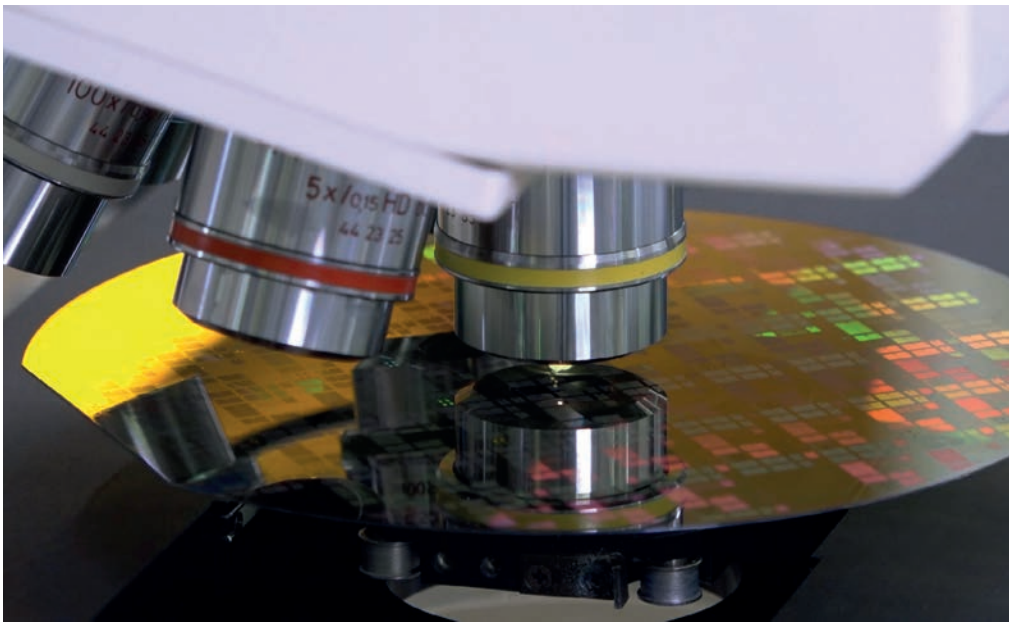
www.yole.fr

Bosch Boosts E-Mobility with SiC

Semiconductors made of Silicon Carbide set new standards for switching speed, heat loss, and size. Compared to Silicon chips used to date, SiC semiconductors have better electrical conductivity. This enables higher switching frequencies while also ensuring that much less energy is dissipated in the form of heat. Automotive tier-1 supplier Bosch now invests heavily in SiC power semiconductors.

"Silicon Carbide semiconductors bring more power to electric motors. For motorists, this means a six percent increase in range at a single battery charge," said Harald Kroeger, member of the Bosch board of management. "Alternatively, car manufacturers can make the battery smaller for a given range. This reduces the cost of an electric car's most expensive component, which in turn reduces the vehicle's price. Thus Silicon Carbide semiconductors will transform e-mobility," Kroeger underlined. The reason is that the new technology also offers further potential savings down the line: the much lower heat losses, combined with the ability to work at much higher operating temperatures, mean that manufacturers can cut back on the expensive cooling of the powertrain components. That has a positive impact on electric vehicles' weight and cost.

Bosch manufactures the new generation of semiconductor chips at its Reutlingen plant, 25 miles south of Stuttgart. At this plant, the company has been turning out several million microchips every day for decades.



semiconductor know-how. The company will be using the SiC semiconductors in its own power electronics in the future. "Thanks to our deep understanding of systems in e-mobility, the benefits of Silicon Carbide technology flow directly into the development of components and systems," Kroeger said. As one of the leading manufacturers of automotive semiconductors, Bosch has been exploiting this advantage for almost 50 years. In addition to power semiconductors, these include microelectromechanical systems (MEMS) and ASICs.

Whether in airbags, belt tensioners, cruise control systems, rain sensors, or powertrains, there is scarcely a domain in modern automotive technology that does not rely on microchips. In 2018, the value of the chips in an average car was around €337 (source: ZVEI). While this amount is growing by 1 to 2 % annually for applications not relating to infotainment, connectivity, automation, and electrification, on average an electric vehicle has additional semiconductor chips worth €410 on board. This figure will increase again by around $1,000 (€910) as a result of automated driving. This makes the automotive market one of the growth drivers in the semiconductor sector.

www.bosch.com

SiC wafer inspection at Boch's new plant in Reutlingen/Germany

ZF Friedrichshafen AG and Cree form SiC Partnership

Danfoss Silicon Power is chosen by ZF Friedrichshafen AG to be supplier of power modules for a range of projects ZF acquired from OEM's. The companies are also intensifying their existing cooperation, with a new strategic partnership for Silicon- and Silicon Carbide-based power modules.

The partners plan to improve the efficiency of electric drivelines by leveraging engineering and cost benefits at the interface between power modules and inverters. One of the first major milestones in this new initiative is a supply contract for Danfoss power modules destined for large-scale ZF volume production projects. The partnership will see the two companies engage in joint research and development, with Danfoss also supplying power modules for Silicon applications. Beside 400 V standard applications the two companies have also begun co-developing an 800 V Silicon Carbide power module for a large volume production project. "This is a robust long-term partnership that enables ZF and Danfoss to pool their strengths. Coming together on this opens up significant innovation potential to improve the technical and commercial competitiveness of our inverters. We will utilize this advantage in all our drivetrain applications; from Hybrid- up to Full Electric Applications," said Jörg Grotendorst, Head of ZF's E-Mobility Division. "We believe this closer cooperation between Danfoss and ZF has the potential to be a game changer for the development and innovation of future drivetrains for electrification of vehicles. Together we can enable an acceleration of the transition of the transport sector," Kim Fausing, CEO of the Danfoss Group concluded.

www.danfoss.com/en/

Power Integrations Delivered One-Millionth GaN-Based InnoSwitch3 IC

Power Integrations announced end of September the delivery of its one-millionth InnoSwitch3 switcher IC featuring PowiGaN™ gallium-nitride technology. InnoSwitch3 ICs are available now, priced at $4/unit in 10,000-piece quantities.

In an event at the Shenzhen headquarters of Anker Innovations, Power Integrations' CEO Balu Balakrishnan presented the one-millionth GaN-based IC (see our Industry News section) to Anker CEO Steven Yang. Anker is a manufacturer of chargers and adapters, supplying retailers worldwide with compact USB PD adapters and a wide range of chargers and adapters for laptops, smart mobile devices, set-top boxes, displays, appliances, networking gear and gaming products. "Anker was the first high-volume customer for InnoSwitch3 products with PowiGaN. I'm pleased to recognize Anker's

Power Integrations' CEO Balu Balakrishnan (left) presented the one-millionth GaN-based switcher IC to Anker CEO Steven Yang

foresight and technical excellence, and to thank Mr. Yang for his critical contribution to the first successful mass-market deployment of high-voltage GaN technology," commented Balu Balakrishnan. "By using PowiGaN-based InnoSwitch3 ICs we are able to offer USB PD chargers that are compact, lightweight, and capable of delivering high power output. This innovative new technology will help us achieve our goal to charge everything faster and keep gaining positive market feedback and customer response," added Steven Yang.

www.power.com

Transphorm Delivered Over Half a Million GaN Power Devices

Transphorm has shipped more than 500 thousand high voltage cascoded GaN FETs. Customers in the broad industrial, infrastructure and IT, and PC Gaming markets have publicly announced in-production devices built with Transphorm's GaN technology. They illustrate the rising confidence in GaN solutions that are projected to be an attractive market.

Industry analyst firm IHS Markit Technology forecasts the total GaN power discrete, module, and system IC revenues to reach $1.2 billion by 2028. Approximately $750 million of those revenues will be driven by high voltage GaN solutions. "We came to market with a two-chip normally-off device at a time when the industry was more familiar with single-chip normally-off Silicon MOSFETs," said Primit Parikh, co-founder and COO of Transphorm. "As proven by our public momentum and also that of other reputable manufacturers like Power Integrations in the consumer adapter space, the two-chip normally-off GaN solution is the most practical high-voltage GaN FET design today. In fact, this design has led to more than 5 billion hours (with <2 FIT) of field reliability data to date." "Following our success in the core higher power markets targeted by GaN, we're also working with customers in fast growing markets that are underserved by Silicon such as consumer adapters and set-top boxes," said Philip Zuk, VP of Worldwide Technical Marketing. "Consider that the majority of products we've shipped to date were targeted for higher power applications. Those 500 thousand-plus 650V FETs equate to more than 4 million lower power (sub 100 Watts) FETs, demonstrating our volume production capabilities."

www.transphormusa.com

IEDM 65th International Electron Devices Meeting

Spotlight on the Latest Advances in Semiconductors

Innovative Devices for an Era of Connected Intelligence – this is the theme of the 2019 IEEE International Electron Devices Meeting (San Francisco, December 7-11, 2019), to reflect the conference's focus on the processors, memories, 3D architectures, power devices, quantum computing concepts and other technologies needed to drive diverse new applications of electronics technology forward.

"The number of papers submitted to the IEDM conference this year is the highest in recent years, no doubt driven by the fact that new, fast-growing applications for semiconductors require different types of devices," said Rihito Kuroda, IEDM 2019 Publicity Chair and Associate Professor at Tohoku University. "As a result, several important trends are apparent from this year's technical program. One is the increasing interest in using 3D techniques to achieve higher levels of integration. Another is the number of papers describing complete technology platforms in wide-ranging areas, from mainstream CMOS scaling to silicon photonics, GaN power devices and human-machine interfaces." "We see that 3D monolithic integration is really coming on strong, because there are so many different reasons and ways to do it to meet the needs of diverse applications," said Dina Triyoso, IEDM 2019 Publicity Vice Chair and Technologist at TEL Technology Center America. "Another development which is very apparent is the trend toward design/technology co-optimization, a sign of unprecedented interdisciplinary collaboration between the people who design today's complex devices and the people who design the manufacturing processes to build them."

The 65th annual IEDM will feature a technical program of 238 papers given by many of the world's top scientists and engineers. It will be preceded by a series of 90-minute tutorials and by day-long short courses.

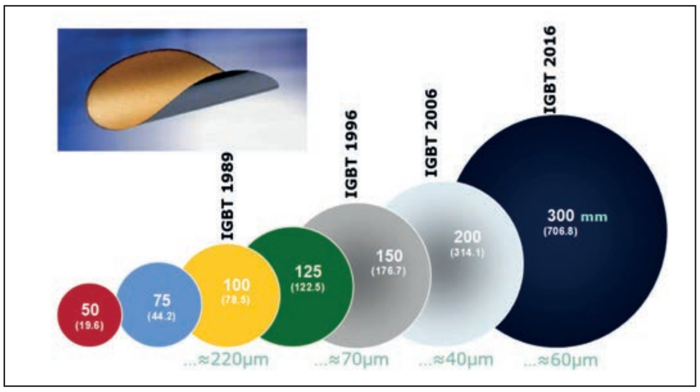
Progress in Si IGBT technology as an ongoing competition with WBG

The Insulated Gate Bipolar Transistor (IGBT) as a high voltage power switch is a combination of a Silicon (Si) power MOSFET and a bipolar transistor. It serves since 30 years as a key component in nearly all medium to high power electronic systems like in industrial drives, UPS, renewables, electric cars and traction. "Tremendous progress in increased power density could be achieved by stepwise reduced on-state and switching losses, increased current densities and maximum junction temperatures. As the wide band gap successor candidates GaN and SiC catching up in the power semiconductor market, it is worth looking closer on today's Silicon IGBT concepts and asking what future options in IGBT technology are possible in competition to the WBG solutions," will underline Thomas Laska from Infineon Technologies (**www.infineon.com**).

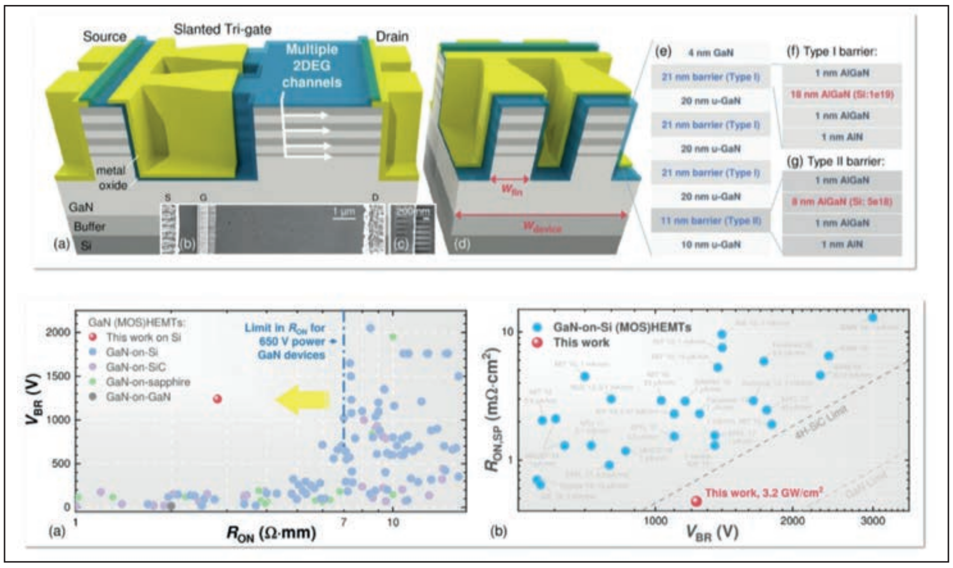
The combination of new interconnect solutions together with innovations in cell and vertical structure as well as gate driving concepts shall open the path to much higher power density than today. As a scenario at least two more IGBT generations with overall about 50 % higher power density at reasonable costs may become possible.

Advancements in GaN

A "1200 V Multi-Channel Power Devices with 2.8 Ω·mm ON-Resistance," will be presented by J. Ma



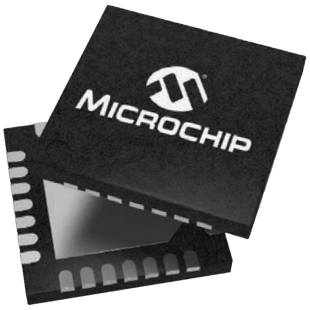
Silicon IGBTs on their path to bigger wafer diameter and thinner wafers, example from Infineon



EPFL/Enkris' multichannel slanted tri-gate MOSHEMTs (a), top view (b), zoomed SEM images (c), cross-sectional schematic of the devices (d), and (e-g) illustrate the four-channel structure which contains four parallel multi-channels formed by two types of barrier layers. The plots below it benchmark the slanted tri-gate MOSHEMTs against conventional single-channel GaN-based HEMTs, showing substantial improvements in on-resistance (left) and breakdown voltage (right)

World-Class Analog from a Microcontroller Leader?

