POWER ELECTRONICS EUROPE

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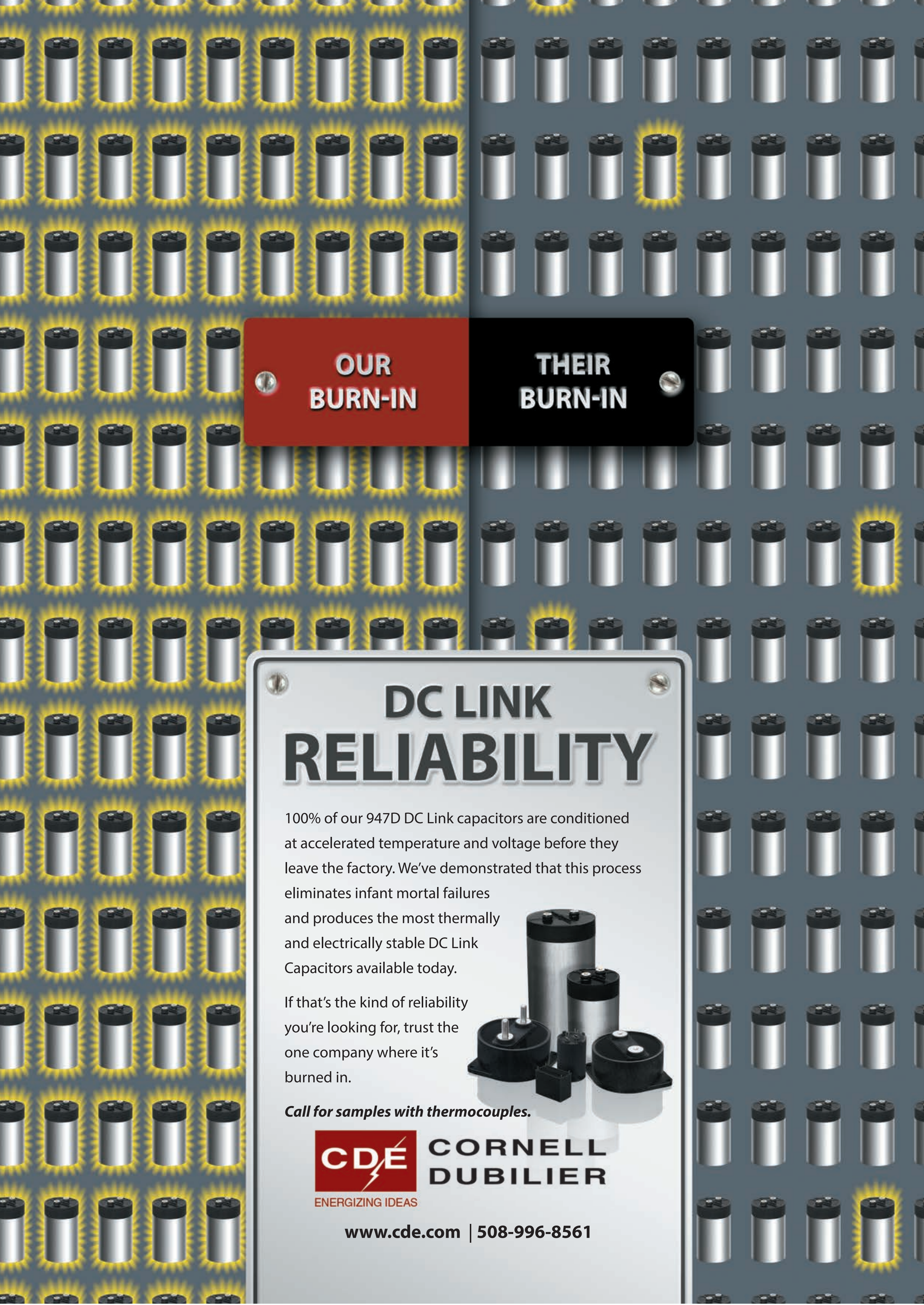
COVER STORY

Using FREDFETs in BLDC Motor Drivers to Overcome Thermal Challenges

A recent IHS report suggests that the global market for brushless DC (BLDC) motors in home appliances is set to rise from around 430 million units per year to 750 million units per year over the next five years. This enormous growth is due to the fact that BLDC motors are smaller and more efficient across a wider range of operating speeds than their more traditional AC induction counterparts – and there are other advantages too. Yet conventional means of driving BLDC motors may be compromising their effectiveness. BLDC motors are being used in all sorts of household appliances – air conditioning, dish washers, washing machines, refrigerators, pumps, fans – to replace AC motors. The main reason for this is that BLDC motors are more efficient than AC motors, particularly when not operating at maximum power and are more controllable. They also run quieter making them the ideal choice for appliances. Efficient operation across the load range is often necessary for products that must meet global energy efficiency regulations. Software-controlled BLDC motors have the flexibility of programmability, variable speed and/or torque can be achieved with high levels of precision. Reliability is another important issue. BLDC motors do not require the provision of power for the rotor eliminating - brushes and slip rings - so reliability and lifetime is increased compared to brushed motors. Given the level of efficiency and controllability that can be brought to BLDC motor the most important considerations for the BLDC drive are the inverter and controller designs. New solutions to drive them are needed and introduced in our cover story. More details on page 27.

Cover image supplied by Power Integrations, USA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More and More Players in GaN

Eight years have passed since the first commercialized power GaN device appeared. International Rectifier (acquired by Infineon), Efficient Power Conversion (EPC), GaN Systems, Transphorm, Panasonic or Navitas, in addition to the power electronics leaders, Infineon Technologies, Texas Instruments and ON Semiconductor are also highly involved in the development of GaN technology. Not surprisingly, the list of GaN start-up players is getting longer over the years - Exagan, GaNPower International or Tagore Technology are also offering power GaN products. According to market researcher Yole most of the power GaN start-ups choose the foundry model, mostly using TSMC, Episil, or X-Fab as their preferred partner. Meanwhile, other foundries might offer this service if the market takes off. The foundry model affords fabless or fab-lite start-ups the possibility of ramping up quickly if the market suddenly takes off, while existing IDM can benefit from previous acquired equipment and knowledge for GaN manufacturing. Infineon Technologies announced it would start volume production for CoolGaN 400V and 600V E-mode HEMT products at the end of 2018. This announcement is a strong sign for the Power GaN industry. Therefore, because of its leadership, Infineon Technologies has already many customers for Silicon products that could shift to GaN solutions in the near future, if their requirements are satisfied, Yole commented.

Infineon has developed a process based on a technology agreement with Panasonic (Gate Injection Technology, GIT), which is now being used to manufacture its CoolGaN family of HEMT devices. While ostensibly similar to other types of FET, the HEMT has one significantly beneficial characteristic, in that it features no intrinsic body diode between the source and drain. This enables what is arguably the single most important feature of GaN transistors, which is their reverse recovery performance. The absence of a body diode removes its impact, which in other types of transistors is a limiting factor. With the reverse recovery charge comes an associated peak current which can be so large in Silicon power transistors that they cannot be used in conversion topologies that feature repetitive reverse recovery, including half-bridge topologies. This is not the case with GaN-on-Si HEMTs. As CoolGaN transistors have no minority carriers and no body diode they do not exhibit a reverse recovery, which makes them well suited to half-bridge topologies and will also allow them to support the development of entirely new power conversion topologies that were previously impossible to realize, without major (and costly) adjustments on the control technique.

The GaN adoption by the biggest player gives confidence for future market growth. In parallel, STMicroelectronics and CEA Leti announced their cooperation in developing GaN-on-Si technologies for both diode and transistor on Leti's 200 mm R&D line. Both partners expect to have validated engineering samples in 2019. Also, STMicroelectronics will create a fully qualified manufacturing line, including GaN-on-Si hetero-epitaxy, for initial production running in the company's front-end wafer fab in Tours, France, by 2020. As a good promise, new commercial products arrived during the last year, and more will come in 2019. The main ones released were power supply products for high end or high volume consumer applications. At the moment, each of the segments is targeted by different company profile: integrated solutions for consumer applications and discrete solutions for high-power/high-end power supplies.

Responding to this increasing offering and associated technical questions the JEDEC Solid State Technology Association announced the publication of JEP173 - Dynamic On-Resistance Test Method Guidelines for GaN HEMT Based Power Conversion Devices. JEP173 addresses a key need of the user community of GaN power FETs, namely a method for the consistent measurement of Drain-to-Source Resistance in the ON-state encompassing dynamic effects. These dynamic effects are characteristic of GaN power FETs, and the value of the resulting measured on-resistance is method dependent. The release of JEP173 will help accelerate industry-wide adoption of GaN by ensuring consistency across the supplier base. This will help advance the adoption of WBG power technologies.

Numerous Technical and Industrial Sessions at the upcoming APEC, the ECPE SiC & GaN User Forum in March or the PCIM Europe in May will also promote market adoption. According to Tim McDonald, Chairman of the PSMA Semiconductor Committee, SiC and GaN have been the most popular topics at APEC over the past several years. It is clear that the promise that these devices have offered in size and efficiency gains are being realized. Thus the PSMA is sponsoring three APEC Industry Sessions that address the rapid emergence of wide bandgap semiconductors as a significant power conversion technology.

Nevertheless, Silicon still is and will be the workhorse of the power electronics industry, as our cover story on integrated power stages for motor drives illustrate. But sooner or later a shift will occur – perhaps. Price is the name of the game so far.

Enjoy reading!

Achim Scharf
PEE Editor


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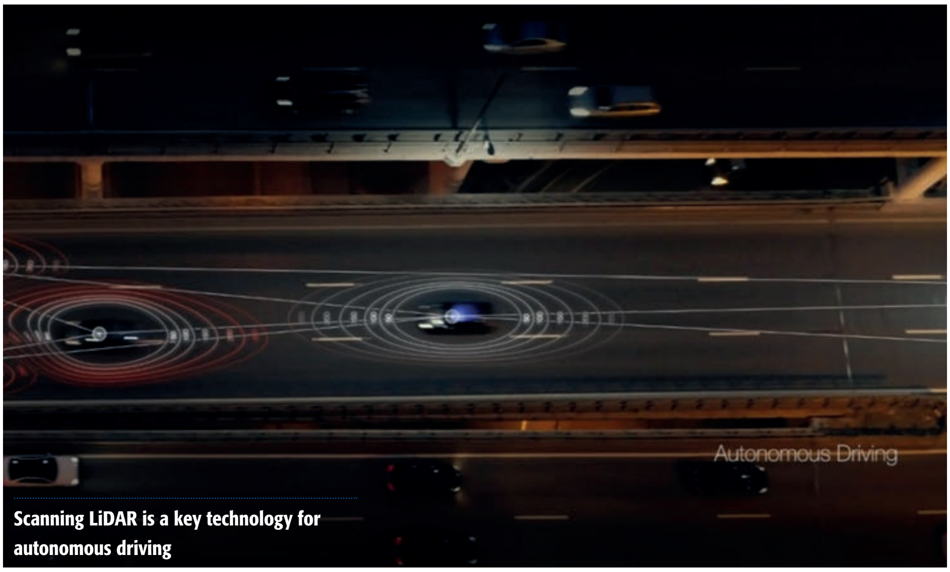
Osram and GaN Systems Design LiDAR Laser Driver

Osram Opto Semiconductors announced an ultrafast laser driver with a multi-channel SMT laser for LiDAR (Light detection and ranging) systems. Osram and GaN Systems partnered in laser driver technology that enables longer range and higher resolution LiDAR architectures.

Osram has continuously expanded its laser portfolio for LiDAR, increasing the peak power of the SPL DS90A_3 to 120 W at 40 A. Osram plans to release a four-channel SMT laser in 2019. The additional channels increase the field of view and total peak power, with each channel being capable of generating 120 W. One of the issues with LiDAR technology has been its inability to transmit lasers at short pulses, while maintaining high peak power, which is necessary to ensure that the LiDAR is eye safe with a long range and high resolution. To address this need, Osram worked with GaN Systems to develop a laser driver with a one nanosecond pulse rise time, while driving all four channels at 40 A each to deliver 480 W peak power. This peak power then can be modulated at low-duty cycles to produce high resolution 3D cloud points at long range for new LiDAR designs. Scanning LiDAR is a key technology for Advanced Driver-Assistance Systems (ADAS), which is designed to increase road safety and enable autonomous driving. Scanning LiDAR creates high-resolution 3D images of a car's surroundings and registers obstacles early enough for ADAS or self-driving cars to initiate the appropriate driving maneuvers, such as automatic braking to prevent collisions. "Osram enables LiDAR technology for autonomous vehicles by not only developing high power, multi-channel SMT lasers that meet automotive quality standards, but also working with eco-system partners like GaN Systems to address the technological barriers that arise," comments Rajeev Thakur, Senior Marketing Manager at Osram Opto Semiconductors.



Scanning LiDAR is a key technology for autonomous driving

www.osram.com, www.gansystems.com

Jedec GaN HEMT Dynamic On-Resistance Test Method

JEDEC Solid State Technology Association announces the publication of JEP173 - Dynamic On-Resistance Test Method Guidelines for GaN HEMT Based Power Conversion Devices. The first publication developed by JEDEC's newest main committee, JC-70 Wide Bandgap Power Electronic Conversion Semiconductors, JEP173 is available for free download from the JEDEC website.

JEP173 addresses a key need of the user community of GaN power FETs, namely a method for the consistent measurement of Drain-to-Source Resistance in the ON-state (RDS(ON)) encompassing dynamic effects. These dynamic effects are characteristic of GaN power FETs, and the value of the resulting measured RDS(ON) is method dependent.

"JEP173 demonstrates how quickly the GaN industry came together to address this important topic and begin to establish standards across suppliers for datasheet, qualification, and test methods," noted Stephanie Watts Butler, technology innovation architect at Texas Instruments and the chair of JC-70. "The release of JEP173 will help accelerate industry-wide adoption of GaN by ensuring consistency across the supplier base." Strong commitment from the committee members was required to complete this work to set up universal standards to help advance the adoption of WBG power technologies. "Our Task Groups are diligently making progress on other key GaN and SiC guidelines in the areas of test, reliability, and datasheets," added Tim McDonald, Senior Advisor to Infineon's CoolGaN program and the chair of the JC-70.1 subcommittee.

Formed in October 2017 with 23 member companies, JC-70 now has over fifty member companies, which underscores industry interest in the development of universal standards to help advance the adoption of wide bandgap (WBG) power technologies. Global multinational corporations and technology startups from the US, Europe, Middle East, and Asia are working together to bring to the industry a set of standards for reliability, testing, and parametrics of WBG power semiconductors. Committee members include industry leaders in power GaN and SiC semiconductors, as well as prospective users of wide bandgap power devices, and test and measurement equipment suppliers. Technical experts from universities and national labs also provided inputs into the new JEP173 guideline. Interested companies worldwide are welcome to join JEDEC to participate in this important standardization effort. JC-70 plans to hold four committee meetings in 2019, including a meeting co-located with the APEC Conference on March 18.

https://www.jedec.org/document_search?search_api_views_fulltext=jep173

Proton-Electrotex Celebrates Its 23rd Anniversary!

2019-02-06, Orel – Proton-Electrotex company celebrates its 23rd anniversary and sums up the latest year.

Today, on February the 6th, Russian manufacturer of power electronics Proton-Electrotex celebrates its 23rd anniversary. The company was established in 1996 and in just few years managed to become an established brand in the high-tech industry of semiconductor devices.

