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POWER GaN

GaN Matures for Industry with Monolithic Power ICs

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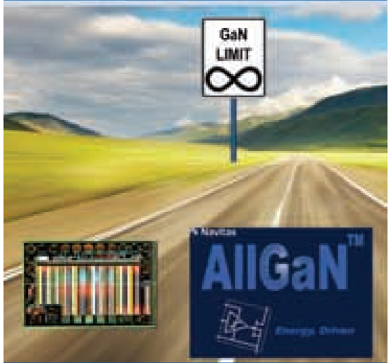
COVER STORY



GaN Matures for Industry with Monolithic Power ICs

Power GaN has come of age with high performance, high frequency and high reliability. It has taken over 15 years for the material to mature from university curiosity to industry-qualified product, from the early days of dMode (normally-on, depletion) to eMode (normally-off, enhancement) devices. Now, manufacturing issues have been resolved and lateral 'GaN-on-Si' devices have been qualified on 6" wafers using conventional, low cost Si fabrication equipment. Now, the introduction of GaN Power ICs – with monolithically-integrated gate drive, logic and FET in low-cost, high volume packaging – enables power systems to run at multi-MHz switching frequencies simply, predictably and with high device and system reliability. Superjunction Silicon (SJ Si) is no longer the best solution for off-line power supplies. Power Gallium Nitride (GaN) manufacturing processes are mature and devices are operating with higher frequencies, higher efficiencies, higher power densities and lower system costs. More details on page 26.

Cover material supplied by Navitas Semiconductor, El Segundo/USA

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IGBT-Modules for 3-Level Configurations

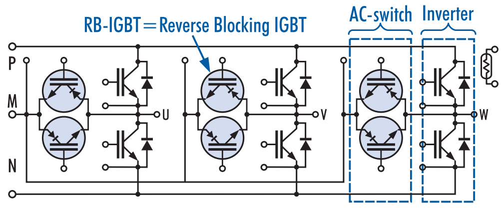
3 Phase

T-Type

With solder pins

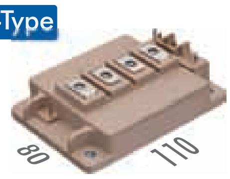
With PressFit contacts

Ic	Inverter	AC-switch
50A	1200V	600V
75A		
100A		

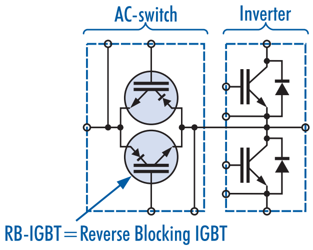


1 Phase

T-Type

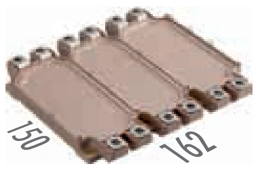


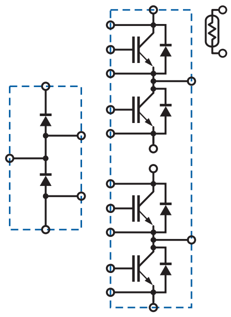
Ic	AC-switch	Inverter
220A	1700V	1200V
300A	1200V	600V
	1200V	900V
340A	1200V	600V
400A	600V	600V
	1200V	600V



1 Phase

I-Type





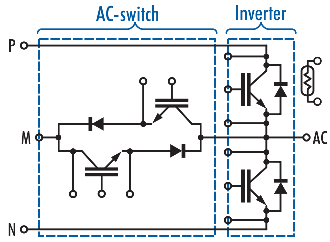
Ic	1200V
600A	●

1 Phase

T-Type

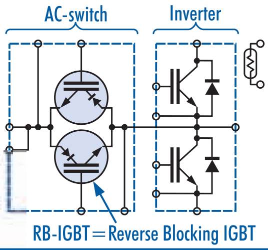
With PressFit contacts

Ic	Inverter	AC-switch
300A	1200V	600V
400A	1200V	600V



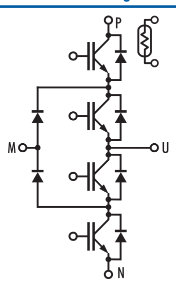
1 Phase

T-Type



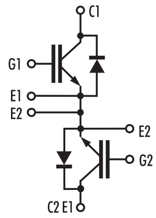
Ic	Inverter	AC-switch
450A	1200V	900V
650A		
900A		
450A	1700V	1200V
600A		