If You Only Know Microchip as an MCU Supplier, We're About to Blow Your Mind



Microchip's success story wouldn't be complete without including our analog solutions. Our history as a leading solution supplier providing comprehensive design support and a broad product portfolio doesn't only include our microcontroller products.

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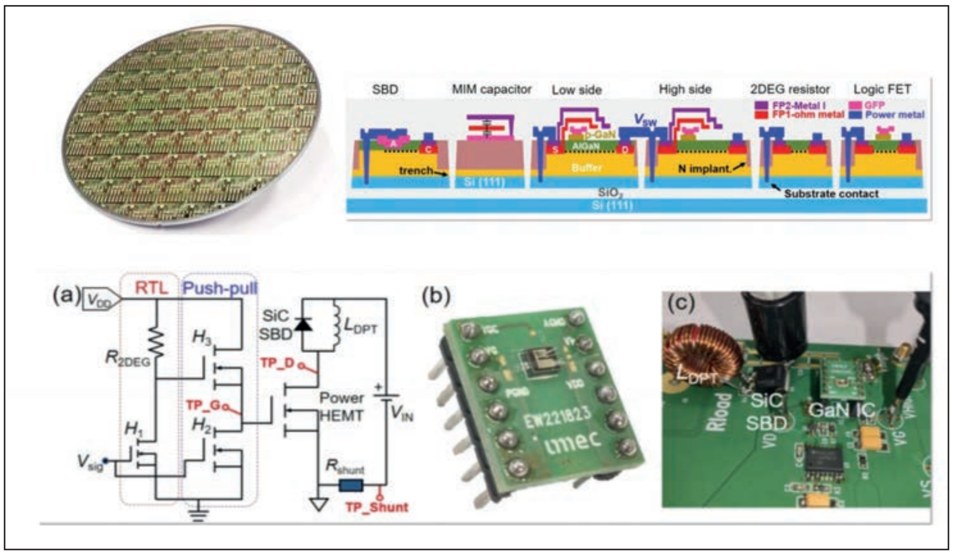


Photograph of the processed GaN ICs on a 200mm GaN-on-SOI substrate (upper left) at Imec. The schematic at right shows process cross-sections of the GaN IC components on GaN-on-SOI substrate. Below is (a) a schematic of a double-pulse test circuit, (b) packaging of the GaN IC with an integrated driver and power HEMT, and (c) printed circuit board

from EPFL/Enkris Semiconductor (**www.enkris.cn**). Lateral GaN-on-Si devices are promising for advanced power ICs because they combine high device performance, low cost, and can make physically smaller systems possible. While GaN HEMTs are commercially available, there is still plenty of room to improve their performance up to the full potential of GaN, and further advances require a major advance in on-resistance while still maintaining high breakdown voltage.

A team led by Swiss EPFL (**www.epfl.ch**) will report on novel lateral multi-channel AlGaN/GaN power devices with high breakdown voltage (1230 V) and low on-resistance (2.8 Ω·mm), resulting in an excellent figure-of-merit of 3.2 GW/cm^2. The researchers call these devices MOSHEMTs, and they have a multi-channel FinFET-like architecture with slanted tri-gates whose structure can be modified to "tune" device performance. The on-resistance is some 5x lower than previously seen at this breakdown voltage with single-channel devices. Until now it has proven difficult to control multiple parallel channels with a typical gate architecture, but the tri-gate structure has proven to be effective in doing so, and it lends itself to building normally-off – and thus more fail-safe – devices.

A team led by Belgium Imec (**www.imec.be**) will discuss monolithically integrated GaN-on-SOI ICs for power conversion, which they used to build a complete buck converter that demonstrated 200 V on-chip power conversion at 1 MHz. An SOI (silicon-on-insulator) substrate was used because it eliminates the back-gating effect which wastes power. It also suppresses parasitics, provides effective electrical isolation and reduces the area required. The team comprehensively investigated the technology from multiple vantage points: substrate, buffer, isolation, device, co-integration and circuit. Different components were successfully integrated monolithically, including a HEMT, Schottky barrier diode, MIM capacitor, 2DEG resistor, and resistor-transistor logic.

The Kavli Institute at Cornell University, Ithaca, USA (**www.cornell.edu**) and Intel Corporation, Components Research (Hillsboro, USA) will introduce "GaN/AlN Schottky-gate p-channel HFETs with InGaN Contacts and 100 mA/mm On-Current". High-performance wide-bandgap p-channel devices which can be monolithically integrated with established wide-bandgap n-channel devices are broadly desirable to expand the design topologies available in power/RF electronics. This work advances the GaN-on-AlN platform as the most promising p-channel contender to enable wide-bandgap complementary electronics. Toward that end, a new generation of GaN-on-AlN p-channel HFETs is fabricated with on-currents exceeding 100 mA/mm at room temperature under moderate drain bias. This work has demonstrated the strongest on-current performance of any significantly modulating p-channel transistor in the III-Nitrides, encouraging further study of the GaN/AlN platform to power a wide-bandgap CMOS technology.

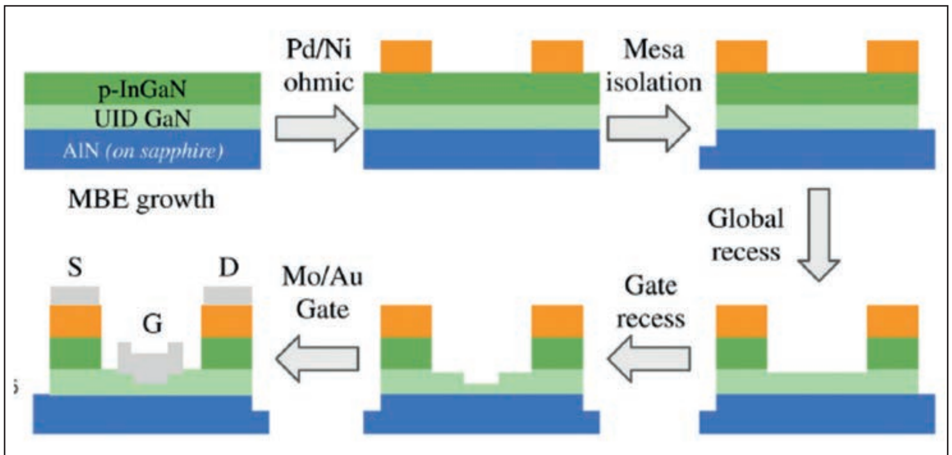
A "First Demonstration of a Self-Aligned GaN p-FET" by MIT (**www.mit.edu**), Enkris Semiconductor and Intel will demonstrate a self-aligned p-FET with a GaN/Al0.2Ga0.8N (20 nm)/GaN heterostructure grown by metal-organic-chemical vapor deposition (MOCVD) on Si substrate. The 100 nm channel length device with recess depth of 70 nm exhibits a record on-resistance of 400 Ω·mm and on-current over 5 mA/mm with ON-OFF ratio of 6×10^5 when compared with other p-FET demonstrations based on GaN/AlGaN heterostructure. The device shows E-mode operation with a threshold voltage of −1 V, making it a promising candidate for GaN-based complementary circuit that can be integrated on a Silicon platform. A monolithically

integrated n-channel transistor with p-GaN gate is also demonstrated. The potential of the reported p-FET for complementary logic application is evaluated through industry-standard compact modeling and inverter circuit simulation.

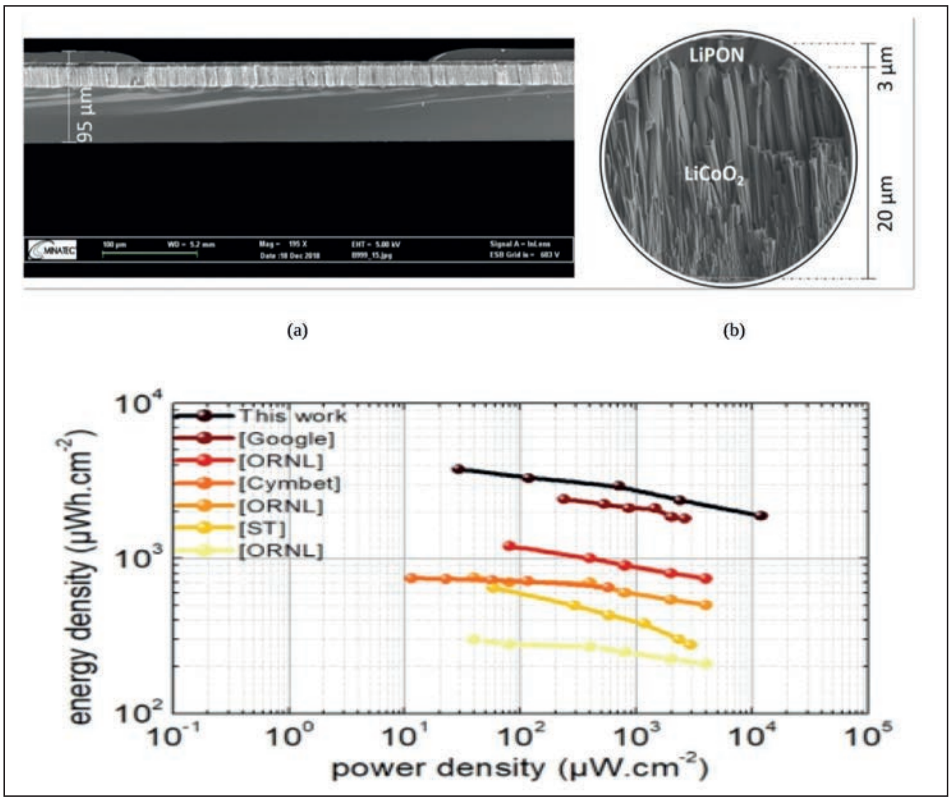
Advancements in SiC

Mitsubishi Electric (**www.mitsubishielectric.com**) and the University of Tokyo will demonstrate a Si-face 4H-SiC MOSFET with oxygen (O) doping in the channel region for the first time. Compared with a conventional device, the O-doped channel was found to provide lower channel resistance and higher threshold voltage, which is expected from the fact that O acts as a deep level donor in 4H-SiC. By applying this novel technique to vertical 4H-SiC MOSFETs, a 32 % reduction of specific on-resistance (R_{on}) at a high V_{th} of 4.5 V is achieved. In order to evaluate gate oxide reliability, negative bias temperature instability (NBTI) of V_{th} is investigated. The O-doped channel shows a smaller V_{th} shift, and its acceleration coefficient of the time to V_{th} shift is similar to that of a conventional one. Therefore, the O-doped channel is found to be a promising approach to further improve NBTI of 4H-SiC MOSFETs by channel engineering using deep level donors.

The "Physical Modeling of Bias Temperature Instabilities in SiC MOSFETs" is the title of the paper given by the TU Vienna (**www.iue.tuwien.ac.at**) to characterize and simulate charge trapping in lateral SiC MOSFETs. Advanced measurements (eMSM, pMSM, RVS) with long stress and recovery times are conducted on both SiC technologies and fully reproduced through simulations. Simulations rely on the two-state NMP model to describe the charge transitions of the involved border traps. Two electron (shallow and fast) and hole trap bands are identified and used to explain PBTI and NBTI in lateral devices. The shallow traps modeled with



GaN/AlN Schottky-gate p-channel HFETs process overview



SEM cross-sectional characterizations of CEA-Leti's (a) sub-100µm-thick TFB structure and (b) active layers. The graph below summarizes the results of the study and compares them to previous work. It shows that these TFBs exhibit the highest energy and power densities yet reported

similar parameters as in Si/SiO2 suggest an intrinsic charge trapping behavior of SiO2, which is supported by a comparison with slow V_{th} drifts in vertical devices. Based on the simulations accurate lifetime predictions can be made. While empirical models appear to provide too pessimistic (power law) predictions, the results provide a physics-based extrapolation at operating conditions.

High energy-density thin-film battery

There has been great progress in miniaturizing electronics but the miniaturization of power sources hasn't kept pace. Although integrated electrochemical capacitors offer high power density, high frequency response and novel form factors, their low energy densities are of limited value for MEMS and autonomous device applications that require long periods between charging. CEA-Leti (**www.leti-cea.fr**) researchers will discuss a thin-film battery (TFB) with the highest areal energy density yet reported (890 µAh/cm^{-2}) and high power density (450 µAh/cm^{-2}). Built on Silicon wafers using UV photolithography and etching for the successive deposition and patterning of each layer, the thin-film battery integrates a 20 µm thick $LiCoO_2$ cathode in a Li-free anode configuration. It showed good cycling behavior over 100 cycles, and the fact it was built using a wafer-level process opens up the possibility to tightly integrate this battery technology with future electronic devices. **AS**

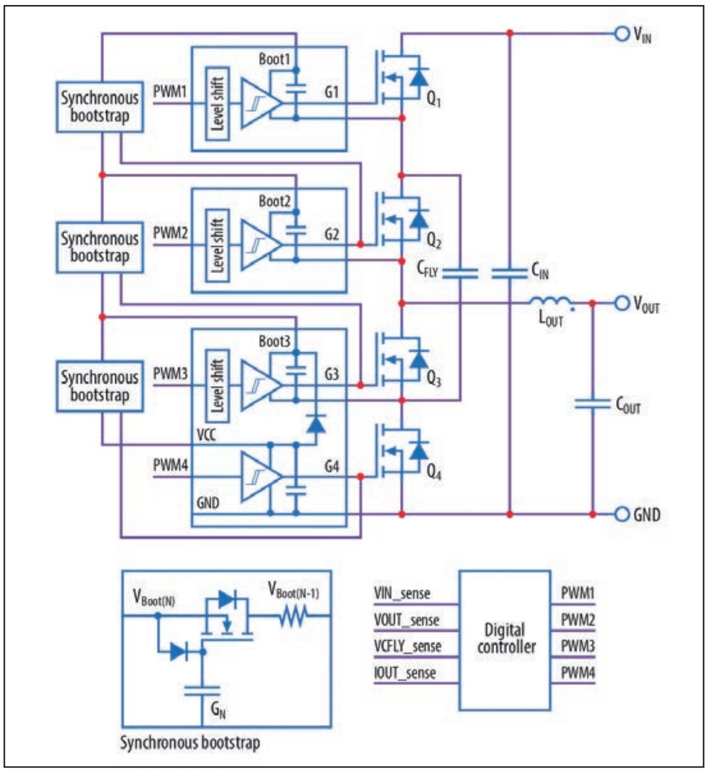
Designing a Multilevel GaN DC/DC Converter

Over the past decade, DC/DC power modules in datacom, telecom, and consumer electronics systems demand more power with increasing limitations on space and volume, requiring ultra-thin and highly efficient solutions. The multilevel converter is an exceptional candidate to shrink the size of the magnetic components and achieve high efficiency in a compact solution. Leveraging the advantages of GaN FETs, such as small size and low loss, would enhance its performance. A 48 V to 20 V, 250 W three-level converter using eGaN® FETs and digital control with a peak total system efficiency of 97.8 % and only 5 mm overall thickness (including PCB) is designed here.