In these years the company has developed a complete portfolio of power semiconductors used in electric transport, power grids, metallurgy, arc welding and many other industries. The first project of the company was disc and stud diodes and thyristors. In 2003 production of power modules was launched, followed by IGBT modules in 2016. Today the company continues its research of new IGBTs, and devices based on silicon carbide.

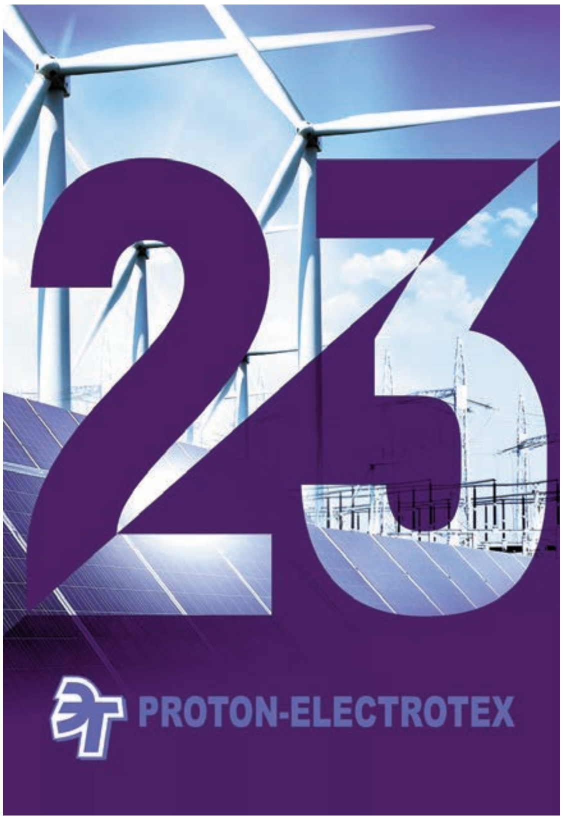
In 2018 the company set several financial and production records. Turnover increased by near 20%, and the number of active clients reached 1,200 organizations. Proton-Electrotex continues to expand its staff and remains the key Russian company in the field of power semiconductors.

Other achievements in 2018 included taking the 10th place among all the industrial organizations of Russia according to the rating of the radio-electronic industry of Russia, passing the second stage of "Made in Russia!" voluntary certification, being listed for the Ministry of Economic Development of the Russian Federation project "National champions", and establishing relations with several new major distributors.

Obviously, the company is not going to stop there and keeps planning new projects. There are still many other successes and achievements ahead. Proton-Electrotex thanks each of our employees and partners for another successful year!

About Proton-Electrotex, JSC:

Proton-Electrotex is the Russian leader in designing and manufacturing power semiconductors including diodes, thyristors and IGBT modules as well as heatsinks, and measurement equipment. The company is located in Orel city and ships its products through its partners and distributors all over the world. Please visit website www.proton-electrotex.com for more details about Proton-Electrotex and its offer of products and services.



Global Solar to Rise 18 Percent

Annual global solar photovoltaic (PV) installations in 2019 are forecast by IHS to rise 18 %, reaching 123 gigawatts (GW) in 2019. Two-thirds of the installed global PV generation capacity will come from outside China, with several new or revived country markets raising totals.

Argentina, Egypt, South Africa, Spain and Vietnam together represent 7 % of total installations in 2019, and 7 GW of total demand growth. PV is becoming more distributed geographically, with annual PV installations growing by more than 20 % in 45 country markets. PV installations in the United States are projected to grow by 28 % year-on-year, as developers seek to complete a share of their project pipelines before the December 2019 deadline for the 30 % investment tax credit (ITC). An even larger share of the pipeline will only be partially initiated through module shipments in order to meet the safe harbor requirements that extend the 30 % ITC if at least 5 % of the components have been procured.

IHS Markit anticipates limited capacity announcements across the supply chain, which should contribute to higher average utilization rates across all nodes in 2019 and an improvement in the overcapacity situation faced by the PV manufacturing industry in the second half of 2018. "As anticipated, module prices collapsed in the second half of 2018, but existing strong demand outside of China – especially in Mexico, Vietnam, Spain – has slowed down price erosion for shipments in the first half of 2019. Many international developers have advanced their procurement, fearing that the upcoming new solar policy in China could affect module availability from tier-one players in the international market", stated IHS Markit analyst Edurne Zoco.

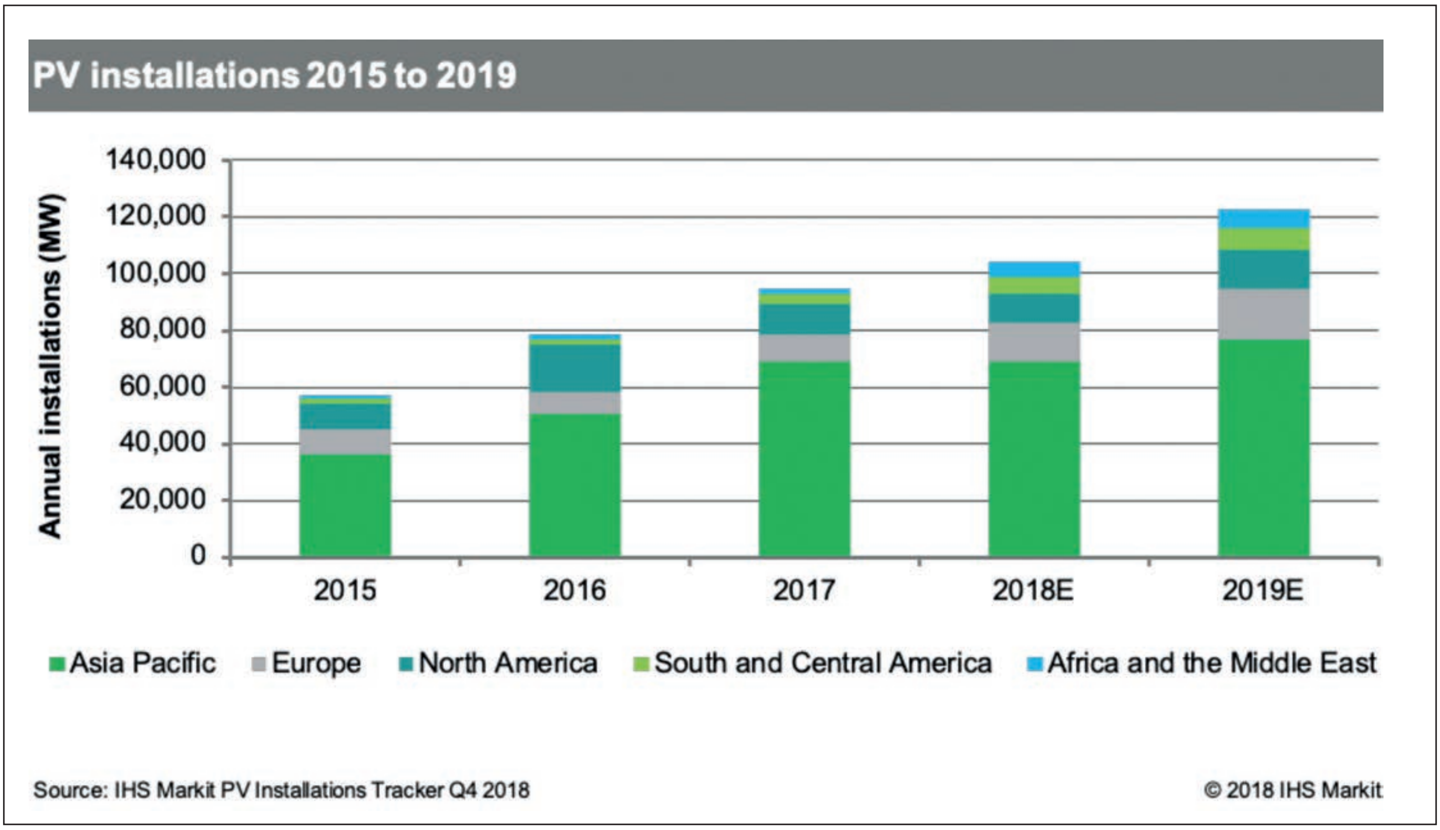
Market for integrated motors

The global market for integrated motors and machine-mounted drives is projected to reach $1.4 billion by 2022, due to the growth in machinery production and additional market revenues from AC brushless servo and AC induction motors and drives. Total market revenue is expected to grow at a compound annual growth rate (CAGR) of 6.8 % through 2022.

AC-brushless-servo and AC-induction are the most common integrated-motor types used in the food, beverage and tobacco industry. Machines for these industries have many of the same attributes that make packaging machines well suited for integrated motors. However, the adoption rate has been hindered by the need for the machinery to withstand wash-down conditions.

"In the global market for machine-mounted drives, the demand for high efficiency, along with the need to reduce energy consumption in these markets, will attract investments in drive solutions. Manufacturers tend to prefer machine-mounted drives over stand-alone drives over the long-term, depending on the anticipated functional technological advancements and the availability of affordable technology. The ideal compatibility of the variable frequency drive with the motor in an integrated motor and drive ensures efficient performance, with efficiency levels exceeding 90 percent. This compatibility also makes drive units easier to deploy than procuring the motor and the drive as two separate components, and then combining them to achieve the desired performance – which consequently helps to reduce lag time and increase productivity", said Sudhakar Chaudhary, manufacturing technology analyst, IHS Markit. Thus the market will continue to benefit from product replacement, as motor suppliers continue to expand their machine-mounted drive product offerings. The material-handling equipment and packaging sectors were the fastest growing sectors in the machine-mounted drive market in 2017, with an estimated value of $57.5 million and $45.1 million, respectively, in 2017. These two sectors are predicted to grow at a CAGR of 8.8 % and 8.9 %, respectively, from 2017 to 2022.

www.ihsmarkit.com



Bosch Invests in Semiconductor Manufacturing

Electric and automated vehicles are driving Bosch's semiconductor business, thus the German company invests € 1 billion in a new semiconductor fabrication plant in Dresden; the largest single investment in the company's history.

The plant is scheduled to start manufacturing in 2021, and will focus on 300 mm wafer technology, which offers greater economies of scale, with up to 700 associates involved in the highly automated chip manufacturing process, working to plan, manage, and monitor production. The Dresden plant will be Bosch's second wafer fab in Germany (existing one in Reutlingen). Bosch has been making semiconductors for more than 45 years, and is one of the world's leading manufacturers of chips for mobility applications. In 2016, every vehicle newly registered worldwide had an average of more than nine Bosch chips on board. Semiconductors are a core feature of every car on the road, controlling the vehicle's electrical systems – including its powertrain and vehicle handling, as well as telling the navigational system which way the vehicle is travelling and signaling the airbag to deploy when needed. The Company currently holds over 1,500 patents and patent applications for engineering and manufacturing its semiconductors.

Bosch's current semiconductor portfolio focuses on microelectromechanical systems (MEMS), ASICs for vehicle ECUs, and power semiconductors. Power semiconductors are essential to hybrid and electrical vehicles, as they regulate the electric motor and make sure that the battery is being used as efficiently as possible.

One focal point of the company's R&D work is automated driving. Some 4,000 engineers at Bosch are working on automated driving. As part of the move toward accident-free mobility, Bosch is pursuing two development paths. The first concerns driver assistance systems, which will enable partially automated driving in private vehicles (automation levels 2 and 3). The company expects to generate sales of 2 billion euros this year with driver assistance systems. The second development path will lead to driverless driving starting at the beginning of the next decade (automation levels 4 and 5). "Driverless driving will be a game changer for individual mobility. It will open the door to disruptive business models such as robotaxis and shuttle-based mobility," said Volkmar Denner, chairman of the board of management of Robert Bosch GmbH.

According to Demmer the market potential of automated driving is huge: between 2015 and 2030, personal mobility will increase by 50 %. Over the next ten years, the market for automated-driving hardware and software to be worth some $60 billion. By 2025, most of the 2.5 million on-demand shuttle buses around the world will be driverless. By 2035, sales relating to shared mobility will reach nearly $160 billion. Bosch will offer both technology and services for this form of mobility.

www.bosch-semiconductors.com

Silicon Carbide Wafer Supply Agreement

CREE announced a $250 million multi-year agreement to produce and supply its Wolfspeed SiC wafers to STMicroelectronics.

CREE signed recently a multi-year agreement to produce and supply its Wolfspeed SiC wafers to Geneva-based STMicroelectronics. In 2017, the Company's net revenues were $8.35 billion. The agreement governs the supply of a quarter billion dollars of Cree's 150 mm bare and epitaxial wafers

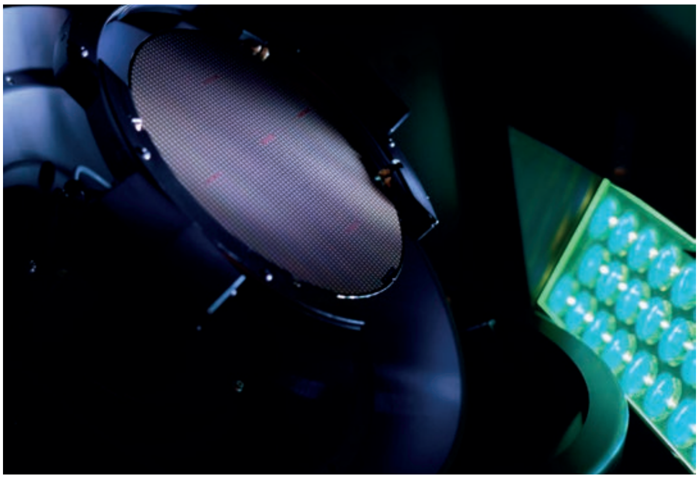
during this period of extraordinary growth and demand for SiC power devices. "ST is the only semiconductor company with automotive-grade silicon carbide in mass production today, and we want to press forward to grow our SiC business both in terms of volume and breadth of applications served, targeting leadership in a market estimated at more than $3 billion in 2025," said Jean-Marc Chery, president and CEO of STMicroelectronics. "This agreement with Cree will improve our flexibility, sustain our ambition and plans, and contribute to boosting the pervasion of SiC in automotive and industrial applications."
"This is the third multi-year agreement that we have signed this past year in support of the industry's transition from Silicon to Silicon Carbide. Cree continues to expand capacity to meet the growing market needs, particularly in industrial and automotive applications. We are extremely pleased to continue to support STMicroelectronics as we both invest to accelerate this market", said Gregg Lowe, CEO of Cree. Wolfspeed, A Cree Company, is the global leader in the manufacture of SiC wafers and epitaxial wafers.

www.st.com, www.cree.com

New High-Voltage Galvanic Isolation Technology at X-Fab

X-FAB Silicon Foundries SE, a leading European analog/mixed-signal and specialty foundry, has announced the full volume production release of its new high temperature galvanic isolation semiconductor process. This proprietary technology is fully automotive qualified. X-FAB's modular CMOS and SOI processes range from 1.0 to 0.13 µm. Analog-digital integrated circuits (mixed-signal ICs), sensors and micro-electro-mechanical systems (MEMS) are manufactured at six production facilities in Germany, France, Malaysia and the U.S. X-FAB employs about 4,000 people worldwide.