I-Type



Ic	1200V
600A	●

AC-switch



Ic	1200V
450A	●

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Game Changer in Times of Change

Wide-bandgap semiconductors like Gallium Nitride (GaN) and Silicon Carbide (SiC) are still a hot topic. These compound semiconductor devices promise improvements in power-converter speed, size and efficiency. This has been demonstrated not only by product specifications but also in end product designs such as the winning inverter of the Google Little Box Challenge which has been on display at the GaN System's booth. The Belgium Red Devils won the $1 million price by using 650-V e-mode GaN power transistors resulting in a power density of 143 W/in? in 14 in? volume, outperforming the Little Box Challenge power density goal by nearly a factor of 3, which is according to Google, ten times more compact than commercially available inverters. The volume of the competing ETH Zurich/Fraunhofer IZM inverter is 14.22 in? resulting in a power density of 140.60 W/in? – also operating with 650 V GaN GITs. And, more important for the power electronics industry, the leading power semiconductor manufacturer Infineon Technologies will focus his power GaN activities on the e-mode Panasonic GIT technology, as a representative at the CIPS conference in March according to a PEE question confirmed and which has been obvious at APEC. This turn obviously marks an industry change to support e-mode or normally-off devices in the future.

The Applied Power Electronics Conference (APEC) is somewhat like a big family reunion. It not only draws many of the same people from industry, academia and government, but it is one of the largest power-electronics conferences in the world (with a record breaking 5,000+ attendees this year). According to EPC's CEO Alex Lidow Moore's law in the digital arena has now been broken, but in power electronics we are just in the beginning with the role of GaN. GaN is the logical technological successor to Silicon for power conversion and analog devices, and possibly also for digital components as well. We are away by the factor of 800 of the theoretical GaN limits, this technology is able to be integrated up to the level of NMOS. Regarding cost – Lidow claims that EPC has beaten already Silicon because EPI (which was more expensive in the past) now comes to equal. And Texas Instruments announced that they have leveraged existing manufacturing infrastructure and capabilities to qualify a 600-V e-mode GaN process.

GaN is ready for the market and Navitas Semiconductor are integrating things which have not been integrated before, stated CTO Dan Kinzer in his APEC keynote. The company has designed a fully integrated GaN IC with integrated gate drive in QFN package. This e-mode device features 20 times lower drive loss than Silicon, the driver impedance is matched to the power stage. Also almost zero inductance leads to low switching losses – and the 650-V process allows switching frequencies of up to 27 and 40 MHz! The switch is not the limit, it is the magnetics. This AllGaN marks the industry's first platform which allows monolithic integration of 650V GaN IC circuits (drive, logic) with GaN FETs. The result is a device which liberates the performance of e-mode GaN using a simple digital signal, with the previously vulnerable gate now safely protected.. This GaN Power IC can contain features such as hysteretic input, voltage regulation and ESD protection – all in the lateral GaN material. This monolithic integration of drive and switch is impossible using vertical GaN, d-mode GaN or SiC. Lateral GaN-on-Si construction means there are no concerns with dislocations, and means immediate high volume capability using existing foundry processes. For power system designers, GaN Power ICs represent breakthrough - yet mature - technology, which brings new benchmarks in switching speed, efficiency and power density to a broad array of applications at a wide range of power levels. Unlike other, earlier wide bandgap proposals, GaN Power ICs also represent a simple, fast, scalable and dependable building-block approach to system design, to minimize risk / respins and maximize chance of success – so the conclusion of our cover story. At APEC visitors can gain informations on new technologies at first hand before they possibly swap over to Europe – even in times of the Internet. Thus this subject is also highlighted in one of the PCIM Europe's keynotes in May, and SiC as well as GaN will play a major role within the conference and on the exhibition floor.