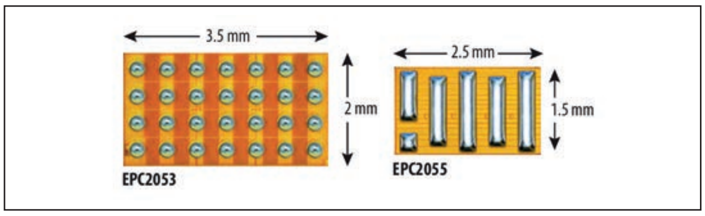
Design of an eGaN-FET-based 3-level converter

The simplified schematic of an eGaN-FET-based 3-level buck converter with synchronous bootstrap circuit is shown in the schematic. The circuit has three operating modes at duty cycle lower than 0.5 : 1) input voltage charges up the flying capacitor and load inductor through Q1 and Q3; 2) flying capacitor discharges while the load inductor charges through Q2 and Q4; 3) inductor current discharges through Q3 and Q 4 (either via the equivalent body diode of one and the channel of the other during deadtime, or via the channel of both FETs).

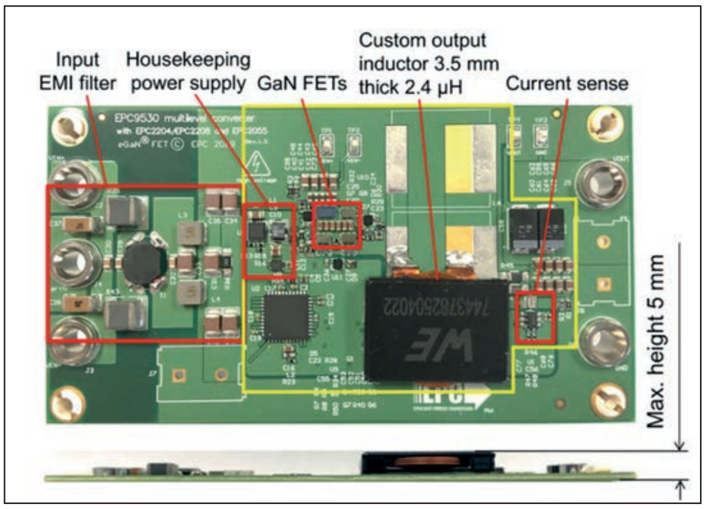
The steady-state operation follows the cycle of 1→3→2→3. The



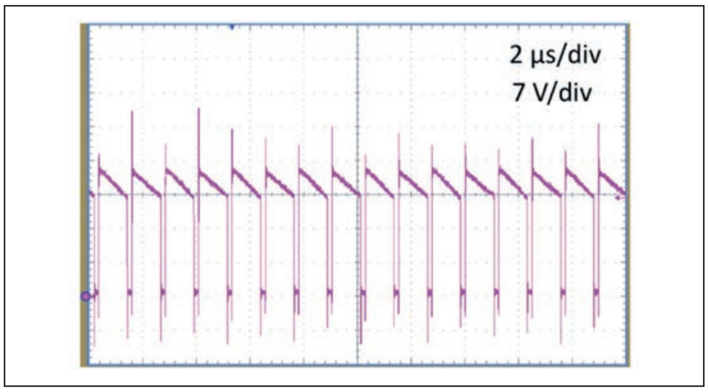
Simplified schematic of the eGaN FET-based three-level converter



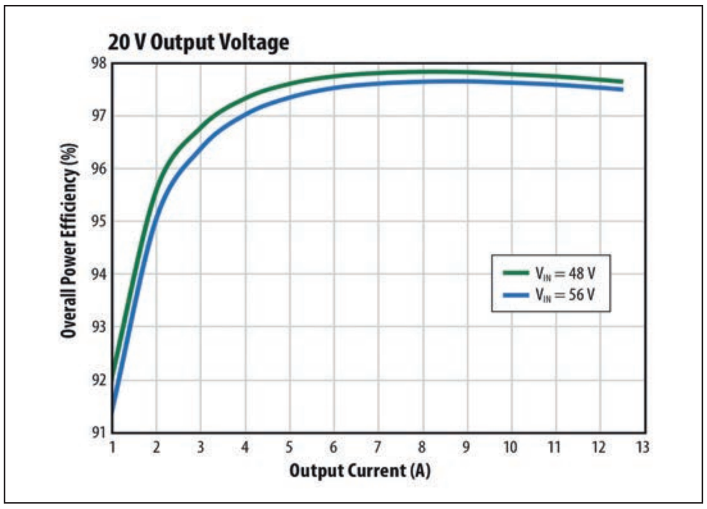
Bump side of EPC2053 (left) and EPC2055 (right)



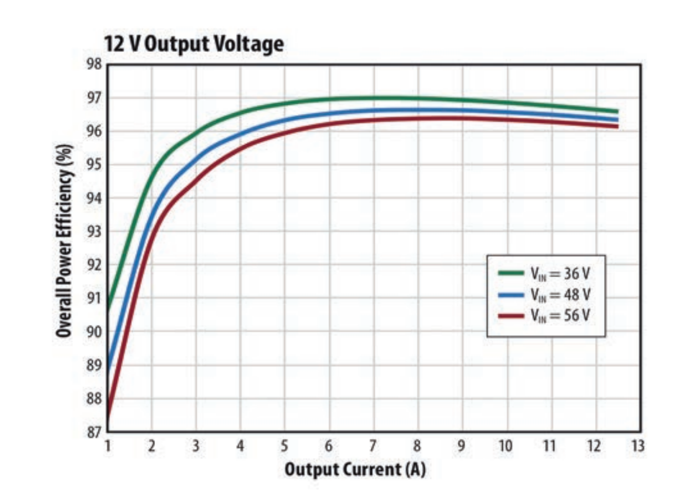
PCB of the 48 V to 20 V three-level buck converter



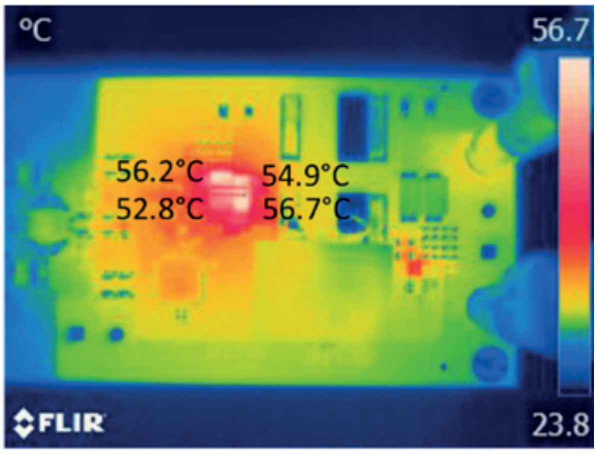
Switch-node voltage VSW waveform at 8 A output current



Total system efficiency including the housekeeping power consumption at 20 V output



Total system efficiency including the housekeeping power consumption at 12 V output



Thermal image of the three-level buck converter at 12.5 A output current and thermal steady state with 800 LFM forced air

effective frequency seen at the output inductor is thus twice of the switching frequency for the FETs, allowing the use of lower inductance value than required in a conventional synchronous buck converter.

The switching frequency of the converter is optimized at 400 kHz so that the effective frequency seen at the inductor is 800 kHz, high enough to allow the use of a 3.5 mm tall, 2.4 µH inductor, whilst maintaining low switching loss and thus high overall efficiency and good thermal performance. The cascaded synchronous bootstrap circuit that ensures adequate gate voltage (>4.5 V) for the upper FETs is adopted.

Three control loops are implemented using a digital controller to regulate the output voltage, output current, and flying capacitor voltage respectively. Flying capacitor voltage should be kept at half of the input voltage at any time to avoid overstressing any of the FETs and ensure correct circuit operation.

Q1 blocks the 48 V input voltage before the flying capacitor voltage is established. As Q2-Q4 only need to block half of the input voltage, they only need to be rated for 24 V. Therefore the 100 V rated EPC2053 with R_{DSon} of 3.8 mΩ and the 40 V rated EPC2055 with R_{DSon} of 3.5 mΩ are selected for Q1 and Q2-Q4 respectively. Both eGaN FETs are of tiny size, and can operate at up to 150°C junction temperature.

Experimental validation

A three-level buck converter was built to verify the design. The overall thickness of the circuit including the circuit board is only 5 mm. The circuit was tested with no forced air up to 12.5 A output current with a temperature rise of 65 °C. The switch-node voltage VSW waveform at 8 A output current shows that the capacitor voltage is well-balanced during charge and discharge phases. The overall power efficiency of the three-level converter operating at

20 V output and with 800 LFM forced air peaks an efficiency of 97.8 %. It maintains efficiency above 97% above 4 A load current.

The thermal image of the converter operating at 48 V to 20 V, 12.5 A output current with 800 LFM forced air cooling shows that the FETs are capable of carrying more current with forced air.

www.epc-co.com

Power Electronics 2019 – Moscow, 22-24 October 2019

Amongst other exhibitors, Proton-Electrotex took part in 16th International exhibition of power electronics components and modules – Power Electronics 2019. The exhibition was held in Crocus Expo, Moscow on 22-24 of October.

Proton-Electrotex traditionally presents its latest research and new products there. Besides, specialists of the company showcase samples of existing portfolio already known to customers. Besides, researchers of the company were presenting few reports:

1. T. Fedorov. New technology Engineer: «WEB version of the software for calculation IGBT power converters»
2. D. Malyy. Lead Research Engineer: «Fast hybrid IGBT modules – an alternative to SiC MOSFET in modern energy efficient mid-power converters» and «Ensuring quality of IGBT modules made by Proton-Electrotex at design and production stages»

Components Bureau Adds Artesyn to Its Expanding Power Portfolio

World leading power franchise brings new opportunities

Components Bureau has signed an agreement with power expert Artesyn covering the UK and Ireland. This new agreement is part of the company's strategy to expand its power product portfolio and build on its already established specialist power franchises.

Artesyn has a broad power offering with products from 3W to hundreds of kW. These products will add an exhaustive range of high power modular and programmable power supplies for high end applications where control and monitoring of the power supply is critical.

The addition of such a will strengthen Component Bureau's targeting of the motive power, automation, robotics and environmental control markets.

This agreement is an extension of the successful partnership between Artesyn and Component Bureau's sister company Emtron in Germany. With excellent technical and design-in support offered by both companies and UK and German warehousing facilities this will be a great addition to find new markets and meet customer requirements.

Commenting on the agreement, Andrew Ferrier, General Manager of Components Bureau said, "this is an exciting addition to our portfolio and allows us to replicate in the UK the success that our sister company has already achieved in Europe which gives us a very strong foundation to build on".

Full details of the Artesyn product range available can be found at **www.componentsbureau.com**

The Need for GaN

In July 2019, Power Integrations announced new members of its InnoSwitchTM3 families of offline CV/CC flyback switcher ICs. The new ICs feature up to 95% efficiency across the full load range and up to 100 W in enclosed adapter implementations without requiring a heatsink. This increase in performance was achieved using an internally developed high-voltage GaN switch technology (PowiGaN).

Gallium Nitride (GaN) is a wide-bandgap semiconductor material that allows fabrication of switches that have very low switching losses both during turn-on and turn-off compared to their Silicon counter parts. In fact, unlike Silicon MOSFETs, GaN switches inherently have near-zero turn-off losses. Turn-on losses in GaN Switches are almost entirely due to inter-nodal capacitances which are much smallerGaN compared to Silicon MOSFETs. This is because both turn-on and turn-off in GaN are almost instantaneous and equivalent R_{DSON} GaN devices are much smaller in die size compared to Silicon.

Performance advantages of PowiGaN

Power Integrations has developed advanced GaN Switch technology (PowiGaN) and has optimized the devices for use in their integrated power solutions. PowiGaN devices allow the InSOP-24C package to deliver much higher power levels without a heatsink while also substantially increasing the overall power supply efficiency.

A major challenge for discrete GaN solutions is the difficulty in driving the transistors and protecting them. GaN is so much faster than Silicon that even small amounts of inductance and capacitance introduced by the discrete GaN packages and PCB trace connections makes it very difficult to drive.

Common challenges are high dv/dt and high frequency oscillation during switching which creates EMI, lowers efficiency and some cases can cause destruction of the device. The high switching speed also makes it very difficult to protect the transistor during fault conditions as the high speed of the GaN switches can cause the switch current to ramp to destructive levels - before the protection circuitry has a chance to safely turn off the device.