Galvanic isolation electrically separates circuits in order to improve noise immunity, remove ground loops, and increase common mode voltage. It can also protect human interfaces from contact with high voltages. An example where this plays an important role is the control of IGBT or SiC power modules in industrial and automotive environments. Further applications include data communication in field bus systems, battery management systems or the usage in medical equipment. X-FAB's galvanic isolation process include operational temperatures of up to 175°C, tested up to 6,000 Vrms @ 50Hz and 10,000 VDC, conformance with latest IEC 60747-17 semiconductor coupler draft standard, and support for working voltages up to 1.7 kV. X-FAB offers two types of packaged galvanic isolation devices for customer



Galvanic isolation technology is manufactured at X-Fab's Dresden cleanroom facility

evaluation. The capacitive coupler test chip, G3-C1, has an isolation layer thickness of 11 µm and was tested to withstand up to 6,000 Vrms (the maximum limit of the test setup). An inductive coupler test chip, G3-T06, is also available for customer evaluation and has an isolation layer thickness of 14 µm. The galvanic isolation technology is manufactured at the company's Dresden facility, which is certified for automotive manufacturing in accordance with the IATF-16949:2016 International Automotive Quality Management System (QMS) standard. Design kits for all major EDA platforms can be downloaded from their customer web portal.

With PowerAmerica support, X-FAB Texas has established an open 150-mm SiC commercial foundry, enabling companies with a variety of device technologies to utilize the foundry for volume production. Rather than building a SiC fab from scratch, X-FAB's existing 6-inch silicon foundry is utilized to process SiC wafers. This approach leverages existing Silicon processing equipment, with the addition of select specialized equipment unique to SiC processing. To provide scalability, a

Process Installation Kit will be developed. This kit will contain documented and characterized standard process blocks that can be integrated with proprietary process blocks such that the foundry customer can bring highly differentiated products to the market.

www.xfab.com

Electric Vehicle Future

Many new electric vehicles were on display at the IDTechEx Show! on November 14-15 in Santa Clara, but that was the tip of the iceberg. The event had a hidden message; the future enabling technologies for electric vehicles (EVs) from buses to cars to mining vehicles.

With its origins in being the world's largest printed electronics event, it has seamlessly extended to similar technology in sensors, 3D printed electronics and one of this year's buzzy topics – In-Mold Electronics (IME) - based on screen printing of stretchable conducting patterns for actuators, lighting, sensing and more connected to embedded LED and IC chips. All this is vital to the future e-aircraft, e-boats and more. Raghu Das, CEO of analyst firm IDTechEx said, "As we continue to rapidly grow the event we shall make it more obvious that your customer and your customers' customers are present. In 2019, we shall have an electric vehicle area in the exhibition. It will major on the new enabling electric vehicle technologies that our current exhibitors have in spades, in addition to adding many more." Exhibitors such as ABeetle Taiwan, DuPont USA and TactoTek Finland demonstrated the virtuosity of replacing 50-100 optical, sensing and actuating components with one in-mold smart material for an overhead control and lighting cluster or dashboard for example. Vital to electric vehicles, this increases reliability and life tenfold, reduces weight and volume up to 90 % and makes things work better. An antenna in the surface of a molding performs best, for example. ABeetle even demonstrated In-mold Electronics going into the mobility vehicles for the disabled, e-scooters and e-bikes made in Taiwan in large numbers. For TactoTek success is imminent in premium electric cars in Europe.

Such structural electronics extends beyond load bearing components and trim not being dumb any more to solar and energy storage bodywork, sometimes using conformal film. Exhibitor Alta Devices showed conformal photovoltaics that will appear all over its parent Hanergy's electric cars in 2020. Hanergy China has a roadmap to produce 1 kW/kg affordably on Energy Independent Electric Vehicles (EIEV) that never plug in. Party trick? Not at all. In that very month Hyundai and Kia announced they were getting into solar bodywork following Tesla and Toyota expressing intentions and Bollore and Audi licensing the Hanergy process for cars.

The next IDTechEx Show! in Europe will be held in Berlin in Germany, on 10 & 11 April 2019.

www.IDTechEx.com/europe

DuPont highlighting In-Mold Electronics at the IDTechEx Show

GaN FET Power Stages Supports 10 kW Applications

High-voltage GaN FET with integrated driver and protection doubles power density in industrial and telecom applications. Texas Instruments announced a new portfolio of 600-V GaN 50-mΩ and 70-mΩ power stages to support applications up to 10 kW. The LMG341x family enables smaller, more efficient and higher-performing designs compared to Silicon FETs in AC/DC power supplies, robotics, renewable energy, grid infrastructure, telecom and personal electronics.

With integrated <100-ns current limiting and over-temperature detection, the devices protect against unintended shoot-through events and prevent thermal runaway, while system interface signals enable a self-monitoring capability. Developed jointly by TI and Siemens, an active demonstrator enables engineers to achieve 99 % efficiency and up to 30 % reduction in power component size compared to a traditional Silicon design. The LMG3410R050, LMG3410R070 and LMG3411R070 are priced at $18.69, $16.45 and $16.45, respectively, in 1,000-unit quantities.

Where GaN will go next

GaN is already replacing Silicon in key industries where improved power density is a premium feature. These industries are among the best candidates for mainstream, mass-produced GaN power supplies:

Manufacturing - today's typical robot arms don't actually contain all of the electronics needed to make the arm work. Power conversion and motor drive components are so large and inefficient that they are often located in separate cabinets, cabled over long distances to the arm itself. This reduces the productivity per cubic meter of industrial robots. GaN will make it easier to incorporate drive and power conversion inside the actual robot. That will streamline designs, reduce inefficient cabling and lower operating costs.

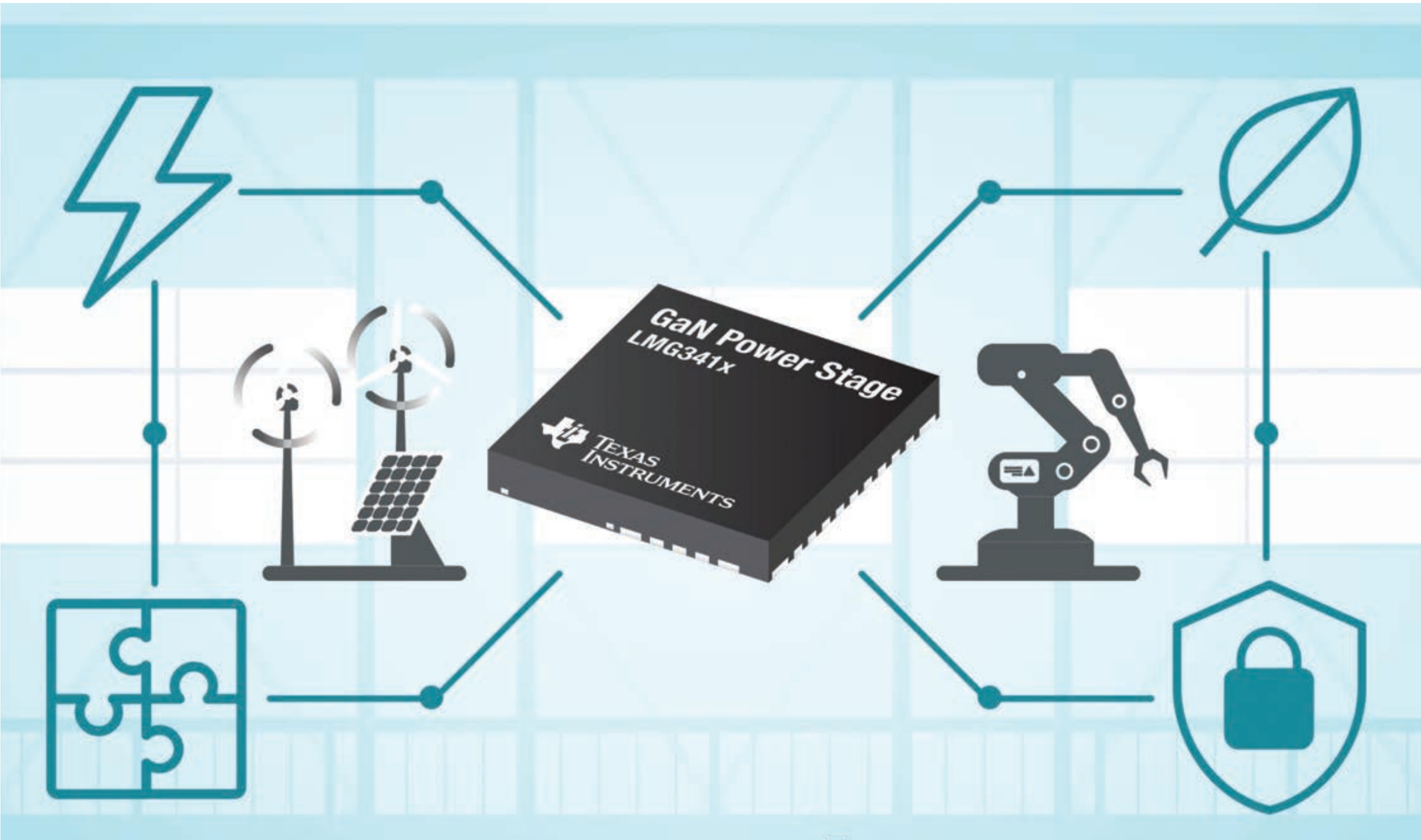
Data centers - spurred by the insatiable demand for more digital services, the data center industry is in the middle of an overhaul to run directly from 48-V DC power. Traditional Silicon power conversion cannot efficiently go from 48 V down to the low voltages required for most computing hardware in a single step. Creating intermediate steps reduces data-center power efficiency. GaN can step down from 48 V to point-of-load before being delivered to servers and chips. This can reduce power distribution losses significantly and cuts conversion losses by 30 %.

Wireless services - the move to blanket populations with comprehensive 5G cellular networks requires network operators to deploy higher-frequency equipment running on more power. Network operators don't want to increase the size of cell tower equipment, so GaN's power-density advantages will play a significant role.

Renewable energy- renewable energy generation and storage also requires power conversion steps, so GaN's efficiency advantages are key. Since renewable energy plans often use a smart grid approach that stores energy for later use – when wind turbines are still or solar panels aren't being powered by the sun – being able to switch power in and out of large-scale batteries more efficiently is a great benefit. TI and partners have demonstrated GaN's ability to convert 10 kW of renewable energy generation with 99 % efficiency, a key benchmark for power utilities.

Device selection by on-state resistance

Internal GaN FETs are rated by $R_{DS(on)}$ – the drain-to-source, or on-state resistance – which plays a big role in the switching and conduction losses in



Ready-to-use 600-V GaN FET power stages supports applications up to 10 kW

Device	Voltage (V)	$R_{DS(on)}$ (mΩ)	FET configuration	Overcurrent protection method
LMG5200	80	15	Half bridge	External
LMG3410R050	600	50	Single channel	Latched
LMG341	600	70	Single channel	Latched
LMG3411R070	600	70	Single channel	Cycle-by-cycle

TI's various GaN devices by their key specifications, structure and typical system power levels

power converters. These losses affect system-level efficiency and thermal and cooling methods. So in general, the lower the $R_{DS(on)}$ rating, the higher level of power achievable while still maintaining high efficiency. But there are some applications or topologies in which a higher $R_{DS(on)}$ may be more appropriate.

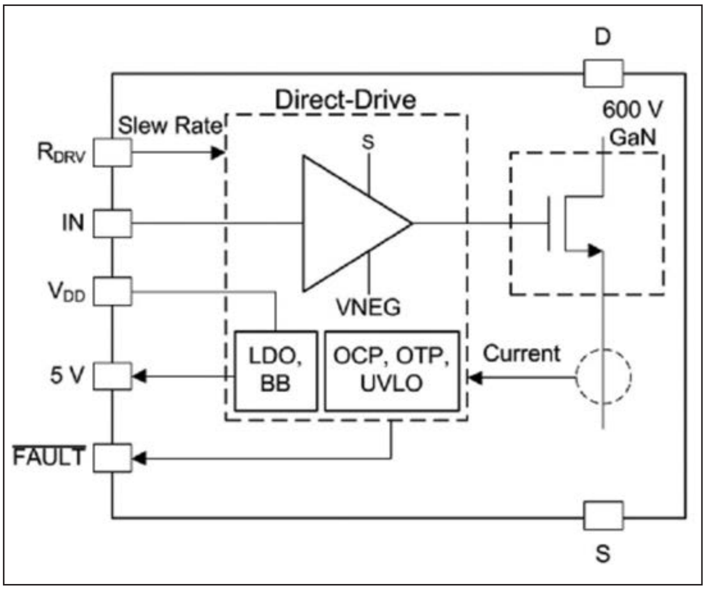
Integrated over-current protection not only eases layout and design for users, but high-speed detection is actually very necessary for device protection in case of a short circuit or other fault conditions. TI's portfolio of GaN devices has <100-ns current response time to self-protect against unintended shoot-through events by safely shutting off the device and allowing it to reset. This protects both the device and the system from fault conditions read out from the fault pin.

Why over-current protection is a must

The power devices can experience over-current due to many reasons including:

- application use conditions such as transient load steps, overloading, start-up current,
- source related transients such as AC line brownout,
- magnetic component saturation.

The graph shows an example of a transient current captured during a line transient from a power factor correction (PFC) circuit running at 750-W of power. During the transient, the current increases about 3 times of its steady-state value. During AC brownouts or start-ups under heavy load, similar transients can be observed. For instance, in higher power server telecom applications such as >2kW PFC, the current can reach to 35-A during the transients. This high transient current may cause a thermal failure in GaN power switches due to high power dissipation.



Internal device structure for the LMG3410/LMG3411 families, including FET, internal gate drive, slew-rate control and protection features

The default over-current protection method is classified as "current-latched" protection; meaning that, if any over-current fault is detected in the device, the FET will safely shut off and remain off until the fault resets. In the 70-mΩ devices, the fault is triggered at 36 A; for 50-mΩ devices, the fault trigger is extended to 61 A.

The LMG3410R070 provides a latched OCP option, by which the FET is shut off and held off until the fault is reset by either holding the IN pin low for more than 350 µs or removing power from VDD.

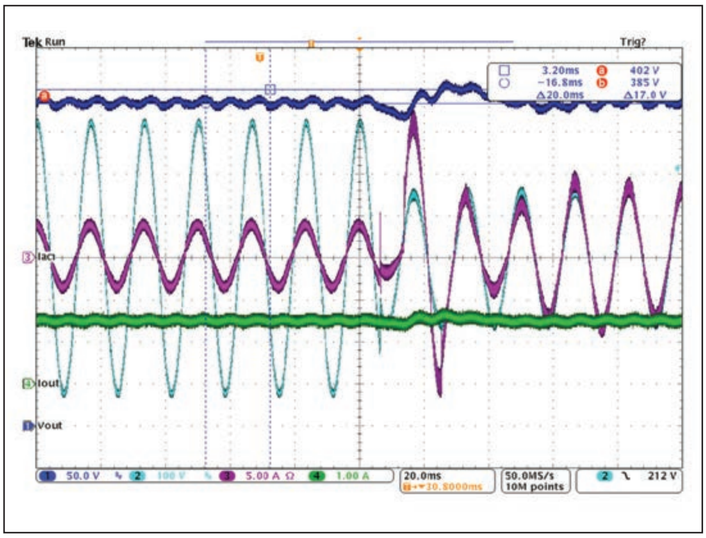
This part is designed for applications where the operation should be interrupted when a fault happens. These include industrial drives as well as safety critical applications. Moreover, latched protection is preferred in applications where controller cannot respond to fault signal.

The OCP is blanked to prevent mis-trigger during the switch node transitions. The blanking time is internally adjusted based on the slew rate. The blanking time for different slew rate settings of LMG341XR070 can be found in the datasheet. Higher slew rates require shorter blanking time as switch node transits faster. The OCP function has less than 100-ns response time when RDRV pin, that is used to adjust the gate drive strength, is set to 15 kΩ. This allows the hard switching turn-on edge to have 100-V/ns slew rate. Therefore, fast response OCP circuit protects the GaN device even under a hard short-circuit condition.