Researchers at HRL (Hughes Research Laboratories) have achieved the first demonstration of GaN CMOS FET technology, and in doing so have established that the semiconductor's superior transistor performance can be harnessed in an IC. GaN transistors have excelled in both power switching and microwave/millimeter wave applications, but their potential for integrated power conversion has been unrealized. Unless the fast-switching GaN power transistor is intentionally slowed down in power circuits, chip-to-chip parasitic inductance causes voltage instabilities, HRL' s researchers noted. They have overcome that limitation by developing a GaN CMOS technology that integrates e-mode GaN NMOS and PMOS on the same chip. Integration of power switches and their driving circuitry on the same chip is the ultimate approach to minimizing the parasitic inductance, and in the long term GaN CMOS has the potential to replace Silicon CMOS in a wide range of products – according to HRL. Their high-voltage e-mode GaN process is also the foundation of Navitas' Gan IC.

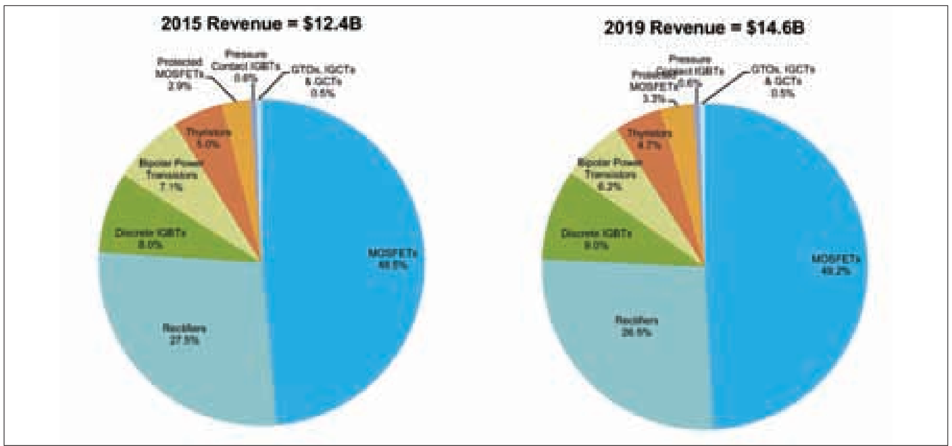
Gallium Nitride is since 2010 a buzz word within the power electronics industry, though its market penetration today is invisible. But this situation might change since more of the bigger players are hopping on the GaN train – along with new research results and industrial start-ups. For me as journalist this is an exciting time being involved in a possible market change, such as the change from pure bipolars to the insulated gate bipolar transistor (IGBT).

Enjoy the following pages!

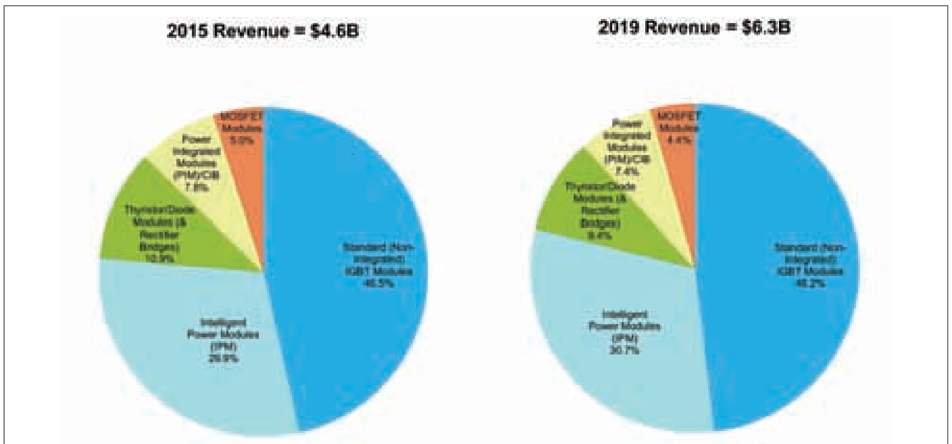
Achim Scharf
PEE Editor

Global Semiconductor Markets Downs And Ups

Global semiconductor revenues fell by 2 percent in 2015. Sequential quarterly growth was weak throughout every quarter of 2015, especially in the first quarter when the market declined 8.9 percent over the previous quarter - the deepest sequential quarterly decline since the semiconductor market collapsed in the fourth quarter of 2008 and first quarter of 2009. Global revenue in 2015 totaled $347.3 billion, down from $354.3 billion in 2014, according to market researcher IHS. The market drop follows solid growth of 8.3 percent in 2014 and 6.4 percent in 2013. "Weak results last year signal the beginning of what is expected to be a three-year period of declining to stagnant growth for semiconductor revenues," said Dale Ford, chief analyst at IHS Technology. "Anemic end-market demand in the major segments of wireless communications, data processing and consumer electronics will hobble semiconductor growth during this time."