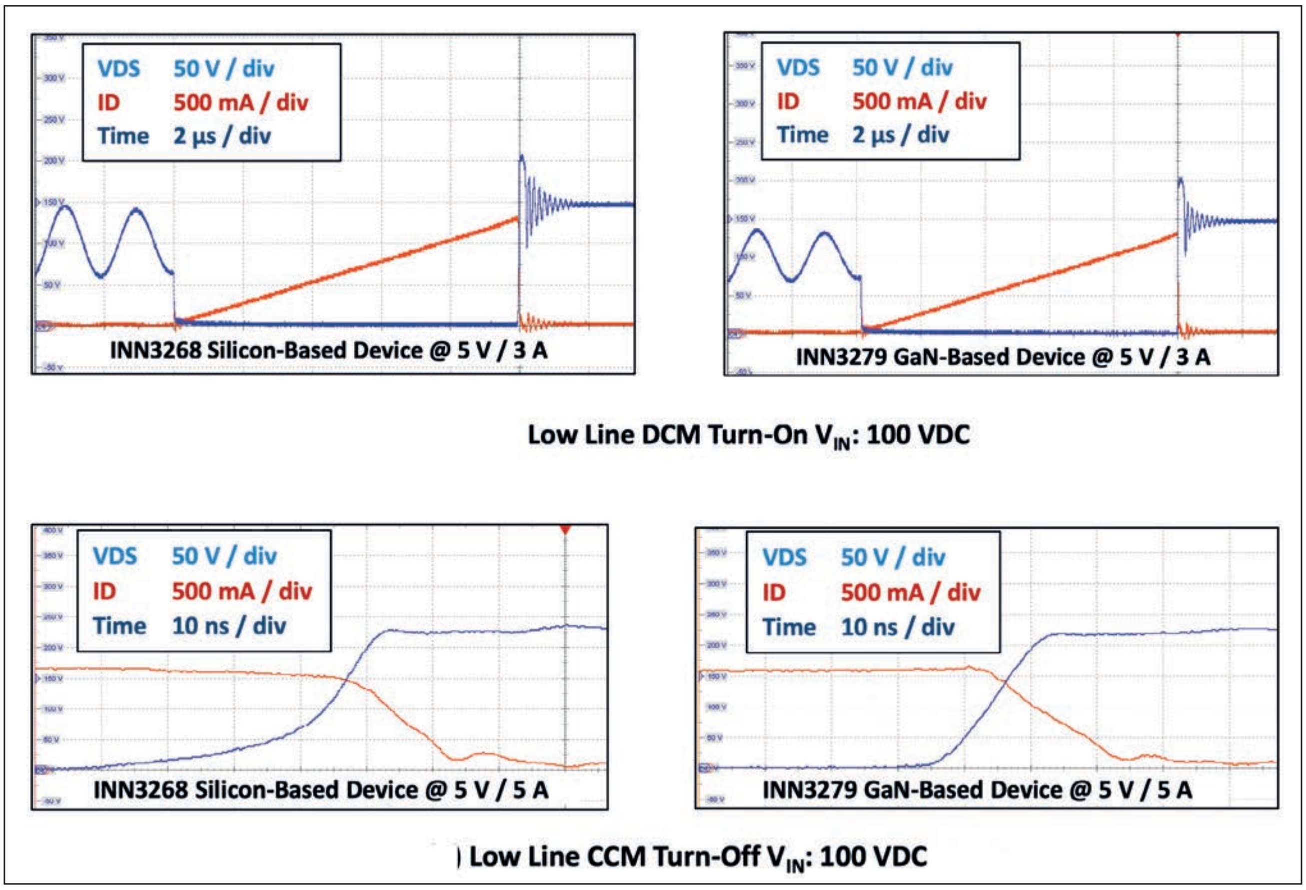
These issues are resolved by embedding the PowiGaN in highly integrated switcher ICs. Integration significantly reduces parasitic inductances and capacitances making it easier to avoid oscillation. PowiGaN-based products incorporate drivers that are tailored to the specific PowiGaN device, optimizing switching speed to minimize EMI, maximize efficiency and effectively eliminate oscillation. The protection circuitry is able to quickly detect unsafe currents and safely shutdown device under fault conditions, and switching converter ICs include start-up circuitry which eliminates the need for external biasing circuits. PowiGaN devices also employ lossless current-sense technology, completely eliminating external sense resistors that frequently exceed the resistance of the GaN switch itself in discrete implementations.

The operation of PowiGaN-based InnoSwitch3 is indistinguishable from that of conventional devices from the same family. Switching frequency, transformer design, EMI filtering, biasing and synchronous rectification circuitry is identical for PowiGaN and Silicon devices. Changes are only necessary to accommodate the higher power of PowiGaN-based designs. The PI Expert automated power-supply-design-software suite supports both MOSFET and PowiGaN based devices, speeding the design process by enabling the selecting of the best component and generating the full schematic, magnetics and BOM from basic parametric inputs.

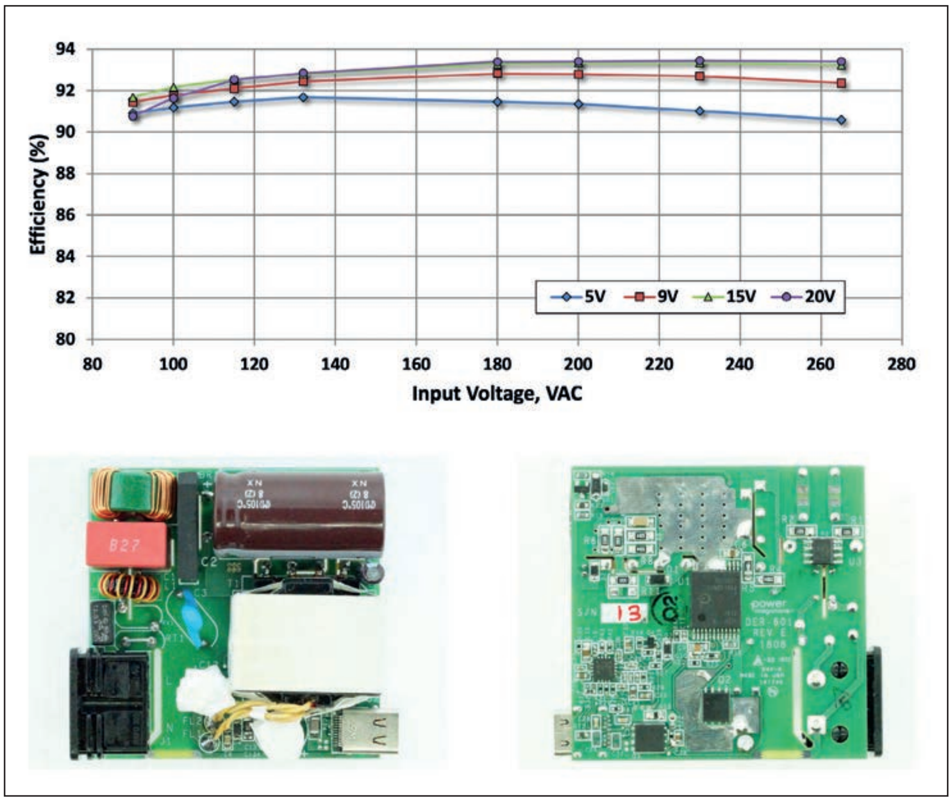
Lower $R_{DSON(MAX)}$ and switching loss increases efficiency compared to conventional Silicon based technologies. Like other InnoSwitch3 devices, efficiency for PowiGaN-based designs is constant across line and load ranges. This makes them ideal for applications calling for high average efficiency and for adjustable output-voltage designs (USB PD and PPS).

Robust and reliable

PowiGaN devices are specifically designed to operate at the voltage levels seen in off-line flyback power conversion. They are manufactured in the same fabs as Power Integrations' conventional Silicon products and have undergone extensive



Seamless transition between GaN and Silicon devices is demonstrated by the comparison of drain-source voltage waveforms during switching for PowiGaN and Silicon InnoSwitch3 devices. The waveforms are virtually identical, the same circuits can be used for Silicon and PowiGaN based devices



InnoSwitch3-Pro 100 W wide-range USB PD + PPS charger (5 V – 20 V output) with no-heatsink required

qualification testing to ensure reliable operation in power conversion circuits. In addition to the qualification tests listed below, the switcher ICs go through extensive long-term testing in real-world power supply designs which has resulted in a field failure rate of less than 0.2 PPM across all our products.

In addition to the standard qualification tests employed, PowiGaN based product qualification includes additional DOPL and HALT testing to confirm an extra degree of survivability for these devices in worst case (real-world) conditions. As part of the PowiGaN development process, unique and proprietary wafer level, die level and final-test level GaN-specific screening tests have been created to ensure device continuity and reliability.

PI switcher devices operate at the highly variable range of mains voltage levels encountered in theline power conversion applications worldwide. Voltage stress on the primary switch in a flyback power supply is a combination of the rectified line voltage (V_{BUS}), the output reflected voltage (V_{OR}) – output voltage reflected across the turns-ratio of the power transformer, and the voltage induced by the the leakage inductance of the transformer primary winding (V_{LE}). In a typical flyback design the worst case voltage stress under normal operation occurs at maximum line voltage (264 VAC for European systems). The Figure below shows the approximate magnitude of the different components compared to voltage rating of a PowiGaN primary switch.

Power supplies attached to mains may also experience line surges and swells, and to address this, two voltage ratings are provided for the PowiGaN switch, enabling the power supply engineer to optimize the power supply design for practical applications. The $V_{MAX(NON\ REPETITIVE)}$ rating (750 V) describes the maximum voltage-withstand under transient, swell and surge conditions. PowiGaN-based parts are 100% production tested at voltages in excess of the $V_{MAX(NON\ REPETITIVE)}$ limit to ensure operational reliability. This parameter is employed for derating purposes in the power supply design in the same way as the “abs-max” BVDss rating for a traditional MOSFET is used. The maximum continuous voltage ($V_{MAX(CONTINUOUS)}$) parameter describes the stress that may be applied continuously to the GaN switch. For PowiGaN devices this figure is 650 V. Operation above this limit will not damage the device, but repeated exposure to higher voltages may cause temporary $R_{DS(ON)}$ shift beyond limits. InnoSwitch products are provided with a fast line-over-voltage protection feature, they will cease switching to protect themselves should line voltage exceed a user-defined limit, ensuring that all of the 750 V of maximum voltage rating is available during transients.

The technology used in the PowiGaN-based InnoSwitch3, InnoSwitch3-Pro and LYTSwitch-6 is effective, reliable and easy to use. As a material for power semiconductors, GaN enables devices that behave much closer to an “ideal switch” than contemporary Silicon. The exceptional performance results of PowiGaN-based devices will be increasingly utilized in PI device-families.

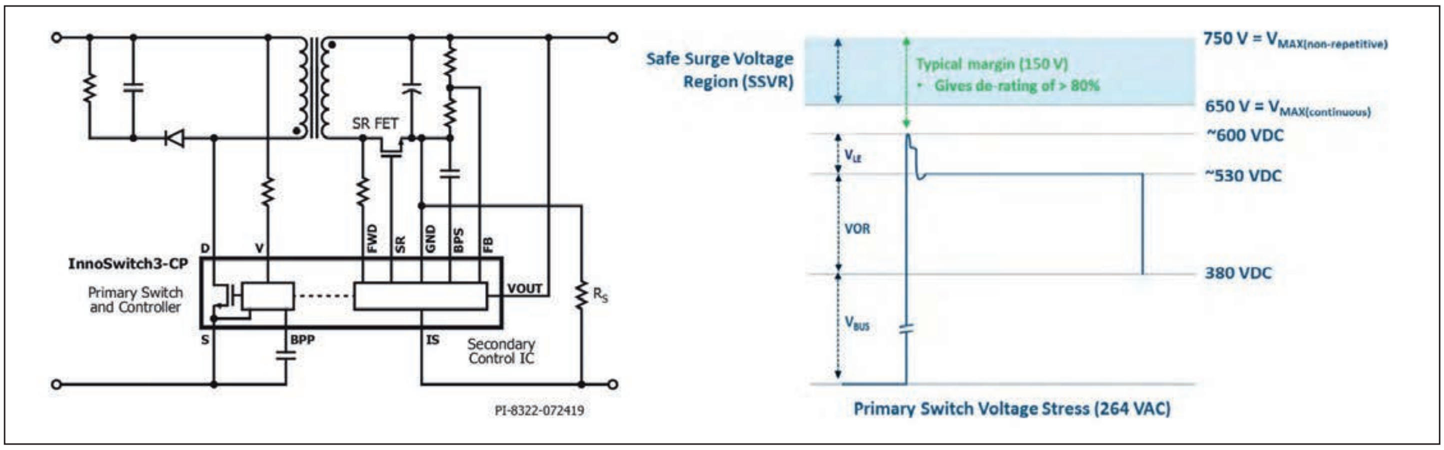
Literature

PI White Paper “GAN-BASED PRIMARY-SIDE POWER SWITCHES EXTEND THE POWER RANGE OF INNOSWITCH3 IC FAMILIES”

Power Electronics Europe 5/2019, pages 16 – 18, “LED Drivers from Power Integrations Use PowiGan Technology”

Power Electronics Europe 4/2019, page 18, “Power I(ntegrations Enters GaN-on-Sapphire Power Applications”

www.power.com/gan



Voltage stress on the primary switch of an offline flyback power supply operating at 264 VAC. VOR is dependent on output voltage (V_S) and transformer design. All InnoSwitch3 families and LYTSwitch-6 devices monitor BUS voltage via the V pin and will interrupt switching to eliminate V_{OR} and V_{LE} voltage-stress components during line surges

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SiC MOSFETs for Bridge Topologies in Three-Phase Power Conversion

Efficiency, productivity and legislation are main market drivers in power applications today. Making more out of less energy, and saving energy costs is putting a greater focus on better conversion efficiency and smaller, lighter systems. Here, power semiconductors provide new potential along the entire electrical energy supply chain, whether it be the growing share of renewables as part of the energy mix in generation, transmission or consumption of electricity in power converters. Although the latest generation of Si-MOSFETs and IGBTs are still good solutions in many cases, transistor functionality in the wide bandgap materials SiC and GaN offers a new degree of design flexibility for achieving new target requirements. Thus the use of SiC MOSFETs to improve power conversion performance or implement system innovation is nowadays a popular scenario for many system designers. In this article, Infineon takes the reader through SiC MOSFET design-in guidelines in bridge topologies, used for example in battery charging and servo drive applications. **Dr. Fanny Björk, Senior Specialist, and Dr. Zhihui Yuan, Technical Marketing Manager, Infineon Technologies, Munich, Germany**

Infineon will complement each leading-edge solution in silicon by a wide bandgap technology. A recent portfolio addition is the comprehensive 1200 V CoolSiC™ SiC MOSFET portfolio in TO247 packages. The intrinsic characteristics of SiC components, primarily the low dynamic losses, at an order of magnitude lower than Si IGBTs in the 1200 V class, can be translated into significant loss reduction at the system level. A performance-based design of the SiC MOSFET product features is here the key. Specifically, this means that Miller capacitance and threshold voltage ratings strongly affect the possible dynamic loss reduction as opposed to Si components. That is in turn crucial for the final result at the power conversion level, i.e. saving percentage points in battery power during bi-directional charging or integrating the inverter into a servo motor.

From Silicon to Silicon Carbide

A 1200 V rated SiC MOSFET offers various reasons for replacing `next-best´ Si technology. Compared to a 1200 V Si IGBT, lower dynamic losses are the most prominent feature. The lack of minority carriers in conduction mode eliminates tail currents, and thus, enables very small turn-off losses. Turn-on losses are also reduced compared to IGBTs, predominantly due to the smaller turn-on current peaks coming from the low reverse-recovery loss nature of body diodes. Both loss types do not show an increase in temperature. However, in contrast to IGBTs, turn-on losses for MOSFETs dominate, while turn-off losses are small, which is often the opposite situation with IGBTs.