The LMG3411R070 provides cycle-by-cycle OCP option. In this mode, the GaN FET is turned off when over-current happens, but the output fault signal will clear after the input PWM goes low. In the next cycle, the FET can turn on as normal. The cycle-by-cycle function can be used in cases where steady-state operation current is below the OCP level but transient response can still reach high current, while the circuit operation cannot be paused. Typical applications include server and telecom power supplies.

During cycle-by-cycle operation, after the current reaches the upper limit with the PWM input still high, the load current can flow through the third quadrant of the other FET of a half-bridge with no synchronous rectification. The extra high negative voltage drop (–6 V to –8 V) from drain to source could lead to high third quadrant loss, similar to dead time loss but with much longer time. Therefore, it is critical to design the control scheme to make sure the number of switching cycles in cycle-by-cycle mode is limited, or to change PWM input based on the fault signal to shorten the time in third quadrant conduction mode of the power stage.

Ultra-fast and reliable OCP is a must in GaN-based applications due to small active chip area and possibility to enter into saturation region during



Transient current of a PFC circuit during an AC line voltage change

a short-circuit event. The response time of the OCP circuit should be less than 250-ns to be able to prevent short-circuit failures. Traditional discrete implementations of OCP either degrade system performance by adding inductance to the power loop and resistance to the current flow path resulting in higher power losses, or unable to achieve good accuracy which impacts to the response time. Moreover, discrete approaches add to the footprint area and cost of the total solution.

Thermal considerations

TI's LMG341XRxxx family uses 8-mm ? 8-mm low inductance bottom side cooled QFN package for switching speeds of greater than 100 V/ns. A good thermal design is important for power electronic converters. An ideal heat transfer should provide good thermal conductivity with minimum thermal resistance in the heat flow path. A typical equivalent thermal circuit includes the thermal resistance of junction to case of GaN FET, PCB, thermal interface material (TIM), and heat sink.

TI's LMG341XRxxx GaN power stages are in low inductance QFN packages to avoid high inductance of long leads and bond wires for fast switching speeds. The thermal pad placed on the bottom of the device is soldered down to the board and used to effectively spread the heat from the junction down to the PCB. The typical junction to case thermal resistance is 0.5°C/W.

The heat from the junction is transferred from the thermal pad to the top layer of the PCB, and then to the bottom layer of the PCB through a number of thermal vias. The thermal resistance of the PCB is a function of the board thickness, copper thickness of layers, orientation, and number of thermal vias.

The top copper layer acts as a heat spreader. As the copper layer area increases, the effective thermal resistance in the vertical direction decreases. The heat spreading reaches saturation beyond a certain point, which is determined by the copper thickness. Therefore, it is beneficial to have large and thick top copper layer that is larger than the thermal pad area.

Literature

TI Application Report "Overcurrent Protection in High-Density GaN Power Designs" by Serkan Dusmez, Lixing Fu, Masoud Beheshti, Paul Brohlin, and Rui Gao

www.ti.com/lmg3410r050-pr-eu

AI Forced Resonant Soft-Switching

California-based Pre-Switch introduces a new driver technology for power semiconductors based on forced resonance soft-switching driven by Artificial Intelligence (AI). The Pre-Switch AI is resident on a new IC controller, which works across all transistor types, load ranges and over a wide input voltage range. According to the company this low-cost technology enables a 70-95 % reduction in switching losses and solves the dv/dt problems.

For the last 30 years, industry efforts to advance AC/DC, DC/DC, DC/AC power converter efficiency have been focused on developing faster switching devices with lower conduction losses (SiC, GaN, Super Junction); further improving the FOM (figure of merit) of IGBT technology; or developing new switching topologies based on legacy hard-switching architectures. It should be no surprise then that IGBTs are still the de-facto standard in 99 % of all inverter designs. It could be expected, however, that the use of SiC and GaN will increase over time as those materials and designs continue their march down the cost curve.

Field-stop (FS) trench technology, with various adaptations and specializations made by each of the key manufactures, is the bed-rock of inverter designs requiring higher power density and rugged operation. Trench FS IGBTs offer significant improvement in terms of loss reduction. Most of the newest generation of IGBTs from the major manufactures use combinations of trench cell geometry and field stop structure to enable an optimized carrier concentration. By using this structure, designers increase the carrier density near the trench gate, which yields products with substantially reduced V_{CEsat}. Additionally, by adopting specific implant and anneal techniques it is possible to deliver low carrier lifetime in proximity of the backside p-emitter that, when combined with a reduced doping and optimized design, allows fast carrier extraction at turn-off with minimized current tail, and therefore obvious benefits for high switching frequency operations.

For the inverter stage, in which IGBTs are the standard today, the improvement of FOM (V_{CEsat} x E_{TS} - Conduction Voltage drop multiplied by Total Switching Energy) provided by GaN based switches, as well as SiC MOSFETs, is almost 3 times lower at a nominal current density of 2 A/mm^2. The quest for improvement of the power conversion efficiency thus will eventually require

the use of GaN and SiC, not Silicon. The path to further optimize the overall conversion efficiency, for all traditional power conversion topologies, requires a power switch with the lowest possible specific R_{ON} x Q_G FOM. The immediate impact of increased operating frequency would have tangible effect on the solar inverter market, for example, with what could be a drastic reduction of the output inductor size, weight, and cost (direct and indirect relative to the overall size of the inverter, installation costs, etc.).

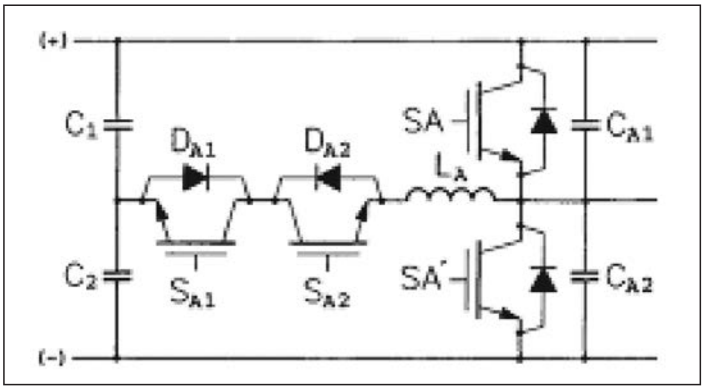
Silicon, and now III-V-based devices, have steadily improved over time, but they still have not addressed the fundamental limitations of hard-switched architectures. This raises the question - is soft-switching the answer? Even though the concept dates back to the 1980's, soft-switching is still only used in self-resonant DC/DC power converters, which represent only a small fraction of the power converter market today. Soft-switching isolated AC/DC power converters has never been perfected, which is why power engineers call soft-switching for high power AC/DC the 'holy grail' of power electronics.

Pre-Switch CEO Bruce T. Renouard demonstrates a sample of his AI-supported soft-switched IGBT driver **Photo: AS**

Soft-Switching with Artificial Intelligence

The Pre-Switch topology for soft-switching is a variation of the Auxiliary Resonant Commutated Pole (ARCP) soft-switching converter topology. Pre-Switch dynamically solves complex timing calculations to ensure accurate soft-switching under changing input voltage, output load, device tolerances, and temperature changes. These adaptations are made on a cycle-by-cycle basis and work on all soft-switched topologies, including ARCP.

ARCP is a conventional inverter topology with an auxiliary circuit that helps soft-switch the main inverter. The auxiliary switches are activated before the main power output switches are active and generate a current in the auxiliary inductor that is used to induce the condition required to soft-switch the main inverter switches. The auxiliary switches are turned on and off at zero current while the main switches are switched at zero voltage. This approach resolves the limitations of ARCP soft-switching and enables the reduction or elimination of switching losses of any power switch. The control algorithm can drive any



Auxiliary Resonant Commutated Pole Converter (ARCP) schematic

Commutation dV/dt and Double Pulse Switching Measurement results

Table 1: Commutation dV/dt @ T_C = 25°C

IL A	Hard-Switching Turn-On dV/dT V/ns	Hard-Switching Turn-Off dV/dT V/ns	Pre-Switch Turn-On dV/dT V/ns	Pre-Switch Turn-On dV/dT V/ns
50	4.1	3.9	1.1	0.3
200	2.2	7	1	1.2

Table 2: Commutation dV/dt @ T_C = 125°C

IL A	Hard-Switching Turn-On dV/dT V/ns	Hard-Switching Turn-Off dV/dT V/ns	Pre-Switch Turn-On dV/dT V/ns	Pre-Switch Turn-On dV/dT V/ns
50	3.2	2.6	1.1	0.3
200	1.7	4.2	1.1	1.1

Table 3: Double Pulse Switching Measurement E_{ON} – E_{OFF} – E_{REC} @ T_C = 125°C

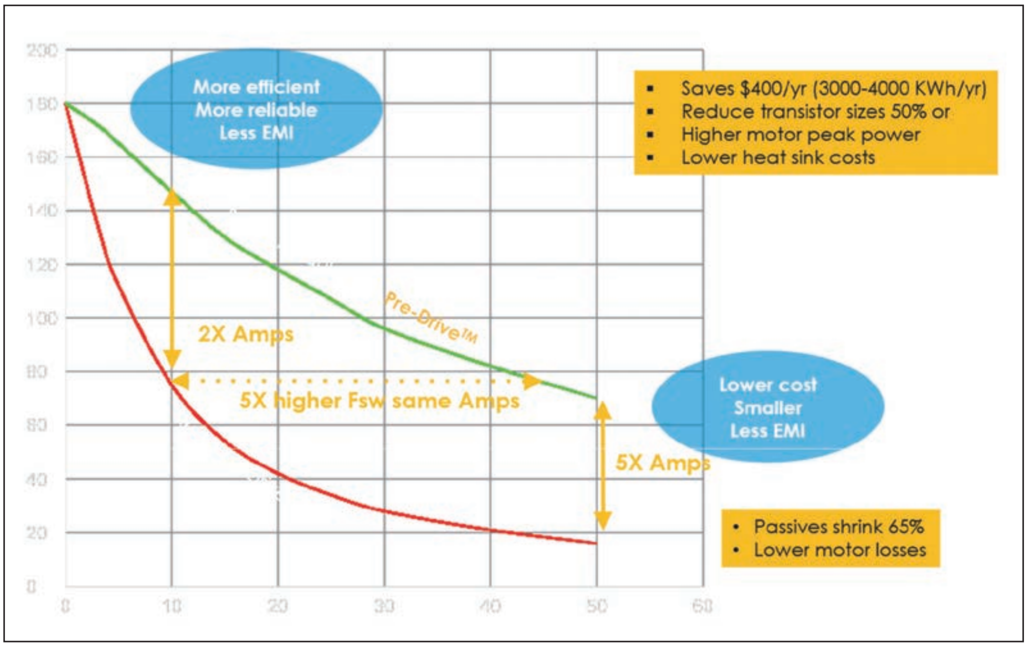
IL	Hard-Switching				Pre-Switch Controlled				X Factor	Δ
	E_{ON}	E_{OFF}	E_{REC}	E_{TOT}	E_{ON}	E_{OFF}	E_{REC}	E_{TOT}		
A	mJ	mJ	mJ	mJ	mJ	mJ	mJ	mJ		%
50	14	7.8	7.8	29.6	0.4	2.8	5.2	8.4	3.52	-71.6
200	51.2	25.6	15.8	92.6	2	14.2	9.8	26	3.56	-72

type of power switch and is suited for anything from Silicon-based IGBTs and MOSFETs, to GaN or SiC power switches. The Pre-Switch topology achieves total inverter efficiency with industry standard IGBTs and MOSFETs that is equal to or higher than state-of-the-art III-V material-based power components.

Pre-Switch has published a series of comparison tests to prove the power loss reductions. These comparisons were performed using industry standard IGBT power modules; specifically, the Infineon EconoDUAL™ FF225R12ME4. The IGBT power module was tested using a standard double-pulse setup at various temperature and current load conditions, under both normal, uncontrolled hard-switching commutation with an additional ARCP network, as well as with a Pre-Switch controller to trigger the gate driver circuitry.

The results collected during the tests illustrate the improvement across all key parameters affecting the inverter design, efficiency and noise. The data can be found in the Tables. The X-Factor in the third Table is a normalized coefficient that provides the multiplier of the nominal current of the hard-switched inverter stage at the same PWM frequency, that returns the same total power loss, assuming the inverter is operated in soft-switching with the Pre-Switch control algorithm.

The Pre-Switch topology and control algorithm can deliver wide-bandgap performance with IGBT prices. The overall envelope for the power losses reduction can be modulated, according to the different point of operation in any given type of application, from doubling of current rating and an up to 5x increase in switching frequency operation.



Normalized Total Output Current vs. PWM switching frequency comparison between Hard-Switching operation and Pre-Switch Soft-switching mode

Literature

White Paper "THE ERA OF FORCED RESONANT SOFT-SWITCHING" by Alberto Guerra, Pre-Switch, Technical Advisor

www.pre-switch.com

Higher Efficiencies Through Gallium Nitride

Efficiency is a powerful driving force in all industries, as inefficiency often translates into unnecessarily high costs. In electronics, efficiency can also lead to limitations on overall performance or, if those limitations are not observed, a shortened product lifetime. The same market forces that impact all commerce and industry drive the pursuit of greater efficiency in power conversion. Just as significantly, however, is the need for increased efficiency in order to enable higher power density. This will not only allow for smaller, lighter and more reliable products, but help lift the limitations on performance and deliver increased levels of power in key infrastructure such as data centers, as well as emerging applications like electric vehicles. This has fueled the research and development into more efficient semiconductor devices in order to increase efficiencies in power conversion, improve power density and lower the overall financial and environmental impact of power management.

Power semiconductors have historically been based on a Silicon substrate, however while Silicon is an excellent general-purpose semiconductor it has well documented limitations when it comes to high voltages. The semiconductor industry has striven to overcome these limitations and has largely been relatively successful. However as the demand for more power continues unabated, the industry at large is moving away from silicon in favor of semiconductor materials that feature characteristics more suitable to power. These materials are classified as wide band-gap, which refers to the fact that they are physically different at the crystalline level to materials like silicon. These differences translate into several important characteristics, one of which is their ability to operate at higher switching frequencies while keeping the losses to a very low, manageable level.

The wide band-gap materials now being used to create power semiconductors include Silicon Carbide (SiC) and Gallium Nitride (GaN). The supply chain for SiC wafers and GaN on Si wafers is still developing, and is not as mature as the huge infrastructure and supply chain already in place for Silicon wafers. To overcome this roadblock to higher efficiency, the industry has put significant efforts into developing new substrates while still leveraging the economies of scale presented by Silicon. This approach isn't without its own challenges, of course, but there is a concerted will to succeed which has been extremely effective in seeding the market for wide band-gap transistors for power conversion. Just as with conventional Silicon process developments this has created a virtuous circle of reinvestment that is already showing significant signs of success.

The basic capability of a semiconductor material is dictated by the mobility of its charge carriers. A material with high electron mobility offers greater current carrying ability, which is clearly a significant benefit when it comes to power electronics.

The high electron mobility transistor (HEMT), is formed by bringing two structurally dissimilar substrates together, creating what is known as a heterojunction transistor. That basically means that the band-gaps of the two substrates are different, but it is this difference that promotes the higher electron mobility. Infineon has developed a process (GaN-on-Si), which is now being used to manufacture its CoolGaN family of HEMT devices.

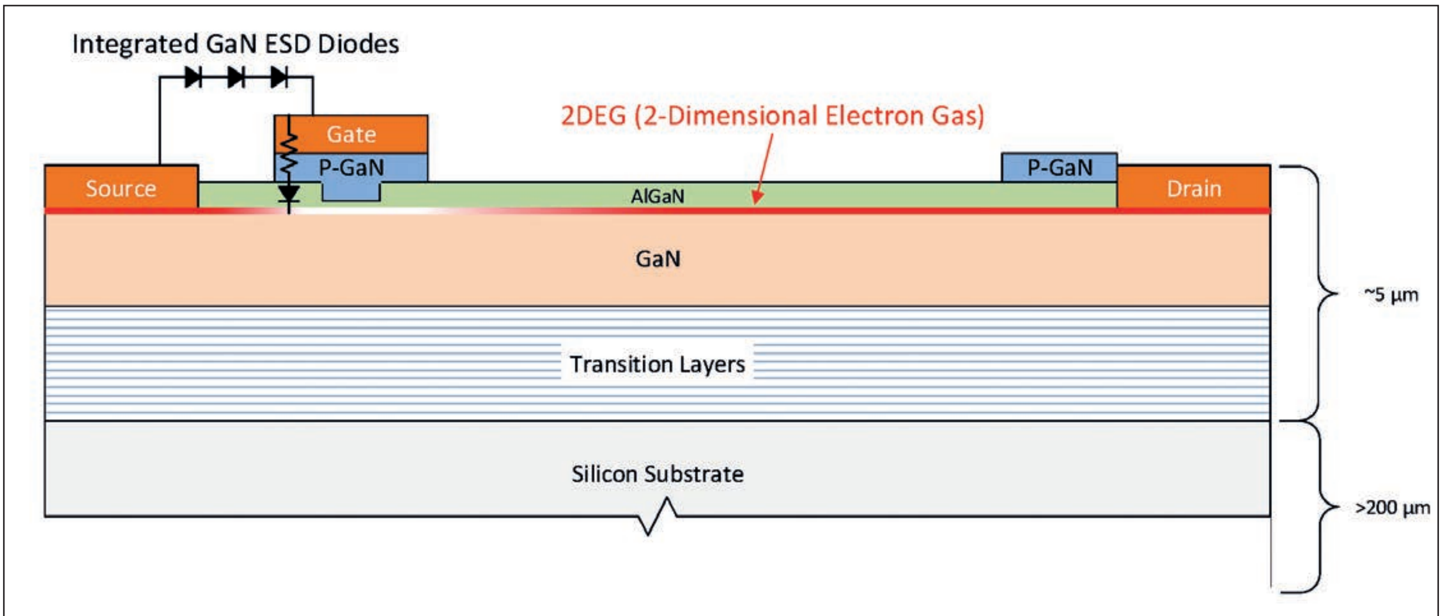
Achieving high efficiency with GaN-on-Si

As well as asking why we need more efficiency in power conversion, it is relevant to consider why GaN-on-Si power transistors are better able to deliver that efficiency than conventional Silicon power transistors.

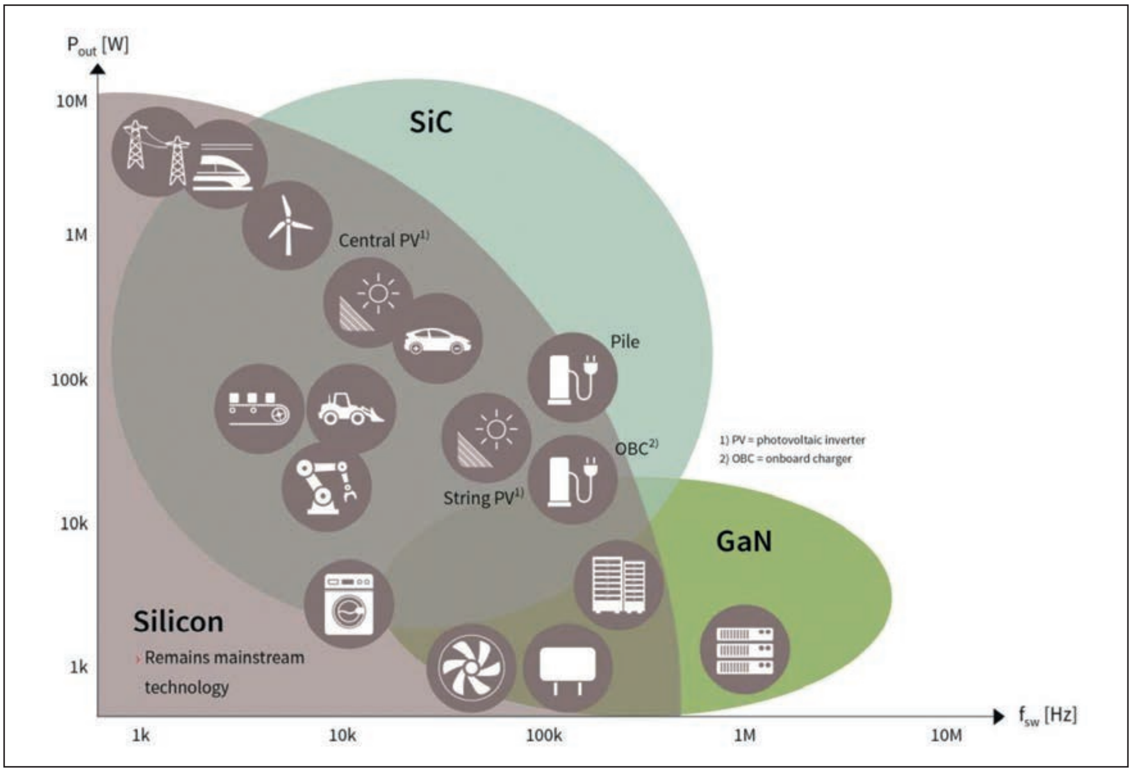
This is partly due to the topology of the converter and the demands that makes on the underlying technology. The topologies favored by power supply manufacturers today developed mainly because they were well-suited to the capabilities of CoolMOS power transistors. This technology has been the foundation of power supply design for many years. But now GaN removes one of the key limitations of CoolMOS - the performance of the body diode. GaN with zero reverse recovery charge enables it to be used in topologies that were not previously considered for power supplies - like the full-bridge totem pole PFC topology. It is this combination of newly enabled topologies used with the new GaN technology that helps to achieve new levels of power supply performance.

The characteristics of MOSFETs limit the performance of purely Silicon power transistors in high-voltage conversion. The new technology removes many of these characteristics, which means the transistors can operate at much higher frequencies without penalizing the efficiency, which can be kept at the highest value.

One of the key technologies that has enabled this significant leap in



Cross section of the CoolGaN GaN-on-Si HEMT showing the transition layers



GaN offers higher efficiency at higher switching frequencies than conventional Siliconor Silicon Carbide for specific applications
Source(2): Infineon Technologies

power conversion is the transition layers that bond the Silicon substrate to the GaN structure. The intellectual property involved here is the subject of many patents, but suffice it to say that the transition layers are a fundamental element of manufacturing HEMT devices.

The transition layers are grown epitaxially on to the silicon substrate, allowing the GaN HEMT structure to be built on the top of these layers, to form a planar transistor, whereby the charge carriers move laterally across the device. This is in contrast to a typical Silicon transistor, in which the charge carriers predominantly travel vertically.

As with the majority of transistors, HEMTs feature three terminals, in the case of FETs and HEMTs these are the drain, the source and the gate. As the name may imply, the gate controls the device, which can be thought of as a voltage-controlled switch. Transistors are designed to be either normally-ON or normally-OFF, the gate controls the state and the aim is to have the lowest possible resistance in the channel whenever the device is on and conducting. CoolGaN are normally-OFF transistors, which is considered nowadays a must-have by the electronics industry.

The resistance between the drain and source terminals, $R_{DS(on)}$, is one of the key parameters when selecting a power transistor, as is the speed at which the 'switch' can react to the gate voltage's polarity (that is, turn on or off). Using GaN-on-Si to create HEMT power devices delivers significant advantages in figures of merit (FOM). However, to take full advantage of these benefits it is necessary to match the power transistor with the best gate driver. That solution is the CoolGaN family, which will comprise 600 V, 400 V, 200 V and 100 V devices (200 V and 100 V are still in development), supported by the new GaN EiceDRIVER series of gate drivers.

Benefits of CoolGaN

While ostensibly similar to other types of FET, the HEMT has one significantly beneficial characteristic, in that it features no intrinsic body diode between the source and drain. This enables what is arguably the single most important feature of GaN transistors, which is their reverse recovery performance. The absence of a body diode removes its impact, which in other types of transistors is a limiting factor. With the reverse recovery charge comes an associated peak current which can be so large in Silicon power transistors that they cannot be used in conversion topologies that feature repetitive reverse recovery, including half-bridge topologies. This is not the case with GaN-on-Si HEMTs.

As CoolGaN transistors have no minority carriers and no body diode they do not exhibit a reverse recovery, which makes them well suited to half-bridge topologies and will also allow them to support the development of entirely new power conversion topologies that were previously impossible to realize, without major (and costly) adjustments on the control technique.

Resistance is by its very nature a liming factor, which is why it is so important to have transistors with a low on resistance, $R_{DS(on)}$. This figure can be interpreted as a conduction loss, which for many transistors is temperature-dependent. The temperature coefficient of $R_{DS(on)}$ in a CoolGaN transistor is significantly lower than in Silicon transistors, less than 2.0 as opposed to 2.4. This difference means CoolGaN transistors conduction losses scale more favorably with respect to Silicon transistors at high temperature.

Linearity is another important factor when considering the operating characteristics of a power transistor during the transition between ON and OFF states. The output capacitance of super junction Silicon power transistors is very non-linear; the voltage across the device (V_{DS}) increases slowly at the beginning, then exhibits a very steep increase, and finally additional time is needed to achieve V_{BUS} (typically 400 V in most of the HV applications where 600 V transistors are utilized). CoolGaN transistors exhibit a linear behavior with an output charge that is approximately one tenth of that seen with Silicon transistors. The smaller, linear output charge means that switching transitions are linear and nearly ten times faster compared to Silicon transistors. The reduced output charge also results in a 25 % smaller energy stored in that output charge E_{OSS}.

In high frequency operations, above 200-250 kHz, switching speed is key to determining how the transfer of energy occurs. CoolGaN's superfast switching speed enable very short dead time. With conventional Silicon transistors, higher I_{RMS} has to be considered, which inevitably increase losses. This means CoolGaN can deliver high efficiency even at high switching frequencies.

Literature

Infineon Technologies White Paper "How GaN-on-Si can help deliver higher efficiencies in power conversion and power management" by Andrea Bricconi, Head of Business Development Automotive GaN

www.infineon.com/gan

Power Electronics at its Best

Once again the Applied Power Electronics Conference (APEC) marks the opening of the power electronic events 2019 from March 17 to 21 in Anaheim/California. With more than 5,000 conference attendees and more than 300 exhibitors it is one of the best recognized conferences worldwide.

Plenery session opens APEC

APEC 2019 and its plenary session on the first day (Monday, March 17) continue the long-standing tradition of addressing issues of immediate and long-term interest to the practicing power electronic engineer. The APEC plenary presentations typically are from invited distinguished professionals.

The future of power electronics in robotic applications

By harnessing the latest advances in power electronics, control, sensors, and communication, robotics are accelerating efficiency gains in our industrialized economy. From smart robots to collaborative robots, and from virtual fences to energy flexibilization, robotics disciplines play a central role in the Industry 4.0 deployment. Yet many new exciting uses for robotics have to be realized. What is the future of power electronics in robotics applications? From control algorithms to smart motor drives usinglatest power semiconductor technologies, power electronics will play a key role in reaching the next level era of making our world greener and our lives safer. Speaker - Peter Wawer, President, Industrial Power Control, Infineon Technologies.

Overview of university research programs in power electronics

Every two years, PSMA publishes an updated Power Technology Roadmap (PTR). The purpose of the PSMA Power Technology Roadmap (PTR) is to present a look at power technology and trends over the next five years. This year, to get a differentand longer-termlook ahead, the PSMA selected universities and research institutions that are leaders in various areas of power electronics research. These universities and institutions were invited toshare information about the research that their institution would be pursuing in upcoming years,as well as provide some metrics about their research program. The results of this survey will be presented. Areas of common interest will be highlighted along with unique activity. Observations will also be shared on potential gaps in coverage. Speaker - Robert V. White, Chief Engineer, Embedded Power Labs (representing PSMA).

Flywheel Energy Storage: A utility scale energy solutionfor the 21st century

Energy storage is now emerging as an essential electric utility resource to effectively enable higher penetration levels of variable renewable generation resources. In California, in response to RPS mandates for increased renewable penetration, Assembly Bill 2514, in conjunction with resulting California Public Utilities Commissionrulings, has calledfor 1.3 GW of flexible energy storage to be incorporated into the energy mix by California utilities by 2024. Similar actions have been enacted, or are in process,in other U.S. states, and worldwide.The talk will review the energy storage landscape, in terms of opportunity, established and emerging storage technologies, and commercial progress. The talk will also focus on the speaker's interests in

Time	211AB	212AB
Tuesday Mar 19th, 2019 08:30-12:00	T01 Hybrid DC-DC Converters (9 papers) Chr: Pradeep Shenoy, Yan-Fei Liu Track: 2	T02 Power Converter Modeling and Simulation (9 papers) Chr: Sara Ahmed, Jing Xu Track: 7
Wednesday Mar 20th, 2019 08:30-10:10	T09 Converters for Data Centers (5 papers) Chr: Xin Zhang, Robert Pilawa-Podgurski Track: 2	T10 Power Device and Module Modeling (5 papers) Chr: Sandeep Bala, Rolando Burgos Track: 7
Wednesday Mar 20th, 2019 14:00-17:30	T17 Single-Phase AC-DC Converters (9 papers) Chr: Gerry Moschopoulos, Qiang Li Track: 1	T18 Resonant DC-DC Converters (9 papers) Chr: Cahit Gezgin, Abey Mathew Track: 2
Thursday Mar 21st, 2019 08:30-11:20	T25 Multilevel and Multi-Phase AC-DC Converters (7 papers) Chr: Daniel Costinett, Michael A. E. Andersen Track: 1	T26 Magnetics Modeling, Design & Applications (7 papers) Chr: Fang Luo, Shuo Wang Track: 7
Thursday Mar 21st, 2019 14:00-17:30	T33 DC-DC Converter Applications (9 papers) Chr: Olivier Trescases, Zach Pan Track: 2	T34 Soft Switching DC-DC Converters (9 papers) Chr: Hanh-Phuc Le, Chenhao Nan Track: 2

advancing flywheel energy storage to meet utility scale challenges. Some details on productand project development on grid scale energy storage at start-upAmber Kinetics will be discussed. Speaker - Seth R. Sanders is Professor in the Department of Electrical Engineering and Computer Sciences at the University of California, Berkeley, and co-founder and Chief Scientist at Amber Kinetics.

Power electronics for the space exploration hype

The market for space electronics is moving from big institutional programs towards more dynamic environment with new players, private investors and commercial customers. There is a strong demand for shorter time to market and a significant price reductionwhile increasing the performances of the electronics. Topics will include extensive use of COTS (Commercial Off the Shelf EEE components) for space, the use of digital control for power units, the need for higher power & higher efficiency and the use of GaN technology in power conditioning units. Speaker - Fernando Gómez-Carpintero, Head of Power Engineering, Airbus Spacecraft Electronics.