Another reason is the similar switching performance with a SiC MOSFET in the 1200 V class as with a Si super-junction MOSFET in the 650 V class. A SiC MOSFET exhibits a low-loss body diode, which is perfectly suitable for hard commutation due to the lack of a super-junction device structure causing snappy behavior. Topologies and solutions that have been up to now only possible in the single-phase power conversion using 650 V rated devices are now feasible at higher bus voltages in three-phase power conversion.

Practical loss reduction

To achieve the low dynamic losses that SiC MOSFET technology promises in theory, there are in reality certain device-design parameters that must come out right. Dynamic losses might be high due to parasitic turn-on effects caused by a gate-voltage rise from capacitive feedback via the Miller capacitance, C_{dg}. The parasitic turn-on phenomenon occurs when the MOSFET is in the off-state and the antiparallel diode is turned off. If the coupling voltage is at a higher level than the gate threshold voltage of the device, then a shoot-through event occurs. The severity of the shoot-through and associated energy losses depends also on the operating conditions and hardware. More critical is high bus voltage, fast dv/dt switching transients, low gate resistance for turn-on, and high gate resistance for turn-off, as explained in detail by Sobe et al [1]. While a MOSFET´s susceptibility to the unwanted effect can be estimated by the MOSFET capacitance ratio $C_{dg}/(C_{dg}+C_{gs})$ and its gate threshold voltage, $V_{gs,th}$.

In Figure 1, a datasheet comparison of the latest generation of SiC MOSFETs available on the market reveals large differences in coupled gate voltage from the Miller capacitance, as well as in the gate threshold voltage. For the example using a bus voltage VDC of 600 V, there are only two vendors that come out with an inherent immunity against parasitic turn-on (PTO) effects, i.e. there is a positive balance between gate-threshold voltage and induced voltage.

It is worth noting that even the switching transients are moderate for several devices; the resulting turn-on loss reduction versus a fast-switching IGBT is still significant. This confirms the impressive functionality of using a MOSFET device in 1200 V class. As also reflected in

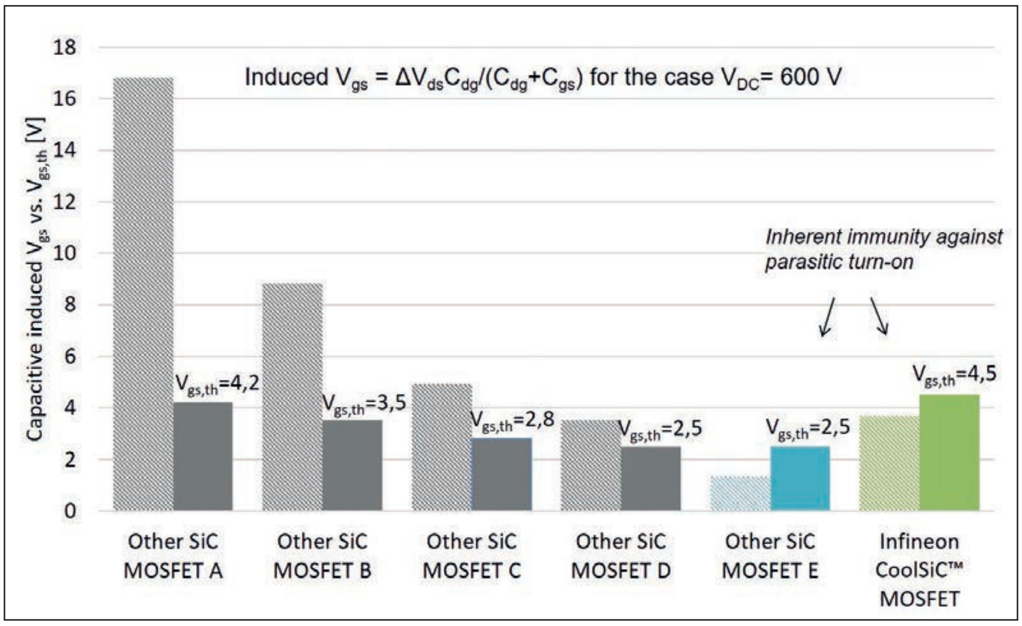


Figure 1: Datasheet comparison of susceptibility to unwanted parasitic turn-on by calculating the capacitive induced gate voltage rise in comparison to the typical Vgs,th rating of the devices. The various 1200 V SiC MOSFET devices have a nominal on-state resistance of 60-80 mΩ

Figure 2, a TO247 4-pin package with a Kelvin source connection operates at even faster dv/dt compared to a 3-pin package, >50 V/ns is reached. This lowers the switching energy by more than 10 % at the 15 A test current condition. For higher currents, the loss reduction from the 4-pin package will be even larger, thanks to the extra driver source pin and its virtual elimination of voltage drop over the lead inductance.

Safe-operation gate-driving scheme

Parasitic turn-on effects in SiC MOSFETs not only affect dynamic losses, but also safe operation with regard to maximum gate-voltage ratings, which is critical for gate-oxide reliability. A negative gate-voltage supply may be used to suppress a parasitic turn-on effect. But instead the problem occurring in many cases is an insufficient margin versus the maximum negative gate voltage specified in the device datasheet. In other words, the coupling voltage may exceed the limitation. Figure 3 shows the schematic overview of such a situation.

The voltage due to a capacitive coupling creates an under-shoot voltage in addition to the turn-off gate voltage. Referring back to Figure 1 and Figure 2, CoolSiC™ MOSFETs in TO247 can be switched at fast dv/dt and low losses without any significant parasitic turn-on and under-shoot voltage occurring. Thus, CoolSiC MOSFETs are tailored towards both performance (lowest dynamic losses) and safe operation within datasheet limits. Assuming a carefully designed PCB layout with minimized gate-drain capacitance, Infineon encourages power electronic designers to operate CoolSiC MOSFETs with a turn-off voltage of 0 V. Thus, a simple unipolar gate drive scheme is feasible without sacrificing performance.

Next generation servo drive with up to 80 percent loss reduction

Servo drive systems, typically characterized by high-performance and compact inverters for industrial robots or in automation, are one application that is impacted by SiC MOSFET performance [4]. Conduction and switching loss reduction can be obtained in all operation modes: acceleration, constant speed and breaking mode. Constant speed mode – when the motor is normally operated with low torque, i.e. low current – is typically ≥90 % of operation time. Here SiC MOSFETs (see Figure 4) enable approximately 80 % total loss reduction versus a Si IGBT. Such loss reduction is not only from the dynamic loss but also from the conduction losses thanks to Ohmic output characteristics without a knee voltage.

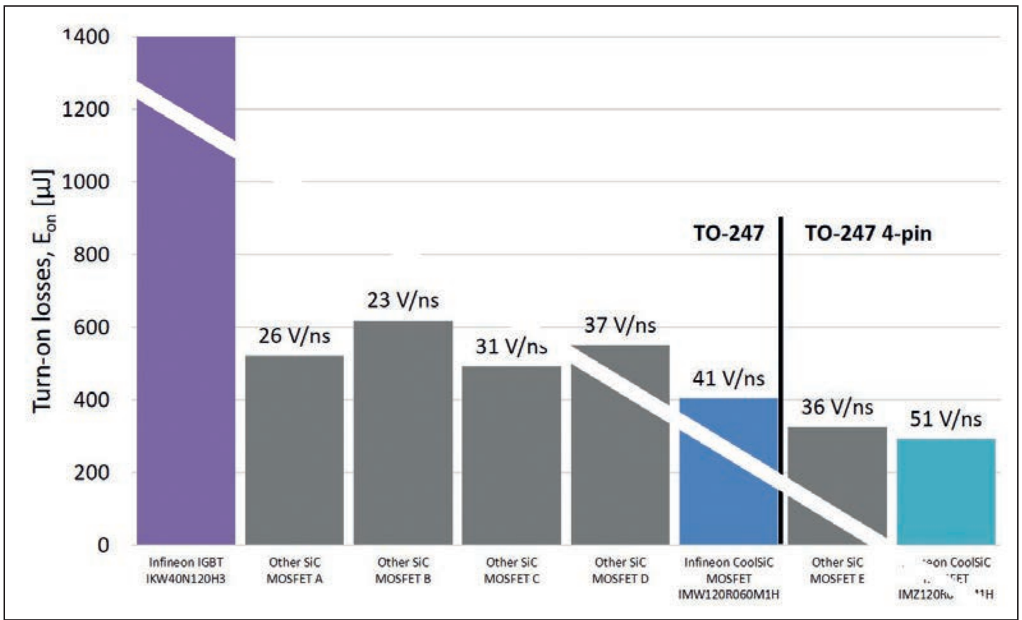


Figure 2: Minimum achievable turn-on switching losses and associated dv/dt switching transients for 0 V turn-off gate voltage, measured in an Infineon double-pulse evaluation board [2] for 60-80 mΩ rated SiC MOSFETs on the market. The high immunity of CoolSiC™ MOSFETs against parasitic turn-on energy losses are confirmed by lowest losses for both TO247 package versions. Test conditions were 800 V, 15 A and 150°C

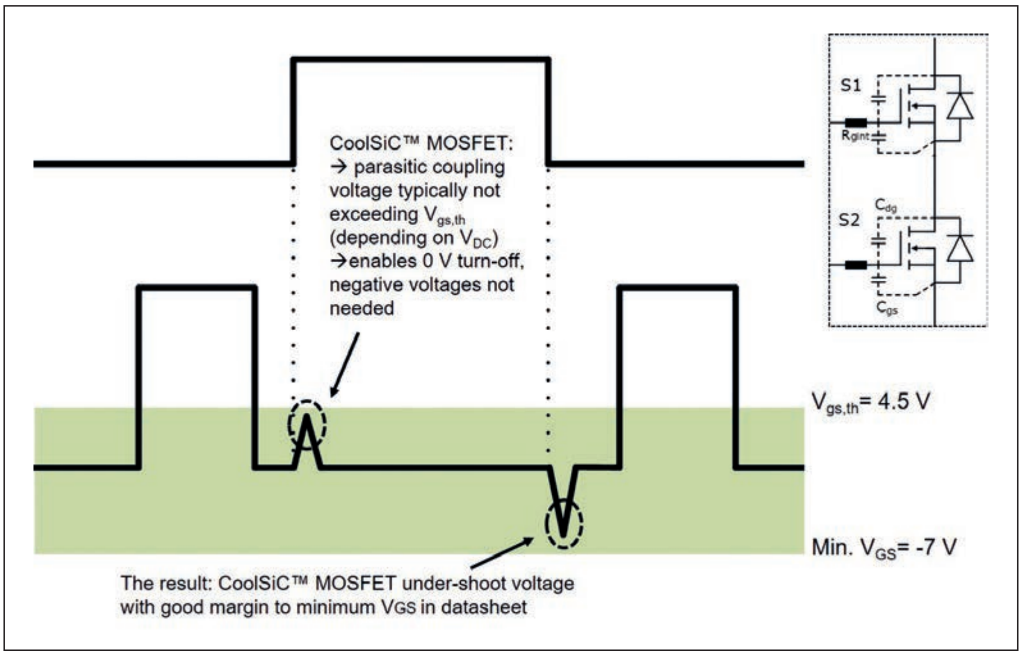


Figure 3: Schematic view of turn-on and under-shoot voltages related to capacitive coupling voltages. Parameters indicated refer to product datasheet for IMZ120R060M1H [3]

In the acceleration and breaking mode, the drive normally operates at a much higher current range. Here the dynamic loss could be reduced up to 50 % compared with a SiC IGBT, even at the same dV/dt of 5 V/ns. The semiconductor loss reduction of about 80 % can in turn be used for the servo drive to increase pulse current capability, make it more compact (same frame with higher current), reducing fan and/or heatsink, and even integrating the inverter into the motor. Due to hard-switching operation in the typically used B6 topology, key SiC MOSFET features for improving application performance are low dynamic losses, no significant parasitic turn-on, and a robust internal body diode rated for hard commutation.

Doubling power density while improving efficiency in battery chargers

Fast DC battery charging connected to a three-phase power supply is the game changer for electric vehicle (EV) market development, as it reduces user´s anxiety in terms of range. Bi-directional charging for energy storage solutions is also emerging with battery containers stationed on more and more sites where sustainable energy sources such as solar panels can be used for charging EVs and for other purposes. State-of-the-art battery chargers use soft-switching LLC topologies in the DC-DC stage, see top picture in Figure 5 (if bi-directional charging is not needed in the user application, the secondary side switch positions use diodes). As low enough dynamic losses are only found in 650 V rated Si devices, two cascaded LLC full-bridges are needed to support an 800 V DC link voltage.

With a 1200 V rated SiC MOSFET, the number of switch positions including driver ICs can be cut in half (middle schematic in Figure 5). Besides the 50 % part count reduction, and thus smaller board space requirement, also efficiency may be optimized. For a SiC MOSFET solution, only two switch positions are turned on in every on-state, in comparison to four switch positions in the 650 V solutions. With system efficiency today typically optimized around 97 % in Si-based systems, the 50 % reduction of conduction losses and lowered turn-off switching losses coming from smaller output capacitance in a SiC MOSFET, over 1 % higher efficiency can be obtained. For bi-directional charging, this means 2 % or more savings of battery power.

The low overall switching losses of a 1200 V SiC MOSFET, combined with a fast internal body diode suitable for hard commutation, also encourage traditional hard-switching solutions such as the dual active bridge (Figure 5 bottom). Significantly less control effort, overall less complexity and a reduced part count are making such solutions increasingly attractive.