Other plenaries cover **Power electronics; enabling zero emission powertrains and fuel cell engines,** Speaker - Abas Goodarzi, President and Chief Executive Officer, US Hybrid Corporation; and **Improving healthcare through power electronics: opportunities in powering medical devices,** Speaker - Rikky Muller, Co-Founder, Cortera Neurotechnologies.

Wide bandgap sessions

The numerous Technical Sessions, just to mention WBG include T08.1 - Design Considerations of High-Voltage Insulated Gate Driver Power Supply for 10 kV Silicon-Carbide MOSFET in Medium-Voltage Application; T08.2 - High Efficiency High Bandwidth Four-Quadrant Fully Digitally Controlled GaN-Based Tracking Power Supply System for Linear Power Amplifiers; T08.3 - A Highly Reliable Short Circuit Protection Method for E-Mode GaN HEMTs; T08.4 - Benchmarking and Qualification of Gate Drivers for Medium Voltage (MV) Operation of 10 kV Silicon Carbide MOSFETs; T08.5 - High-Frequency GaN-Based Induction Heating Versatile Module for Flexible Cooking Surfaces; T08.6 - Characteristics Analysis for Paralleled SIC MOSFETS; T08.7 - Active Gate Control for Two Series Connected SiC MOSFETs; T08.8 - A Versatile Large-Signal High-Frequency Arbitrary Waveform Generator Using GaNDevices; T08.9 - Sequential Parallel Switching for Drain-Source Synchronous Rectifier Efficiency and Light-Load Stability Improvement.

Industry sessions and workshops complement the program.

The Power Sources Manufacturers Association (PSMA) Semiconductor Committee is sponsoring three Industry Sessions that address the rapid emergence of wide bandgap semiconductors as a significant power conversion technology. The sessions will take place on Tuesday, Wednesday and Thursday, March 19-21, 2019, in the Anaheim Convention Center.

Taken as a whole, these Industry Sessions will address the "Coming of Age" of GaN and SiC power semiconductors, with each session focusing on one aspect of the topic as follows:

- IS4: Tuesday March 19, 8:30 to 11:55 a.m
  "Getting up to speed on switching: wide bandgap and other high-performance components"
- IS11: Wednesday March 20 from 2:00 to 5:25 p.m.
  "Current reliability and product qualification topics for SiC and GaN wide bandgap devices"
- IS16: Thursday March 21 from 8:30 to 11:30 a.m.
  "Production use cases of wide bandgap semiconductors: systems in production today, drivers and controllers for tomorrow"

"SiC and GaN have been the most popular topics at APEC over the past several years. It is clear that the promise that these devices have offered in size and efficiency gains are being realized," said Tim McDonald, Chairman of the PSMA Semiconductor Committee. "This 'Coming of Age' series of Industry Sessions will serve to inform attendees on this vital technology

APEC 2019 Lecture Session Schedule

213C	213D	303AB	303CD	304AB	304CD
T03 Photovoltaic Power Conversion Systems (9 papers) Chr: Yongheng Yang, Jian Sun Track: 10	T04 Control of DC-DC Converters (9 papers) Chr: Lucas Lu, Chao Fei Track: 8	T05 Drives & Inverters: Topologies & Control (9 papers) Chr: Arijit Banerjee, Karthik Jayaraman Track: 4	T06 Devices and Components I (9 papers) Chr: Alex Huang, Pete Losee Track: 5	T07 Topologies for Grid-Tied Converters (9 papers) Chr: Majid Pahlevani, Suzan Eren Track: 3	T08 WideBand Gap Applications (8 papers) Chr: Pedro Alou, Doug Osterhout Track: 12
T11 Microgrids Applications (5 papers) Chr: Zeng Liu, Haoyu Wang Track: 10	T12 Rectifiers for EV Charging (5 papers) Chr: Yingying Kuai, Arun K. Kadavelugu Track: 11	T13 Inverter Modulation & Control Strategies (5 papers) Chr: Poria Fajri, Ali Bazzi Track: 4	T14 Integration & EMI Considerations of Power Converters (5 papers) Chr: Yu Du, Fred Weber Track: 6	T15 Optimization of Wireless Power Transfer Systems (5 papers) Chr: Khurram Afridi, Raghav Khanna Track: 9	T16 Medical/Computing/Lighting Applications (5 papers) Chr: Indumini Ranmuthu, Ed Massey Track: 12
T19 Wireless Power Transfer Applications (9 papers) Chr: Sheldon Williamson, Faisal Khan Track: 9	T20 Control Strategies for Inverters and Motor Drives (9 papers) Chr: Jaber Abu Qahouq, Yusi Liu Track: 8	T21 Driving WBG devices (9 papers) Chr: Alireza Dayerizadeh, Dong Dong Track: 5	T22 Drives & Inverters: Parameter Identification, Measurement & Diagnostics (9 papers) Chr: Mehdi Farasat, Mithat Kisacikoglu Track: 4	T23 Diagnostic and Fault-Tolerant Control of Renewable Energy Systems (9 papers) Chr: Fei Lu, Minjie Chen Track: 10	T24 Transportation/Storage/Grid (9 papers) Chr: Petar Grbović, Tae Hong Kim Track: 12
T27 Step-up DC-DC Converters (7 papers) Chr: Gab-Su Seo, Wisam Moussa Track: 2	T28 Control Strategies for Improving Quality and Performance (7 papers) Chr: Seungdeog Choi, Panagiotis Kakosimos Track: 8	T29 SiC & GaN based Power Converters (7 papers) Chr: Victor Veliadis, Qing Ye Track: 6	T30 Magnetics optimization (7 papers) Chr: Seungryul Moon, Matthew Wilkowski Track: 5	T31 Control Algorithms for Utility Interactive Systems (7 papers) Chr: Praveen Jain, Xiongfei Wang Track: 3	T32 Wireless Power Transfer Design Techniques (7 papers) Chr: Faisal Khan, Wisam Alhoor Track: 9
T35 Power Electronics for Transportation (9 papers) Chr: Omer Onar, Behrooz Mirafzal Track: 11	T36 Control Applications (9 papers) Chr: Martin Ordonez, Weiming Zhang Track: 8	T37 Faults and Dynamics in Grid-Tied Systems (9 papers) Chr: Majid Pahlevani, Xiaoqing Song Track: 3	T38 Motor Drive Modulation & Control Strategies (9 papers) Chr: Rakib Islam, Zhe Zhang Track: 4	T39 Power Converter Design for Renewable Energy Applications (9 papers) Chr: Yinglai Xia, Ashish Kumar Track: 10	T40 Industrial Applications (9 papers) Chr: Jesus Acero, Sombuddha Chakraborty Track: 12

area." In addition to informative presentations, these Industry Sessions will afford attendees the opportunity to interact and network with industry colleagues engaged in power conversion system design. I encourage APEC attendees to register and attend these valuable industry sessions, and to consider participating in the other PSMA-sponsored meetings during the week."

The PSMA and PELS are co-sponsoring an all-day workshop "The Impact of Wideband Technologies on Application of Capacitors - A Deep Dive on Capacitor Technology" on March 16, the Saturday before APEC 2019.

Many consider that a capacitor is a capacitor, it can be charged and discharged, no more no less. In 2018 the first PSMA/ IEEE PELS pre-APEC Capacitor Workshop started to lift the curtain to show some of the magical behaviors that designers must understand in the capacitor world for use in their designs. In the 2019 workshop, we will do much more than that. The primary focus will be on applications to highlight the specific requirements that must be satisfied by capacitors. Not only are evolving GaN and SiC based topologies challenging designers, the worldwide tight market for certain capacitors limit designers when selecting available capacitors that will satisfy their applications.

More **http://www.psma.com/technical-forums/capacitor/workshop**

PowerAmerica will once again moderate an industry panel. The panel (APEC Industry Session 19), "Advances in the Adoption of Wide Bandgap Semiconductors in Commercial and Industrial Applications," will take place Thursday, March 21, from 8:30-11:30 a.m. and will feature PowerAmerica members ABB, GE Aviation Systems, Navitas Semicondutor, ON Semiconductor, United Silicon Carbide, University of Tennessee-Knoxville and Hella.

Additionally the Rap Session 1 "When will WBG have significant volume? Is the system benefit worth the cost? Is WBG reliable?" will be offered on Tuesday, March 19, from 5:00 - 6:30 pm. Now that the availability and performance of wide-bandgap semiconductors in the marketplace has been established, the focus is shifting from promise to reality. What application spaces face the most disruption? What opportunities are presenting themselves? The panel for this rap session includes manufacturers selling SiC and GaN components, and the companies designing their current and future products with them.

Magnetics

PSMA and PELS are also co-sponsoring a "Power Magnetics @ High Frequency" all-day workshop on the Saturday before APEC 2019.

The purpose and focus of the workshop is to identify the latest improvements in magnetic materials, coil (winding) design, construction and fabrication, evaluation and characterization techniques and modelling and simulation tools so as to target the advancements that are deemed necessary by the participants for power magnetics to meet the technical expectations and requirements of higher application frequencies and emerging topologies that are being driven by continuous advances in circuits topologies and semi-conductor devices driven by new market applications. The registration fee for the workshop is $375 per participant, reduced to $275 for PSMA members and IEEE PELS members.

More **http://www.psma.com/technical-forums/magnetics/workshop**

Also on this topic there is a Rap Session "High Technology Holdup- Is magnetics really the constraint or are magnetics waiting for everything else to catch up?" on Tuesday, March 19, from | 5:00 - 6:30 pm. Enormous efforts are being made to uncover new semiconductor technologies and circuit topologies to supply the ever-changing demands of modern electronics. At each step, magnetics seem to be there for those companies that understand how to design them properly. Panelists will debate this and explore the constraints.

3D Power Packaging

The PSMA Packaging Committee is sponsoring an Industry Session titled, "Making Power Sources Small with 3D Power Packaging." Featuring speakers from leading industry and research organizations, the session (IS12) will present an up-to-date look at current and future component and manufacturing technologies utilizing high-density 3D packaging. The session will take place on Wednesday afternoon, March 20th, 2018, from 2:00 - 5:25 p.m. in Room 210A of the Anaheim Convention Center.

Manufacturers utilizing power sources in their products are continually asking for smaller solutions. The industry can deliver with new components, design and manufacturing techniques that support higher density, higher reliability, and higher frequency operation. A 3D packaging approach using embedded components (actives and passives) combined with advanced manufacturing technologies is proving to be the most reliable solution, offering the fastest time to market for achieving increased power density in a smaller footprint. This solution is already in production in semiconductor, component and power supply designs.

The 3D Power Packaging Industry Session will feature seven invited experts, offering application details, real-world examples of implementation and insights to help attendees identify potential opportunities for their companies and to explore the potential of applying this emerging technology to meet their market demands.

Now that the availability and performance of wide-bandgap semiconductors in the marketplace has been established, the focus is shifting from promise to reality. What application spaces face the most disruption? What opportunities are presenting themselves? The panel for this rap session includes manufacturers selling Silicon Carbide (SiC) and Gallium Nitride (GaN) components, and the companies designing their current and future products with them. What is the current state of the wide-bandgap industry? Come participate in our rap session and find out!

The Rap Session 2 covers "Power supply on chip (Pwr SOC) vs. Power supply in package (Pwr SIP) vs discrete. What is the future?" on Tuesday, March 19, 5:00 - 6:30 pm. There is significant trend in the industry towards higher power density and integration in power supplies. This integration has given rise to complex issues such as building complete power supplies on chip, 3D packaging for power supply in single package, highly miniaturized passives, thermal density and efficiency. The panelists for this session includes experts from actual design of power supply on chip, 3D packaging, design of miniaturized inductors and capacitors.

Energy harvesting

An other Industry Session sponsored by the Energy Harvesting Committee of the PSMA featuring seven industry experts, will address the latest developments in this rapidly emerging technology ecosystem that is disruptively increasing in relevance for a wide variety of power electronic applications, particularly IoT where the grand challenge is to get the battery to outlive the IoT edge device. The Energy Harvesting Session (IS15) will be held on Wednesday, March 20, from 2:00 pm to 5:25 pm in the Anaheim Convention Center, Room 213B.

Following on the well-attended Industry Session at APEC2018, last March in San Antonio and the inaugural EnerHarv Workshop held in May in Cork, Ireland, the APEC2019 Energy Harvesting Industry Session reflects the global nature of the work being done in this area emphasizing the need to optimise power consumption of the load as well as collaborating to understand the industry application. There will also be a decided 'non-presentation' slot showing various energy harvesting and power management-related demos where attendees can talk directly with the developer and integrators in real-life applications and understand its potential use.

The PSMA Energy Harvesting Committee Chair Mike Hayes (Tyndall National Institute) and Co-Chair Brian Zahnstecher (PowerRox) have geared the session for a wide audience, including potential collaborators and adopters of energy harvesting for the self-powering of ultra-low-power applications, as well as those who want to eliminate the need for a battery or storage device replacement in low-power devices. Industrial and academic developers of material and devices (both active and passive) also will find this session helpful in understanding application requirements.

All APEC attendees are also invited to attend the PSMA Packaging Committee meeting scheduled for Wednesday, March 20, 2019, from 8:00 am to 10:00 am in the Anaheim Marriott, Meeting Room Platinum 9. **AS**

The European Power Event

The Power Electronics industry has been meeting in Nuremberg since 1979. The PCIM Europe from May 7 – 9 is one of the leading international exhibition and conference for power electronics and its applications.

This is where experts from industry and academia meet, where new trends and developments are presented to the public. In this way, the event mirrors the entire value chain – from components, drives control and packaging to the final intelligent system. The international trade visitors are experts and decision makers mainly from management, product and system design, purchasing as well as R&D management departments. As a highly specialized exhibition, the PCIM Europe is distinguished by an intensive working atmosphere. Visitors attend the exhibition to discuss specific problems and individual approaches at the exhibition stand, initiating investment decisions directly on site.

The 2018 event attracted 803 conference attendees with more than 300 oral presentations, 506 exhibitors, and 11,600 visitors. "From today's figures we expect slightly more this year", said Lisette Hausser, Vice President of PCIM Europe, on occasion of a preview meeting in February. "Due to electrification in various industries we are confident to achieve record results".

WBG is the direction

The PCIM Europe offers a top-quality lecture program – at the application-oriented conference as well as at the three exhibition forums. "More than 100 presentations will cover SiC and GaN, by far the biggest share of the conference presentations", remarks Prof. Dr. Leo Lorenz, General Conference Director. "An other important topic is packaging and die interfacing, which is co-relating with WBG due to high switching frequencies and higher temperature capabilities. Here 50 papers will be presented. Also new ferrite materials and electrolytes are necessary to cope with WBG progress, here we will present 10 papers".

Keynotes open the three conference days with "Next Generation of Power Supplies" - Speaker Fred Lee, Virginia Tech; The Age of Optimization in Power Electronics" - Speaker Ki-Bum Park, ABB Research Center; and "GaN and Industry 4.0 – A small change that is revolutionizing the industry" - Speaker Jim Witham, GaN Systems.

In today's power electronics products, quality and reliability are given. Great emphases are placed on high efficiency, high power density and low cost. The current practice has reached a level of maturity that further advances will be closely linked to improvement in power devices, materials, and fabrication techniques. With recent advances in wide-band-gap (WBG) power semiconductor devices, namely, SiC and GaN, we have witnessed significant improvements in efficiency and power density while operating at a frequency an order of magnitude higher than the current practice using silicon counterparts. With this dramatic increased operating frequency, current design practices are challenged. Design trade off previously considered impractical or inconceivable can be realized not only with significant gain in efficiency and power density, but also drastic improvement of EMI/EMC and manufacturability. Several examples will be given to illustrate the potential impact of WBG devices in performance improvements and ease of manufacturability of future power electronics products. Fred Lee expects that due to improvement of efficiency (up to 2%), improvement of power density (5 -10X), and improvement of EMI/EMC (20dB) GaN will replace Silicon in power supply applications.

Due to the significant growth of renewables, worldwide installation of grid-tied converters is increasing rapidly. To cope with ever-increasing technical challenges in grid connection, recent advances in power electronics optimization in academia is being applied to industrial research as a backbone of developing high power density grid-tied converters. In ABB's talk, in order to push the performance boundaries of the current technologies, the impact of each core technology (modulation, topology, magnetics, filter, and Si/SiC) on power densities of the grid-tied converters is explored, which lead to the future research directions with upcoming challenges.

Modern manufacturing companies need to respond to the new technology and energy requirements that accompany the inevitable evolution to tomorrow's Industry 4.0 smart factories. Escalating use and costs of electricity to power increasingly automated robotic and motorized production lines means that manufacturers need to develop new operational practices if they hope to stay competitive. In order to keep costs down and revenue up, increased energy efficiencies are needed across the factory floor. And to maintain continuous operations 24/7, simpler, more reliable, and yet more powerful motor drives in all forms of machinery will be a requirement. GaN semiconductors enable the design and production of small, high efficiency motor drives that ease filtering and enable the use of longer length and lower cost unshielded cables as well as long range wireless charging in factories. Additionally, wireless charging and longer runtime robots are driving manufacturing and warehouse efficiencies, according to Jim Witham's talk. GaN power semiconductors deliver the power density and conversion efficiency demanded by the 4th industrial revolution. And he will demonstrate how this then translates into the costs savings and flexibility they need to be ahead of the market.

Novelties at the exhibition floor

E-mobility as a longstanding key topic at the PCIM Europe will be presented in a new set-up that offers a variety of attractive opportunities for participation to exhibitors with an extensive product range in this field.

The first change is in the »presence area« of the E-mobility Area. Here, exhibitors can use posters and marketing materials to invite visitors to their main stand so they can find out all about their newest product innovations on electromobility. Places in this presence area are available for registered exhibitors on request. For the first time there will be Guided Tours on the trend topic of e-mobility, introducing exhibitors that specialize in this application of power electronics. Interested visitors have the possibility of signing up for these tours online prior to the event. The organized tours are targeted towards experts in this sector and will take place twice a day. They will lead the way to exhibitors with a distinctive focus on e-mobility, and who will be showcasing their portfolio as well as answering any questions that may arise.

More in our next issue.

Conference

Tuesday, 7 May 2019

Conference Opening and Award Ceremony

Keynote »Next Generation of Power Supplies«
Fred Lee, Virginia Tech, USA

Technologies for DC Grids	Advanced SiC MOSFET	DC-DC Hard and Soft Switched Converters I	Thermal Management	Magnetic Components
Smart Functions in Power Electronics	Advanced IGBT's	DC-DC Hard and Soft Switched Converters II	Advanced Device Technologies	Control Techniques and Electrical Drives

Poster / Dialogue Session

Wednesday, 8 May 2019

Keynote »The Age of Optimization in Power Electronics«
Ki-Bum Park, ABB Corporate Research Center, CH

Automotive Power Converters	Safety in Motion	High Voltage SiC	New Packages	Intelligent Gate Drivers
Automotive DC-DC Converters	High Power Converters	GaN System Integration	Reliability	Current Sensing

Poster / Dialogue Session

Thursday, 9 May 2019

Keynote »GaN and Industry 4.0 – A Small Change that is Revolutionizing the Industry«
Jim Witham, GaN Systems, USA

High Voltage IGBT's	Smart Transformers	Control Methods for Power Converters	Power Quality and EMC
GaN Devices	AC-DC and DC-AC Converters	Chip Bond Technologies	Power Modules Design

Using FREDFETs in BLDC Motor Drivers to Overcome Thermal Challenges

A recent IHS report suggests that the global market for brushless DC (BLDC) motors in home appliances is set to rise from around 430 million units per year to 750 million units per year over the next five years. This enormous growth is due to the fact that BLDC motors are smaller and more efficient across a wider range of operating speeds than their more traditional AC induction counterparts – and there are other advantages too. Yet conventional means of driving BLDC motors may be compromising their effectiveness. New solutions are needed. **Cristian Ionescu-Catrina. Product Marketing Manager, Power Integrations, San Jose, California**

BLDC motors are being used in all sorts of household appliances – air conditioning, dish washers, washing machines, refrigerators, pumps, fans – to replace AC motors. The main reason for this is that BLDC motors more efficient than AC motors, particularly when not operating at maximum power and are more controllable. They also run quieter making them the ideal choice for appliances. Efficient operation across the load range is often necessary for products that must meet global energy efficiency regulations.

Software-controlled BLDC motors have the flexibility of programmability, variable speed and/or torque can be achieved with high levels of precision. Reliability is another important issue. BLDC motors do not require the provision of power for the rotor eliminating - brushes and slip rings - so reliability and lifetime is increased compared to brushed motors. Given the level of efficiency and controllability that can be brought to BLDC motor the most important considerations for the BLDC drive are the inverter and controller designs

Efficiency and thermals

Thermal challenges limit inverter performance. It's pretty obvious that increased device temperature decreases inverter life time, thereby adversely affecting reliability.

Increased temperatures will also make it harder to pass safety regulations, and may dictate the need for a heatsink and a cooling fan. This all adds to the BOM, size and cost, increases module size (negating another key advantage of BLDC motors) and will have a negative impact on reliability.

It is perhaps surprising how great an effect an apparently-small increase in inverter efficiency can have in reducing power losses – which translates into heat savings. For example, if you can increase the inverter efficiency by 1 % from 97 % to 98 %, given an inverter input power of 260 W the power losses will drop from 7.8 W to 5.2 W - a power saving of 2.6 W and a whopping 33 % less dissipated heat.

Power Integrations has very successfully delivered products into the appliance sector for many years. Devices such as the InnoSwitch™-EP and LinkSwitch™ families are highly-integrated, high-voltage ICs for off-line power conversion, and they are widely specified because of their high efficiency and ruggedness. So when Power Integrations decided to enter the brushless DC motor driver market already replete with excellent switching devices, the company realized that it needed to take a new approach, in order to deliver class-leading efficiency and performance.

The BridgeSwitch™ IC family of Integrated Half-Bridge (IHB) motor drivers delivers 98.5 % efficiency for designs from 30 W to 300 W – largely eliminating any

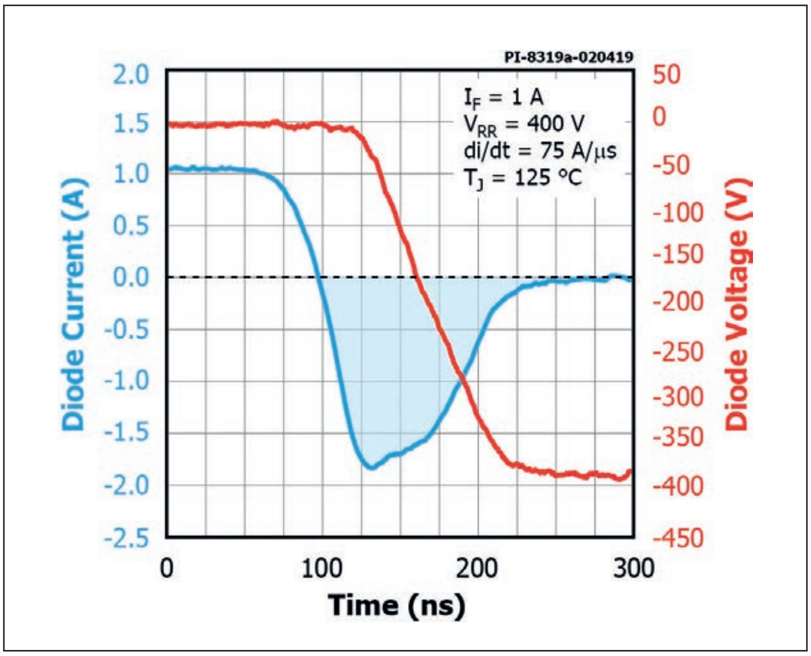


Figure 1: **Reverse-recovery charge, Q_{RR}, of the BridgeSwitch FREDFETs and Reverse Recovery Softness Factor (SSVR) in normal operation**

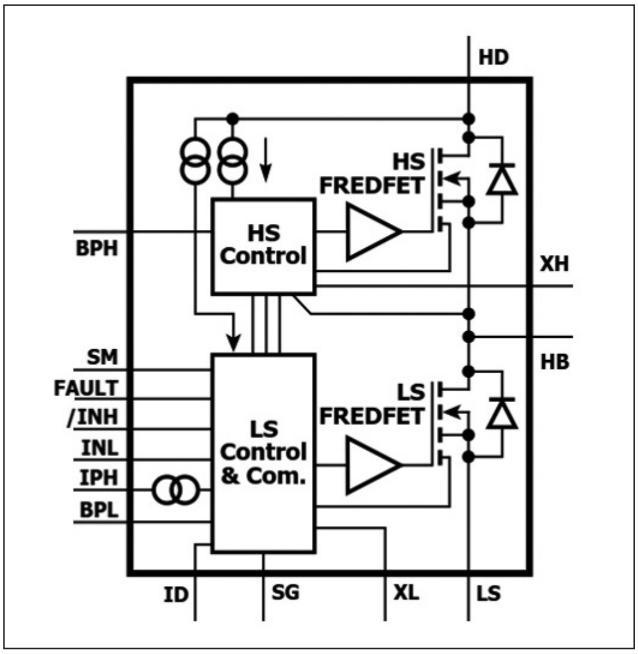


Figure 2: Block diagram showing the elements that are included within a BridgeSwitch IC

thermal challenge. It does this by integrating 600 V FREDFETs which incorporate fast but ultra-soft-recovery body diodes. A FREDFET is a fast-reverse (aka fast-recovery) epitaxial diode field-effect transistor. This specialised FET is designed to provide a very fast recovery (turn-off) of the body diode. Figure 1 shows the low reverse-recovery charge, Q_{RR}, of the BridgeSwitch FREDFETs in normal operation. The curve also shows the Reverse Recovery Softness Factor (SSVR) which is greater than one and indicates that the switch will have an excellent EMI characteristic.

Fast recovery body diode

The body-diode in a typical switching MOSFET is a parasitic device, derived from the structure of the switch. The diode so formed is not optimized for conduction and has poor performance. IGBT structures do not form an intrinsic body-diode. In order to overcome these issues, integrated switch solutions will often co-package anti-parallel diodes with the switching devices, which adds significant cost. Provided that these diodes exhibit a lower forward voltage drop than the intrinsic body-diode they will effectively shunt the body-diode (reducing its effect) and provide a more efficient demagnetization-current-path. As we will see later, the behaviour of the anti-parallel diode is important in determining switching efficiency and limiting EMI.

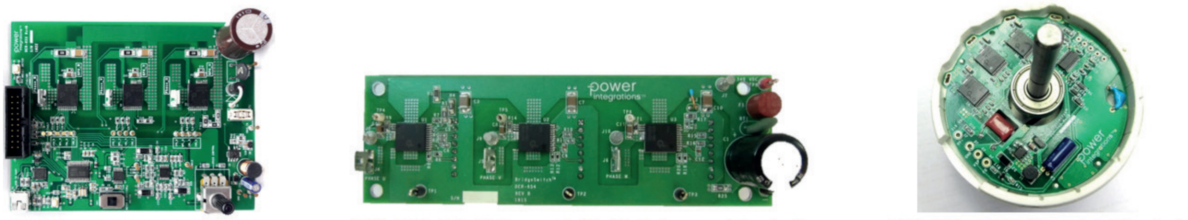
The negative slope of the current curve is dictated by circuit-inductance and is independent of the switching device. At the beginning of the reverse recovery period the diode voltage bias reverses. This causes carriers in the PN structure to also reverse direction. The carriers continue to carry charge (in the opposite direction) until they are swept-out of the P-N depletion zone giving rise to the reverse diode current.

The diode structure in Power Integrations' FREDFET quickly causes elimination of these charge carriers which limits the amount of reverse charge that is transported during the recovery period. This results in a reduced reverse recovery current amplitude and duration (reduced-area-under-the-curve = total charge).

The rate of elimination of the charge carriers (slope of the recovery characteristic) must also be controlled to reduce EMI and defines the softness of the diode. Softness (SSVR) is now typically described using the steepest part of the recovery curve, and referenced to the negative current slope seen at the beginning of the reverse recovery event.

As can be seen, the reduction in switching losses is significant. In addition, the soft recovery characteristic, with well controlled current transition rates reduces system EMI.

Figure 2 is a block diagram which shows the elements that are included within a BridgeSwitch IC – two drivers, controller, level shifter and two FREDFETs. BridgeSwitch offers uniquely offers self-powered operation - there is no need for a low voltage secondary power supply, resulting in a smaller and simpler auxiliary power stage; for example this would enable the use of a single-output buck converter such as Power Integrations' LinkSwitch-TN2 rather than the



DER-653: 300 W FOC | DER-654: 300 W Supports Multiple types of Control | DER-749: 40 W Sinusoidal Control

DER	Part #	I_{DC} (A)	Power (W)	Control	Full Load Efficiency	Sensor	Microcontroller
DER-653	BRD1265C	5.5	300	FOC	98%	Sensorless	Toshiba MCU TMP375FSDMG
DER-654	BRD1265C	5.5	300	Any	98.3%	Hall Sensor input	Any Microcontroller
DER-749	BRD1260C	1	40	Sinusoidal	94%	Hall Sensor	Princeton PT2505

Figure 3: BridgeSwitch architecture flexibility. - the same layout can be used as a building block for either single or multi-phase BLDC motor

conventional multi-output flyback design for the motor drive stage. Overall, the level of integration has a significant impact on BOM size, PCB space and reliability.

One very significant benefit of this architecture is that not only does it not produce as much heat (in the form of wasted power) as traditional designs in the first place, but also that it eliminates hot spots by distributing the heat that is produced. A traditional IPM (Integrated Power Module) design showing a hot spot at 118°C; the IHB BridgeSwitch design which shows a maximum 'spot' temperature of 92.3°C (minimum in this example is 87.2°C). This means that the PCB alone can be used to dissipate the heat, eliminating heatsinks – a further BOM, weight, space and cost saving. Comparing the BridgeSwitch thermal performance against an IGBT or other FET-based solutions shows similar benefits.

A further advantage of the BridgeSwitch architecture is its flexibility. The same layout – shown in Figure 3 - can be used as a building block for either single or multi-phase BLDC motor. Reference designs are available that support the wide variety of control algorithms that exist in the BLDC motor market.

Compliance with international safety regulations

Achieving compliance with international safety regulations can be challenging. To gain IEC 60335-1 and IEC 60730-1 approval, traditional BLDC motor solutions require Class B software protection, which is not only expensive and time-consuming to obtain, but will also require re-certification for any software changes, and aadditional software integrity checks for OTA (Over-the-Air) updates. The IHB system architecture reduces these costs and saves time because BridgeSwitch has unique hard-wired cycle-by-cycle low-side (LS) and high-side (HS) over-current protection BridgeSwitch monitors line voltage, providing both OV and UV protection and also measures switch and winding/PCB temperature to provide additional system alerts and hard-wired end-stop safety. This simplifies the software requirement from Class B to Class A, simplifying and shortening the qualification process. Plus there is no need for any re-certification when system software changes occur. As well as hard-wired protection BridgeSwitch devices transmit fault information to the system microcontroller via a unique single wire bi-directional communication interface.