Conclusion

The 1200 V CoolSiC MOSFET portfolio in TO247 packages is the go-to solution for both emerging applications such as battery-

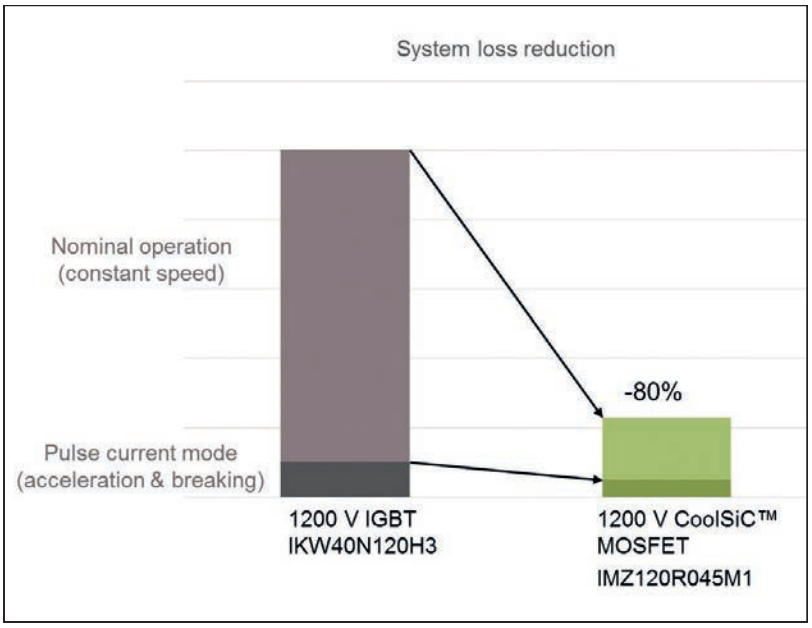


Figure 4: Typical system loss reduction in a servo-drive inverter considering all operation modes. For the calculation, a 45 mΩ rated 1200 V CoolSiC™ MOSFET was compared to a 40 A rated 1200 V Si IGBT in a two-level B6 topology

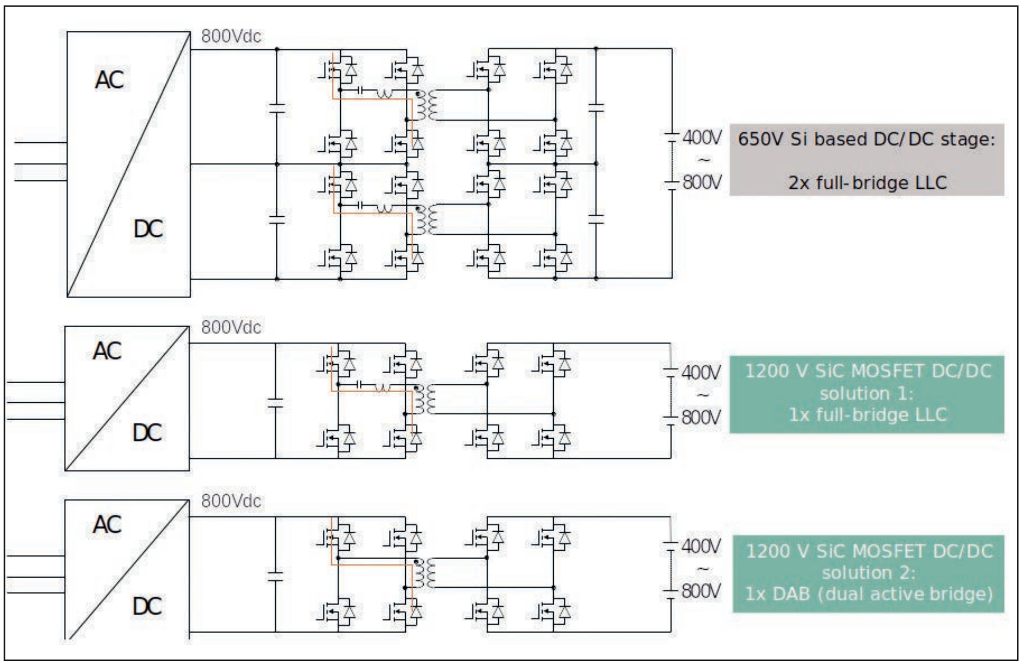


Figure 5: Three-phase fast DC battery charging including bi-directional feature on secondary side: comparison of Si-based solution with solutions using a 1200 V rated SiC MOSFET. Arrows indicate the 50 % conduction loss reduction feasible with SiC MOSFET due to less switch positions in turn-on current path

charging infrastructure and energy-storage solutions, as well as for established applications such as servo drives. In hard-switching and soft-switching topologies, CoolSiC MOSFETs improve efficiency, and reduce part count and system complexity. CoolSiC MOSFETs exhibit an excellent immunity against unwanted parasitic turn-on effects. The result is lowest dynamic losses among SiC MOSFETs, easy design-in regarding safe operation within datasheet limits, and an enabling of 0 V turn-off gate voltage. A simple unipolar gate drive scheme is feasible without sacrificing performance.

Literature

[1] K. Sobe et al, "Characterization of the parasitic turn-on behavior of discrete CoolSiC™ MOSFETs", PCIM Europe 2019, Nuremberg, Germany, 2019

[2] https://www.infineon.com/cms/en/product/evaluation-boards/eval-igbt-1200v-247

[3] https://www.infineon.com/dgdl/Infineon-IMZ120R060M1H-DS-v01_01-EN.pdf?fileId=5546d46269e1c019016a92fdba796693

[4] https://wirautomatisierer.industrie.de/messe/sps-ipc-drives/beckhoff-zeigt-dezentrales-servoantriebssystem-amp8000/

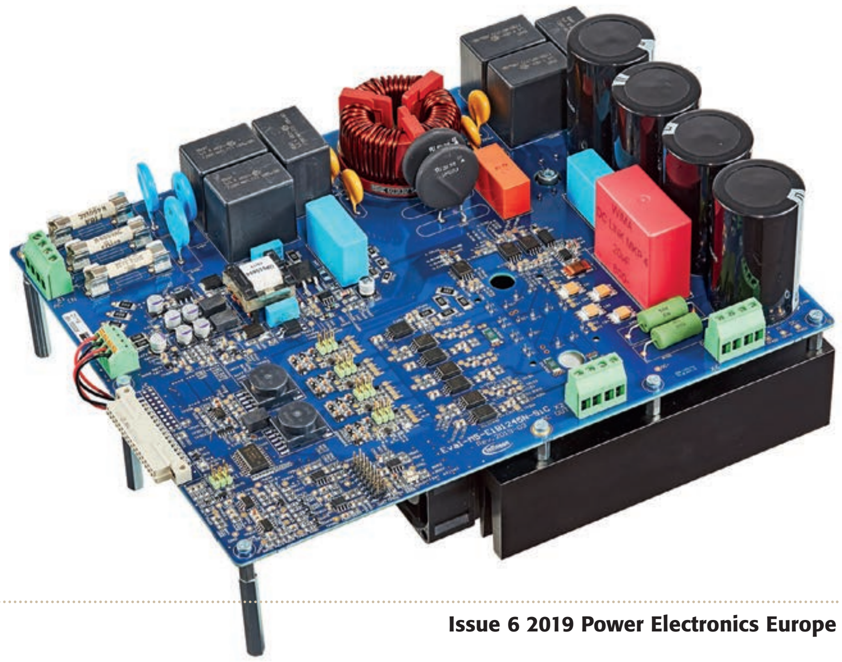
Evaluation Board for 7.5 kW Motor Drives

The evaluation board EVAL-M5-E1B1245N-SiC will help to pave the way for SiC in motor drives. It was developed to support customers during their first steps in designing industrial drives applications with a maximum of 7.5 kW motor output.

The evaluation board comprises an EasyPACK™ 1B with CoolSiC™ MOSFET (FS45MR12W1M1_B11), a 3-phase AC connector, EMI filter, rectifier and a 3-phase output for connecting the motor. Based on the Modular Application Design Kit (MADK) the board is equipped with the Infineon standard M5 32-pin interface which allows the connection to a control unit such as the XMC DriveCard 4400 or 1300. Its input voltage covers the range of 340 to 480 VAC.

The new member of the MADK family is optimized for general purpose drives as well as for servo drives with very high frequency. It features the EasyPACK 1B in Sixpack configuration with a 1200 V CoolSiC MOSFET and a typical on-state resistance of 45 mΩ. The power stage contains sensing circuits for current and voltage; it is equipped with all assembly elements for sensorless field oriented control (FOC). The EVAL-M5-E1B1245N-SiC has a low inductive design, integrated NTC temperature sensors and a lead-free terminal plating, which makes it RoHS compliant.

www.infineon.com/cms/de/product/evaluation-boards/eval-m5-e1b1245n-sic/



Power Capacitor Technologies for WBG Power Semiconductors

In the field of power electronics conventional semiconductors based on Silicon are increasingly being replaced by wide band-gap (WBG) technologies based on GaN and SiC. These demand a great deal from the passive components – particularly the DC link capacitors. TDK is designing innovative solutions, enabling the advantages of the new semiconductors to be fully exploited, particularly in high-frequency switching applications. **Dr. Lucia Cabo and Fernando Rodríguez, Aluminum & Film Capacitors Business Group, TDK Electronics, Munich, Germany**

For switched applications in power electronics such as power supplies and converters, WBG semiconductors offer the advantage that they can be operated with switching frequencies in the triple-digit kHz range. At the same time, they feature steep pulse edges, thereby achieving greater energy efficiency. Due to these high switching frequencies, film capacitors are increasingly being used as DC link capacitors. In order to minimize the lead lengths, and thus the parasitic inductances, the capacitors are connected directly to the WBG modules by means of busbars. The problem here is that WBG semiconductors are operated with high barrier termination temperatures, which can also be conducted via the busbars to the DC link capacitors. The temperature limit of conventional film capacitors with a dielectric of biaxially oriented polypropylene (BOPP), however, is only 105°C.

New dielectric for high-temperature

TDK has succeeded in developing a dielectric that can also be used continuously at high temperatures. This involves a combination of two basic materials. One component is semicrystalline polypropylene, which is ideal for processing into films; the other is amorphous cyclic olefin copolymer (COC), which can tolerate high temperatures. The resulting dielectric (COC-PP) can be used at temperatures in excess of 125°C with considerably lower derating, while retaining the good self-healing properties of BOPP and comparable dielectric constant. In addition, this enables extremely thin films of just 3 µm to be manufactured. Figure 1 shows the significantly improved shrinking and derating behavior of COC-PP in comparison with conventional BOPP.

Outstanding performance

Like all capacitors, film capacitors also feature a complex ESR, a series connection comprising an ohmic and a capacitive part. Accordingly, this produces a frequency-dependent resistance that increases sharply as the frequencies rise. This rise is essentially caused by inhomogeneous impedances, skin effects and winding geometries, leading to unwanted resonances and electromagnetic effects. The result is a heating of the capacitor. This has a particularly negative effect if the internal design of a capacitor consists of several windings. Different internal lead lengths and other factors then lead to a pronounced frequency-dependent current

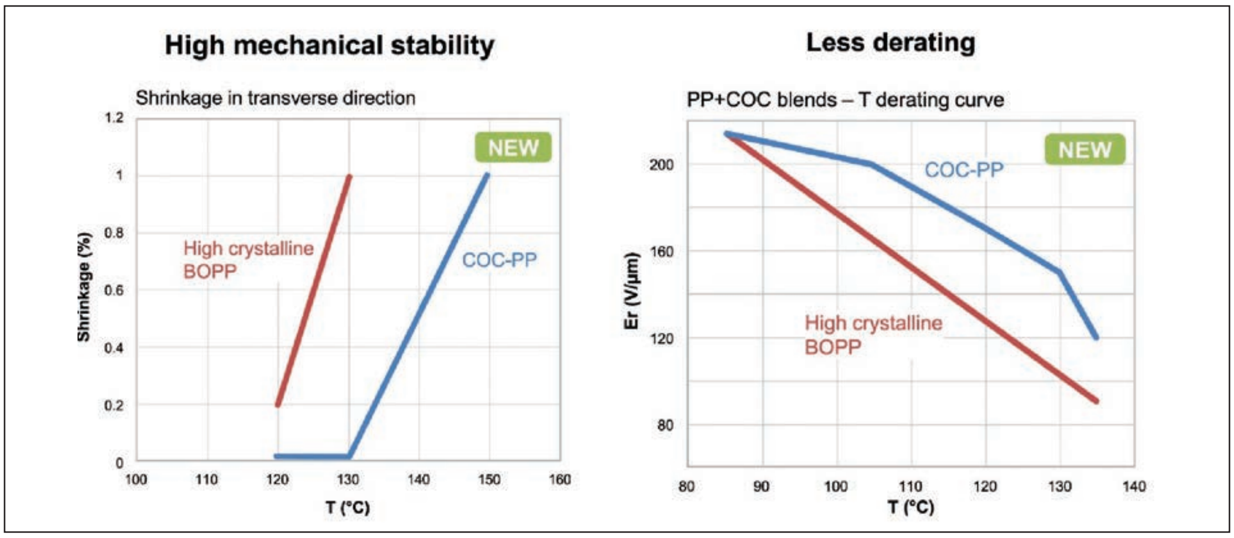


Figure 1: **At temperatures of up to 130°C the new COC-PP material exhibits no shrinkage in a transverse direction (left), voltage derating of the new material is also significantly better (right)**

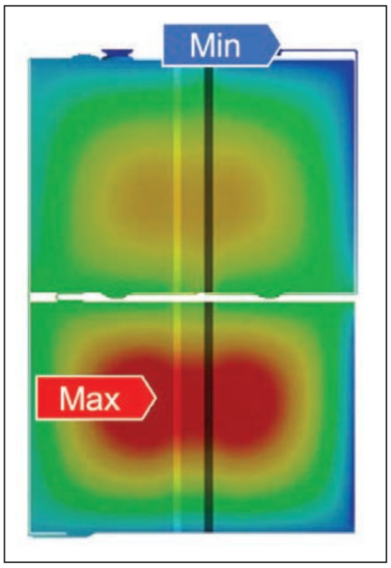


Figure 2: **A frequency of 5 kHz produces a significant inhomogeneous distribution of current, and therefore losses, over both windings**

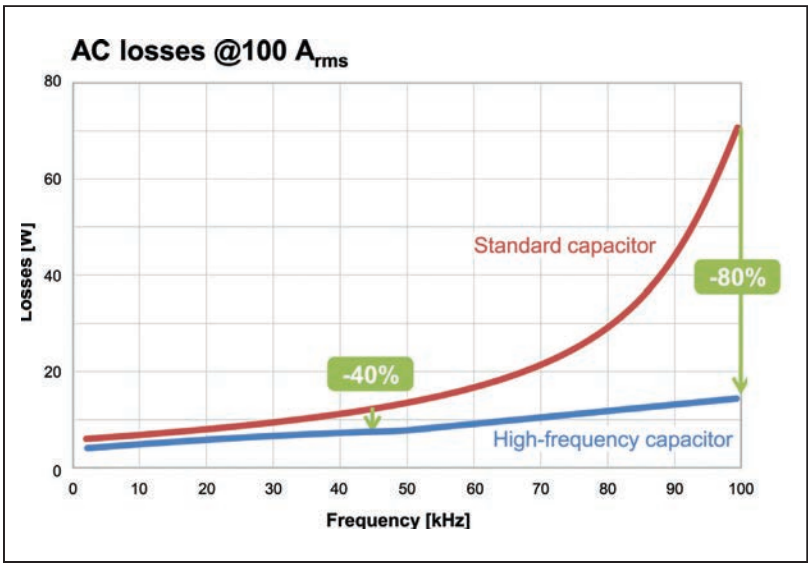


Figure 3: **At high frequencies the new HF power capacitors exhibit a dramatic reduction in power losses in comparison with conventional capacitors**

distribution across the individual windings, as shown in Figure 2.

With the aid of CAD and FEA (finite element analysis) simulation software HF (high-frequency) power capacitors with an optimized internal design have been developed. Even at the high frequencies and temperatures at which WBG semiconductors are operated, these capacitors offer high performance with low losses, thanks to a minimized ESR (Figure 3).

The new B25640* series of HF power capacitors of the (Figure 4) is especially tailor-made for SiC semiconductors. With rated voltages of between 700 and 2200 V DC and capacitance values from 370 to 2300 µF, the capacitors are suitable for the new generation of converters for traction, industrial drives and renewable energy applications. With the COC- PP dielectric the capacitors can also be operated without voltage derating at temperatures of up to 125°C. One great advantage of the new capacitors is their extremely low ESL value of just 10 nH. This means that, even at high, rapidly switched currents, their voltage overshoot remains very low, so that in most cases they even make snubber capacitors unnecessary (Figure 5).

Figure 4: **The new HF power capacitors are specially tailored to the requirements of WBG semiconductors**

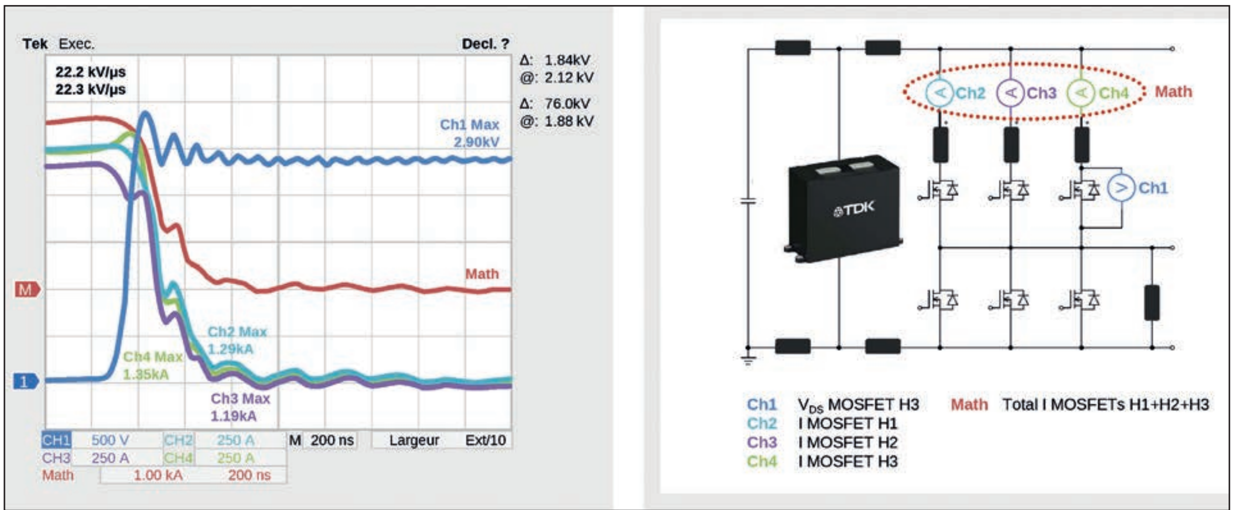


Figure 5: **The new HF film capacitor series features extremely low voltage overshoot and ringing**

High-Voltage Boost and Inverting Converters for Communications

The field of electronic communications is rapidly expanding into every aspect of ordinary life. Detection, transmission, and reception of data require a wide array of devices such as optical sensors, RF MEMS, PIN diodes, APDs, laser diodes, and high voltage DACs, to name just a few. In many cases, these devices require several hundred volts to operate, calling for DC/DC converters that meet stringent efficiency, space, and cost requirements. **Jesus Rosales, Analog Devices, Milpitas, USA**

Analog Devices' LT8365 is a versatile monolithic boost converter that integrates a 150 V, 1.5 A switch, making it suited for high-voltage applications found in the communications field, including portable devices. High voltage outputs are easily produced from inputs as low as 2.8 V and as high as 60 V. It features optional spread spectrum frequency modulation, which can help mitigate EMI, and many other popular features detailed in the data sheet.

The converters shown in Figure 1 and Figure 2 have been used to provide the positive and negative voltage rails for high voltage DACs, MEMS, RF switches, and high voltage op amps, from a 12 V input source. These converters operate in discontinuous conduction mode (DCM) and deliver as much as 10 mA, with +250 V and –250 V output voltages with a conversion efficiency of about 80 %.

One benefit of DCM operation in a boost converter is the ability to achieve a

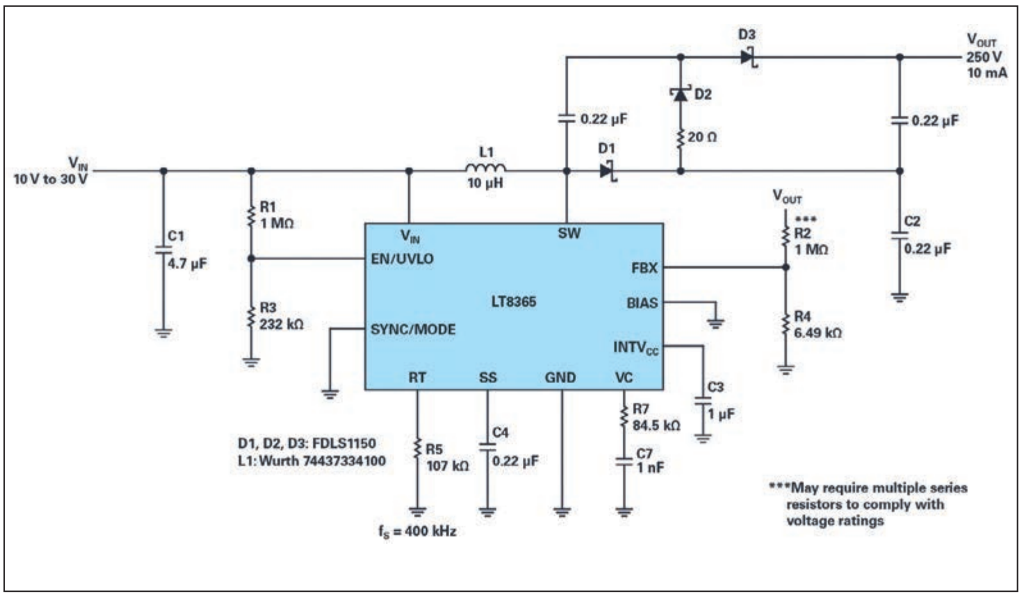


Figure 1: 12 V input to 250 V output 2-stage boost converter

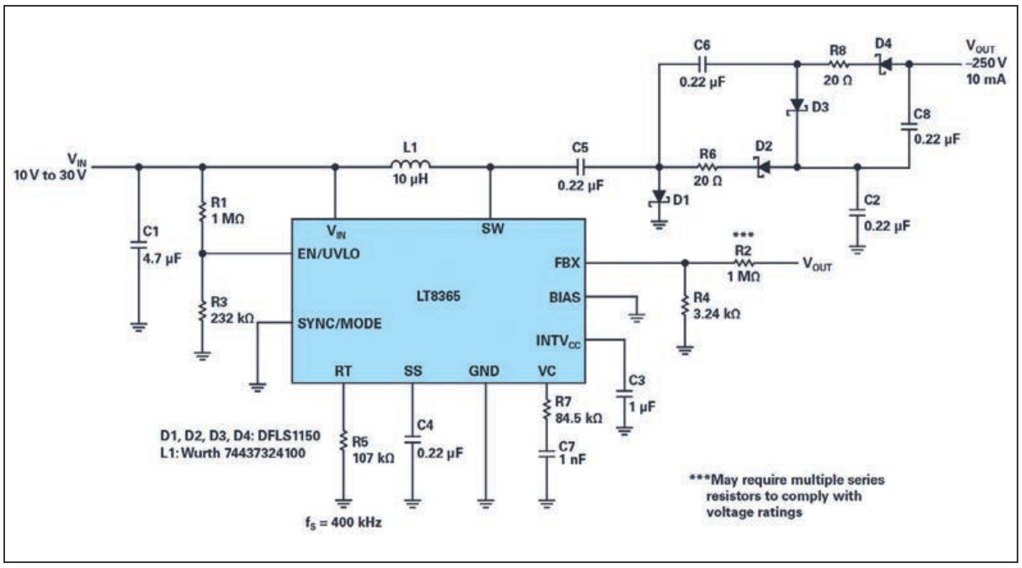


Figure 2: 12 V input to –250 V output 2-stage inverting converter

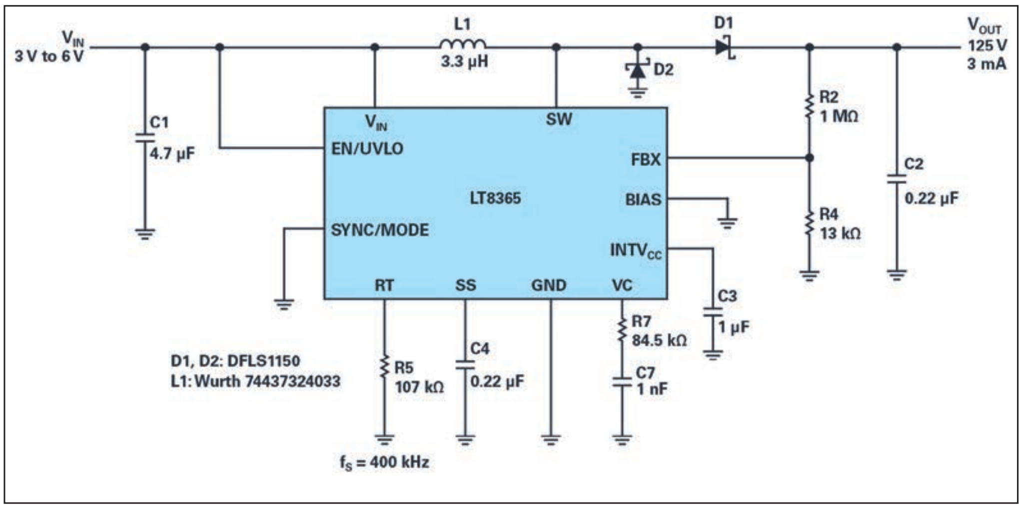


Figure 3: 3 V input to 125 V output boost converter

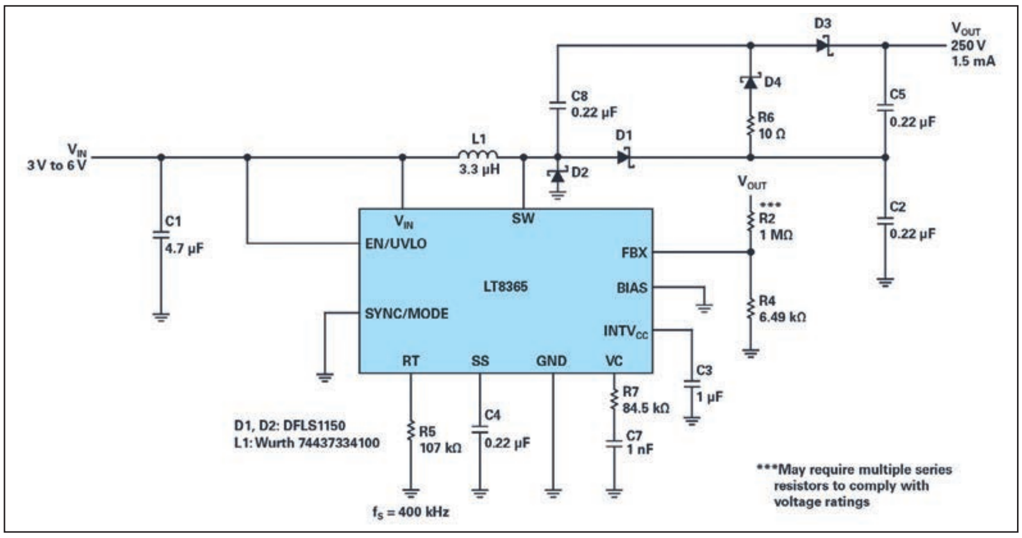


Figure 4: 3 V input to 250 V output 2-stage boost converter

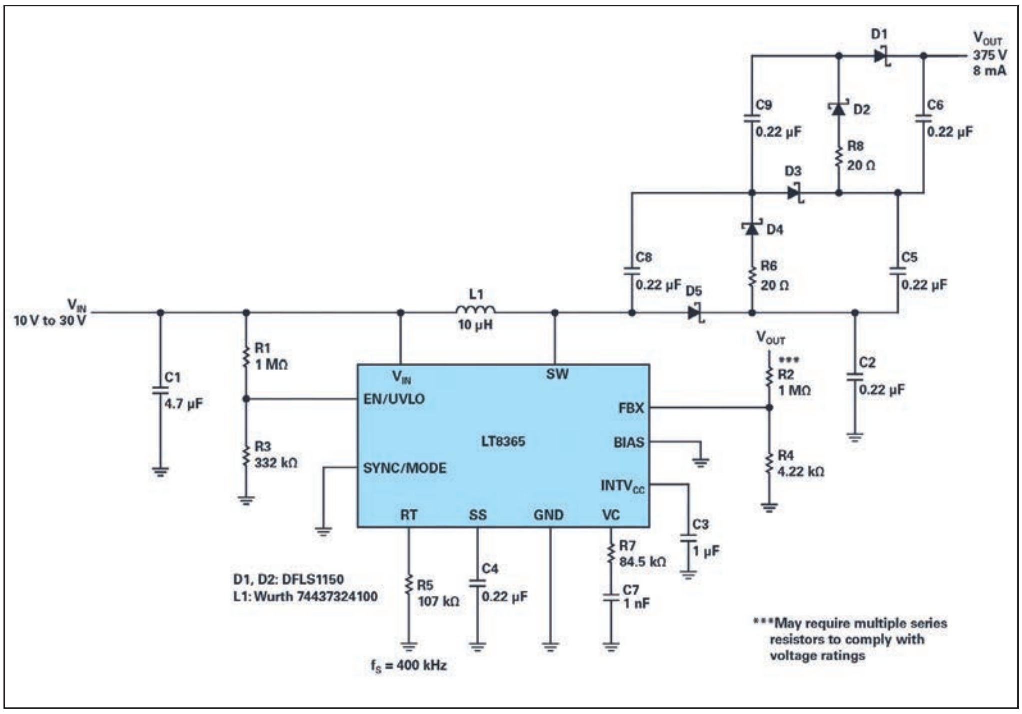


Figure 5: 12 V input to 375 V output 3-stage boost converter

high step-up ratio independent of duty cycle. Additionally, the values and physical sizes of the inductor and output capacitor can be reduced, which leads to a smaller overall footprint solution on the PCB. The circuit in Figure 3 can easily fit in an area less than 1 cm^2.