A higher level of protection is achieved by this method as the hardware implementation in BridgeSwitch safety features reacts very quickly (~150 ns). Each BridgeSwitch device in the circuit monitors switch current, adding redundancy for each winding phase. Lastly, precise control of switch slew rates (<3 V/ns turn-off and <2.5 V/ns turn-on) from the integrated HS/LS/driver combination means that EMI is significantly reduced when compared to conventional designs.

Aside from its various technical, regulatory and commercial benefits, the higher overall efficiency saves energy, enabling a superior market positioning ('Green' energy-efficiency branding) as well as permitting the designer to add extra system features (e.g. displays, connectivity) within the same system power budget.

Electric Vehicle Fast Charging Challenges

With the pressure on governments to reduce carbon emissions continuing, the interest in battery electric vehicles (BEV) continues to grow as part of the solution to this challenge. The BEV market continues to offer ever more choice at increasingly attractive price points. However, range angst remains a key concern among consumers. This issue is compounded by the need to re-think refuelling. Parking the vehicle while at work could be the perfect opportunity to recharge, but a lack of infrastructure means that many BEV owners feel bound to recharge at home. For longer journeys, such as vacations, consumers expect that recharging can be undertaken with a rapidity that matches, or comes close to, refuelling an internal combustion engine (ICE) vehicle. **Pradip Chatterjee and Markus Hermwille, Infineon Technologies, Germany**

In order to facilitate charging at home, most vehicles provide support for charging via a household single-phase alternative current (AC) supply. This allows them to be charged overnight. Solutions range from simple provision of a cable to connect the vehicle to a power outlet, to in-cable control and protection devices (IC-CPD), and wall-box chargers that may include further complexity, such as communication between the vehicle and power unit, with grounding and protection inside.

The batteries themselves of course require a direct current (DC) supply for charging, with the conversion from AC to DC occurring in charging electronics built into the vehicle. This approach requires that every vehicle be fitted with a charging solution that must be designed according to all the normal constraints of cooling, efficiency and weight, factors that ultimately limit charging power and, therefore, charging speed. The obvious way forward is to develop universal off-board DC chargers.

Approaches to fast DC charging

A typical 22 kW AC charger provides enough charge in 120 minutes to provide an additional 200 km of vehicle range, more than enough for topping up while at work. However, in order to reduce the 200 km range charge time to 16 minutes requires recourse to a 150 kW DC charging station. At 350 kW, the charging time for this range can be reduced to around just 7 minutes, somewhere approaching an ICE vehicle refuelling visit. These figures, of course, additionally assume that the target battery can support such charging rates. And, just like refuelling at the pump, consumers expect the industry to provide a standardized fuelling experience regardless of where they recharge.

In Europe, the organization CharIN e. V. focusses on developing and promoting the Combined Charging System (CCS). Their specifications define the charging plug, charging sequence and even data communication. Other regions, such as Japan and China, have similar organizations such as CHAdeMO and GB/T respectively,

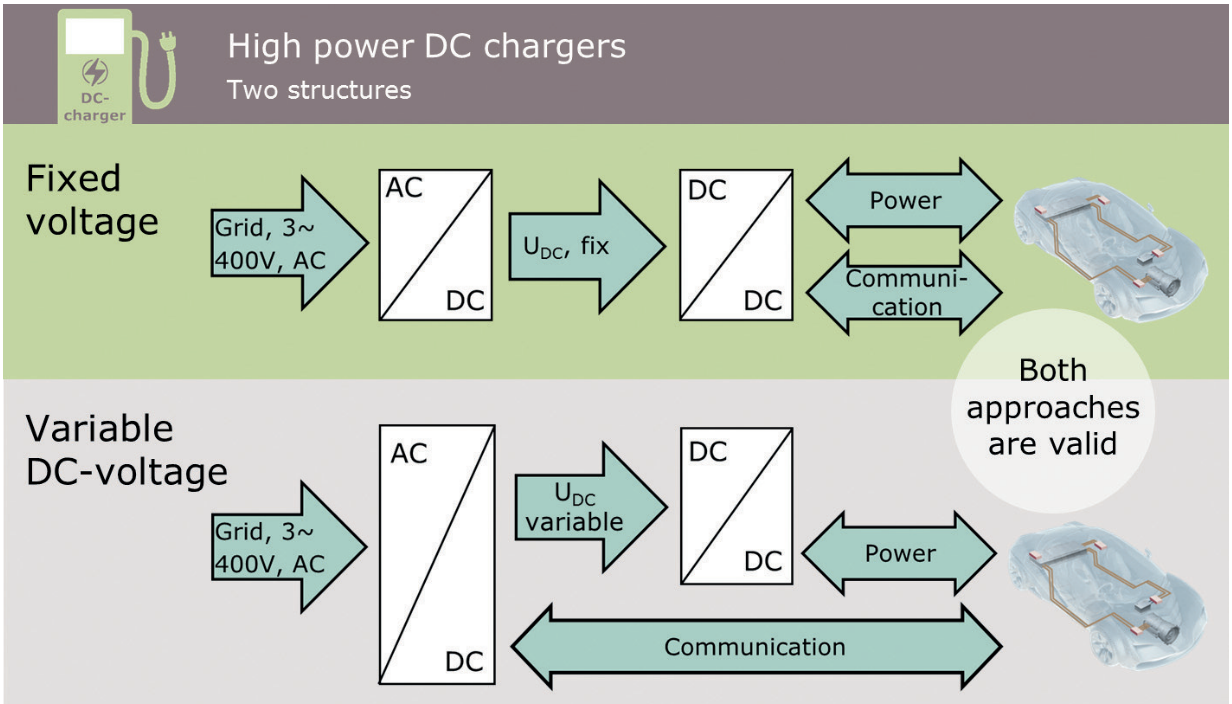


Figure 1: **Block diagrams for two potential high-power DC charger approaches**

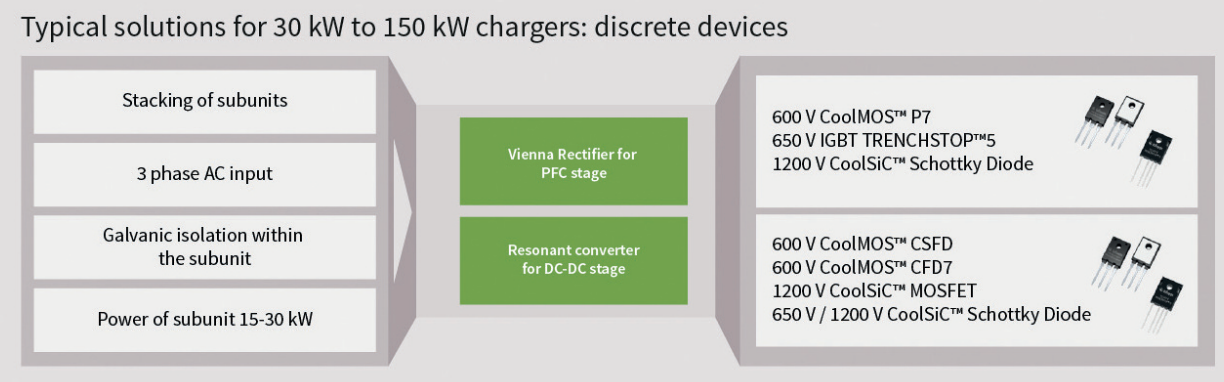


Figure 2: Typical topology for a charger made of discrete devices

while Tesla has its own proprietary system.

The CharIN specifications define support for both AC and DC charging via their plug and socket implementation. They also envisage a maximum constant current output of 500 A at 700 VDC, with support up to 920 VDC. System efficiency is also set at 95 %, although this will rise to 98 % in the future. It should be noted that a 1 % loss in efficiency for a 150 kW charger is equivalent to 1.5 kW. Thus, reducing losses to an absolute minimum is a priority in fast DC charger designs.

Fast DC charger architectures

High-power DC charger design typically follows one of two basic approaches. The first converts a 3-phase AC supply into a variable DC output that feeds a DC/DC converter. The exact DC voltage is defined after communication with the vehicle being charged. The alternative approach is to convert the incoming AC to a fixed DC voltage, whereupon a DC/DC converter adjusts the output voltage to match the needs of the vehicle's battery (Figure 1). With neither approach considered to have a clear advantage or disadvantage in comparison with the other, it is system challenges that determine the optimal approach. Such high-power solutions will not use a monolithic approach; instead the desired power output will be achieved by combining multiple charging subunits, each contributing somewhere between 15 and 60 kW. Thus, the key design goals are the minimization of cooling effort, delivery of high-power density, and the reduction of overall system size.

Design efficiency starts at the front end with the AC/DC conversion stage. The implementation of this power factor correction stage is usually implemented by Vienna rectifier topology. The possibility of using 600 V active devices helps it to achieve the right balance of cost and performance. With the availability of high-voltage SiC devices, a normal two- level PWM type AC/DC conversion stage is also becoming popular in the power range of 50 kW or higher. With both the approaches, a controlled output voltage, sinusoidal input current can be achieved with a power factor above 0.95, a THD of below 5 %, and efficiencies of 97 % or better. With applications where grid-side isolation by a medium-voltage transformer is a possibility, multi-pulse rectifier topologies with a diode or thyristor at the front end are becoming popular due to their simplicity and reliability along with higher efficiency.

In the DC/DC conversion stage, resonant topologies are often preferred due to their efficiency and galvanic isolation. This design fulfils demand for higher power density and smaller volume and the zero-voltage switching (ZVS) reduces switching losses and contributes to overall higher system efficiency. The phase-shifted full-bridge topology with the SiC devices also constitutes an alternative solution in the isolated categories. For grid-isolated architectures, multi-interleaved buck converters are the DC/DC topology of choice. This has the advantage of load sharing across phases, reduced ripple and filter size, but at the cost of a larger number of components.

In the 15 to 30 kW power range, subunits are most optimally implemented using discrete components (Figure 2). Implementing the Vienna rectifier using TRENCHSTOP™ 5 IGBTs together with CoolSiC™ Schottky diodes is a good combination for more cost-sensitive applications. Slight efficiency improvements are gained by replacing the IGBTs with CoolMOS™ P7 SJ MOSFETs. For the DC/DC converter, a resonant converter using CoolMOS CFD7 MOSFETs achieves a respectable efficiency, while selection of MOSFETs from the CoolSiC portfolio is recommended when targeting highest efficiency.

When developing subunits that can be combined or upgraded to provide fast DC charging, or chargers at the top end of the spectrum, a solution based upon power modules is recommended. At this power level, liquid cooling is preferred, although air-cooling remains a possibility. The Vienna rectifier is implemented using CoolSiC Easy 2B modules with a switching frequency of 40 kHz. The DC/DC section leverages an interleaved 3-phase or multi-phase buck converter, switching at up to a few hundred kHz. Here a combination of CoolSiC Easy 1B modules combined with discrete CoolSiC diodes make for a highly efficient combination.

The CoolSiC family offers the F3L15MR12WM1_B69, a Vienna rectifier topology device in its Easy 2B package. With a $R_{DS(ON)}$ of 15 mΩ, the devices provide high power density in a package that simplifies design implementation. The isolation gel-filled ceramic devices have a low capacitance, and their switching losses are independent of temperature. Half-bridge topologies are available in both the Easy 2B and smaller Easy 1B packages, featuring $R_{DS(ON)}$ values as low as 6 mΩ (Figure 3).

Control, communication and security

Control of the power stages is typically implemented using a microcontroller. Devices such as the XMC4000 series provide flexible analogue-to-digital converters (ADC) along with highly configurable timers and pulse-width-modulation (PWM) peripherals to implement the control loop. CAN

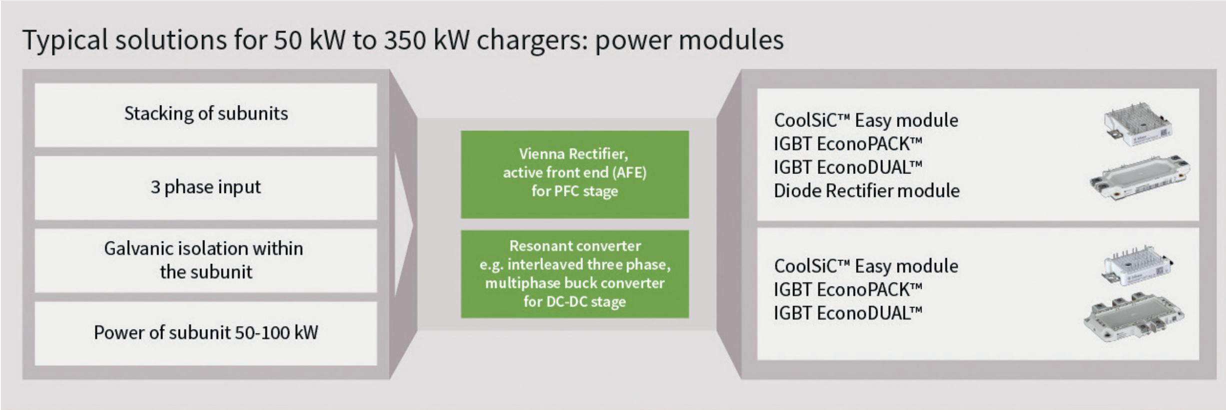


Figure 3: Typical solutions for a charger made of module devices

connectivity ensures that subunits can communicate with one another and respond to the varying needs of different battery types. Service billing and authentication of software updates or hardware changes can be handled by the Hardware Security Module (HSM) of the AURIX™ family of microcontrollers, a family that is well-known for safety-relevant applications in the automotive space.

The authentication of replacement subunits can be ensured using devices such as the OPTIGA™ Trust B anti-counterfeit security chip, while more demanding integrity protection is offered by the OPTIGA TPM trusted platform module.

Summary

The roll-out of fast DC charging infrastructure is an essential part of the strategy to increase the numbers of BEVs. Without the availability of reasonable charging opportunities offering an acceptable charging time, BEVs will inevitably remain restricted to those with a disposition toward green transport solutions and consumers with limited-distance daily journeys. The preparatory work, in specifying the chargers and connectors, has been done. In addition, the necessary offerings of innovate semiconductor solutions are available. These range from traditional Silicon power devices to Silicon carbide solutions that offer higher-frequency switching and more efficient power conversion, ensuring that chargers are efficient and reliable. When coupled with microcontroller devices, and clever authentication and security solutions, it is clear that multi-subunit approaches to delivering the DC charging infrastructure are ready to power the future of transport.

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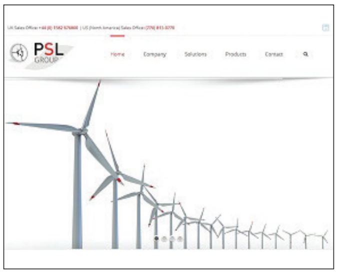

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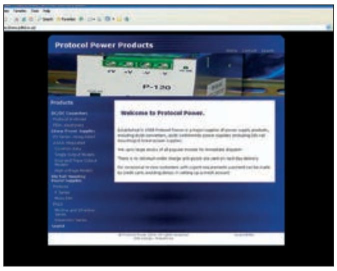

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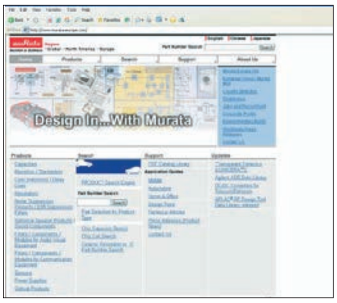

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