There are situations when only a very low input source is available and a high output voltage is needed. The converter shown in Figure 3 could be used to drive a variety of avalanche photo diodes, PIN diodes, and other devices requiring high bias voltages. This boost converter produces 125 V from a 3 V input source with up to 3 mA of load current.

The converter shown in Figure 4 extends the 125 V output to 250 V from a 3 V input source and supports about 1.5 mA. There are many devices in the communications field requiring such high bias voltages from low input voltage sources.

How high or low to go

For situations where very high voltage is needed, whether positive or negative, a boost converter can use multiplier stages to boost the output 2×, 3?×, or more.

The converters in Figure 1 and Figure 2 show how to double the switch voltage in both directions, positive and negative. The 3-stage boost converter in Figure 5 delivers 375 V at 8 mA from a 12 V input source.

Note that the available output current must decrease as output voltage increases, since the switch capability does not change. As an example, a single-stage converter designed to deliver 20 mA will deliver about 10 mA when a second stage is added. As additional stages are added, always ensure the peak switch current stays within the guaranteed switch current limit.

The LT8365 offers a single FBX pin to sense the output voltage. A simple resistor divider connected to the FBX pin senses the output voltage, independent of output polarity, as observed on all the schematics presented in this article.

Conclusion

The LT8365 enables applications that require compact, efficient, high output voltage boost conversion from input voltages as low as 2.8 V, which is common in the field of communications. It can also be used as an inverting converter and in popular topologies such as CUK and SEPIC converters. The LT8365 is available in a small, thermally enhanced, 16-lead MSOP package.

90 W of Power over Ethernet

Microchip enables both pre-standard and IEEE-compliant Powered Devices (PDs) to receive up to 90W of power without changing Power over Ethernet (PoE) switches or cabling. This development eases the transition to using IEEE 802.3bt-2018-compliant PoE injectors and midspans for users, and Power Sourcing Equipment (PSE) chipsets for system developers. As the industry adopts the latest generation of PoE technology for managing data and power over a single Ethernet cable, users face the challenge of making pre-standard PDs work with new IEEE 802.3bt-2018-compliant PDs without changing PoE switches or cabling. Microchip has offered a PSE chipset for implementing the widely adopted PoH four-pair power standard for 95W PDs. It is now the first to also offer an IEEE 802.3af/at/bt chipset that enables pre-standard switches to interoperate with new IEEE 802.3bt-2018-compliant products. Its complete IEEE 802.3bt-compliant offering includes a range of products. The PSE chipset's unique design balances thermal dissipation more evenly across the system while enabling scalability for supporting two-pair and four-pair systems with a single board design. It provides all required manager and controller functionality for building power sourcing equipment with the industry's most extensive interoperability and can source 90 to 99.9 W per port while supporting up to 48 ports for IEEE 802.3bt Type 3 (Classes 1-6) and Type 4 (Classes 7-8) applications.

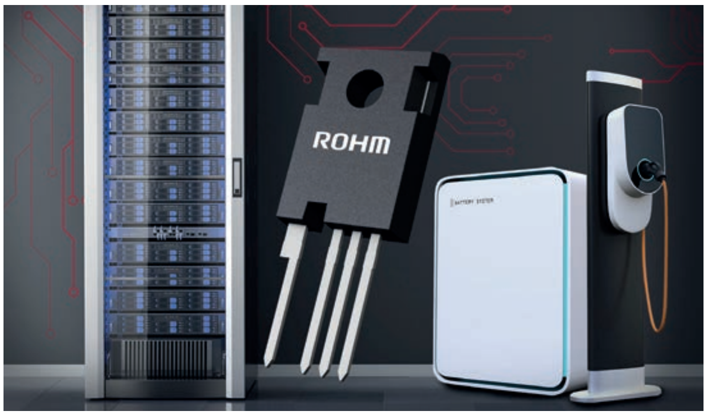
www.microchip.com/design-centers/power-over-ethernet

10 mΩ Cascoded SiC JFETs

UnitedSiC is introducing four new SiC FETs, with on-resistance levels as low as 7 mΩ, delivering high efficiency in high-power applications such as electric vehicle (EV) inverters, DC/DC converters, battery chargers and solid-state circuit breakers. Of the four new UF3C SiC FET devices, one is rated at 650 V/7 mΩ, and three rated at 1200 V/9 and 16mΩ. All are available in the TO247 package. These new SiC FETs combine a third-generation SiC JFET and a cascode-optimized Si MOSFET. This circuit configuration creates a fast, efficient device in a familiar package that can be driven with the same gate voltages as Si IGBTs, Si MOSFETS and SiC MOSFETs. In addition, to optimize high temperature operation, silver sintering provides low thermal-resistance mounting for the TO247 package. The low switching losses allow designers to operate the inverter at higher frequencies in order to produce a cleaner output current waveform. The parts also work well in parallel to handle very high currents. Loss calculations show that the combined switching and conduction losses of a 200 kW, 8 kHz inverter built using six UF3SC120009K4S SiC FETs in parallel will be about one third those of a similar inverter built using state of the art IGBT/diode modules. 1000+ unit pricing ranges from $35.77 for the UF3SC0120016K3S to $59.98 for the UF3SC120009K4S. Samples are available now, with production volumes in Q2'2020.

www.unitedsic.com

Trench SiC MOSFETs



ROHM launched six new trench gate SiC MOSFETs (650 V/1200 V), the SCT3xxx xR-Serie, for server power supplies, UPS systems, solar power inverters, and EV charging stations requiring high efficiency. The SCT3xxx xR series utilizes a 4-pin package (TO-247-4L) that maximizes switching performance, making it possible to reduce switching loss by up to 35 % over conventional 3-pin package types (TO-247N). With conventional 3-pin packages (TO-247N), the effective gate voltage at the chip reduces due to the voltage dropped across the parasitic inductance of the source terminal. This causes the switching speed to reduce. Adopting the 4-pin TO-247-4L package separates the driver and power source pins, minimizing the effects of the parasitic inductance component. This makes it possible to maximize the switching speed of SiC MOSFETs, reducing total switching loss (turn ON and turn OFF) over conventional package. ROHM's SiC MOSFET evaluation board (P02SCT3040KR-EVK-001) is equipped with gate driver ICs (BM6101FV-C), optimized for driving SiC devices along with multiple power supply ICs and additional discrete components that facilitate application evaluation and development. Compatibility with both the TO-247-4L and TO-247N package types enable evaluation of both packages under the same conditions. The board can be used for double pulse testing as well as the evaluation of components in boost circuits, 2-level inverters and synchronous rectification buck circuits.

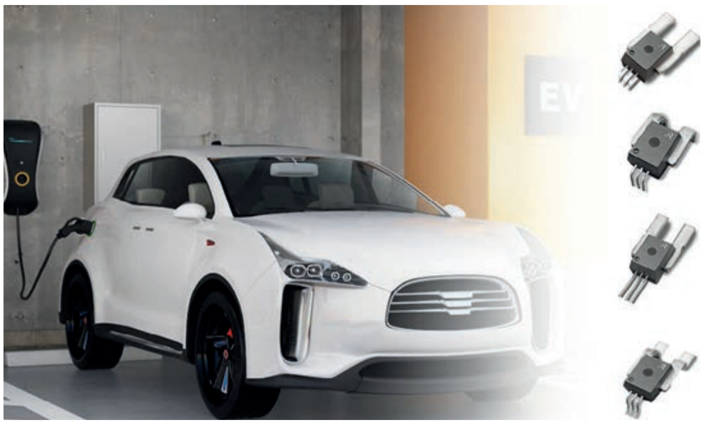
www.rohm.com/power-device-support

Magic Micro Modules

The MagI³C-VDMM (Variable Step Down Micro Module) power module family from Würth Elektronik is supplemented by more powerful 1 A and 1.2 A versions. The input voltage range (from 2.5 to 5.5 V) covers the standard 3.3 and 5 V bus voltages, and the adjustable output voltage ranges from 0.8 to 5.5 V. The modules have been designed for high efficiency in the low load range. Integration of the DC/DC converter and inductor makes for a very compact solution in an LGA-6EP package. The MagI³C-VDMM series is particularly suitable as a replacement for linear regulators. Applications include the supply of interfaces, microcontrollers, microprocessors, DSPs and FPGAs. Thanks to their small size and high efficiency (over 96%), they are particularly suitable for use in mobile and battery-powered devices. To save energy, the VDMM can be "put to sleep" using an additional pin, which extends battery life.

www.we-online.com

Enhanced Isolation Voltage for Current Sensors

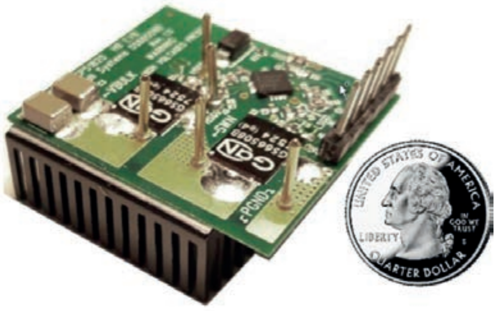


Allegro's automotive grade high voltage isolation current sensors ACS772/3 provide economical and precise solutions for both AC and DC current sensing up to 400A. The new surface-mount leadform option for the CB package is the answer to many customer challenges by providing a flexible solution for space constrained applications. High current PCB designs improve power density and efficiency and this surface-mount option allows a simpler manufacturing process.

The ACS772/3 family of current sensor ICs has an enhanced feature set that helps engineers simplify their bill of materials and improve efficiency by small form footprint, fast 2.5 µs response time that enables over-current fault detection, working isolation voltages up to 1300 V+ for basic DC voltage, and 650 V+ for reinforced isolation DC voltage, and no need for opto-isolators. Accuracy is 2.1 % over the lifetime of the IC. Applications range from industrial robotics to electric vehicles.

www.allegromicro.com

GaN Half-Bridge Evaluation Board



GaN Systems and On Semiconductor have designed a daughter board using 650 V/30 A GaN E-HEMTs and NCP51820 high speed gate driver. This evaluation board is developed for existing and new PCB designs and allows designers to easily evaluate GaN in existing half-bridge or full?bridge power supplies. The kit has a reduced component count in an ultra-small 25 mm x 25 mm layout, minimizing PCB board space. Features, which include 1 MHz+ operation and a 200 V/ns CMTI rating, provide increased power density and improved performance with fast-switching GaN power transistors. Benefits include significant reductions in power losses, weight, size (up to 80 % in layout size), and system costs (up to 60 % BOM cost savings) and ideal in applications such as AC/DC adapters, data center power supplies, PV inverters, energy storage systems, and Bridgeless Totem Pole topologies. This solution is one of many upcoming GaN-based power solutions both companies are developing.

www.gansystems.com, www.onsemi.com

Soft-Switching Gate Drive Reduce Losses and Cost

Pre-Switch has announced that its soft-switching IGBT and SiC gate driver architecture can significantly reduce the cost of solar inverters. The two-stage architecture delivers the same switching loss performance – or better – as a five-level design, resulting in reduced cost, control complexity and BOM count. Also a simplification and size reduction of inverters and filters used in renewable energy systems can be achieved, enabling energy to be put back into the grid efficiently. The Pre-Switch soft-switching platform enables a doubling of power output for a typical inverter, or an increase in switching speed by a factor of up to 20. Soft-switching has so far never been successfully implemented for DC/AC systems with varying input voltage, temperature and load conditions. However, the challenges have been overcome by using neural networks to constantly adjust the relative timing of elements within the switching system to force a resonance to offset the current and voltage wave forms – thereby minimizing switching losses. The architecture also allows the grid tie filter size to be reduced by up to 66.67 % for IGBT systems and by up to 80 % for SiC MOSFETs.

www.pre-switch.com

Conductive Polymer-Aluminum-Electrolytic-Capacitors

Panasonic Industry Europe has added a new long-life surface mount type series to its product line of SP-Cap Conductive Polymer-Aluminum-Electrolytic capacitors. Available with a rated voltage of 2.0 VDC or 2.5 VDC, GY capacitors benefit from huge capacitance values (680 µF up to 820 µF) and a very low ESR characteristics (3 mΩ max.) which is unique in the market. The components are able to withstand +105°C for up to 2.000 hours making them ideal for use in demanding applications. Also with the high ripple current of only 10.200 mA rms maximum, the new GY capacitor series is a suitable component for power circuits in servers, base stations as well as industrial applications.

http://industry.panasonic.eu

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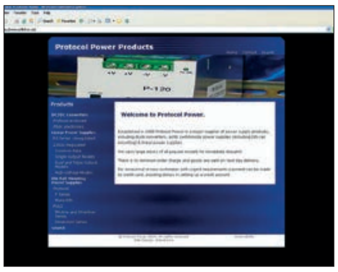

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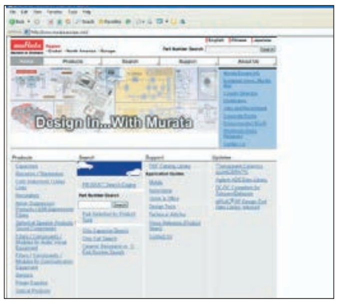

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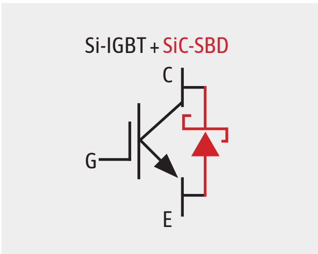

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