Power discrete revenues by device type 2015 – 2019



Power module revenues by device type 2015 – 2019

Rank	2006	2015
1	STMicroelectronics	Infineon Technologies
2	Fairchild Semiconductor	Mitsubishi
3	International Rectifier	Toshiba
4	Toshiba	Fairchild Semiconductor
5	Infineon Technologies	STMicroelectronics
6	Mitsubishi	Vishay Intertechnology
7	Vishay Intertechnology	Fuji Electric
8	Fuji Electric	ON Semiconductor
9	ON Semiconductor	Renesas Electronics Corporation
10	Sanken Electric Company	ROHM Semiconductor

Ranking of top 10 power discrete and module suppliers 206 to 2015 (Source 3: IHS March 2016)

Overall semiconductor revenue growth will limp along at roughly 2.1 percent growth compound annual growth rate (CAGR) between 2015 and 2020. Current technology, economic, market and product trends suggest that sometime between 2020 and 2022 new products will come to market that will enable a significant level of growth in semiconductor revenues.

"Of course the big story for the semiconductor industry was the record level of merger-and-acquisition activity last year," Ford said. "Top players pursued bold, strategic maneuvers to enhance their market position and improve overall revenue growth and profitability", Ford stated. Intel retained its number one ranking in 2015, after completing its acquisition of Altera, which allowed the company to offset declining processor revenues and achieve 2.9 percent overall growth in 2015. Qualcomm slipped to number 4 in the rankings as its revenues fell by 14.5 percent, because the company's 2015 acquisition of CSR was not enough to counter declining revenues in the wireless markets. The final major deal among the top 10 in 2015 was NXP's acquisition of Freescale, which boosted it from number 15 in the 2014 rankings to number 7 in 2015. Among the top 20, Infineon's acquisition of International Rectifier enabled it to jump to number 12 in 2015. Announced deals that are expected to close in the first half of 2016 will continue to reshape the leader board. Avago Technologies continues its aggressive acquisition activity with its purchase of Broadcom. Broadcom is already ranked at number 9 in 2015. The combined revenues of the two companies would place them at number 5 overall. ON Semiconductor's acquisition of Fairchild Semiconductor should boost it up two notches in the rankings.

Only ten semiconductor market sub-segments worth more than $1 billion in annual revenue grew more than 5 percent year over year in 2015. Wireless communications logic application-specific integrated circuits (ASICs) and analog ASICs both grew 30 percent, while radio-frequency (RF) small signal transistors, wired communications logic ASICs and wireless communications application-specific standard products (ASSPs) grew between 10 percent and 20 percent.

But power discretes will see healthy growth of $12.4 billion in 2015 up to $14.6 billion in 2019, with MOSFETs keeping the highest market share of nearly 50 percent and IGBTs around 8.5 percent. The market for discrete power modules is predicted to grow in this time frame from $4.6 billion up to $6.3 billion with standard IGBT modules covering nearly 50 percent, IPMs 30 percent, and MOSFET modules arounf 5 percent.

www.ihs.com

China is Investing Heavily in Power Semiconductor Production

The Chinese power electronics market used to be dominated by foreign players. That situation is rapidly changing. Local players with different business models are emerging in different sectors, challenging the established ones, not only in China but also internationally.

"Local players are presented all along the supply chain," commented Hong Lin, Technology & Market Analyst at Yole Développement (**www.yole.fr**)."However it is often in the inverter market the competition comes the fiercest." But the Chinese government and private companies are investing in power semiconductors, aiming to catch up with more developed countries. Local players in China are making progress at the end application and inverter levels. Some of them are capable of competing with established players in the international market. However, when moving down to the power semiconductor level, the technology gap between Chinese players and established players grows. For example, China still imports more than 95 % of the IGBTs it uses.

In this context, China is investing to catch up with developed countries. Several recent news items, such as the opening of CSR Times Electric's 8-inch IGBT wafer and module production base and the 6500 V/200 A IGBT module co-developed by Yongji and ASMC, show China's progress in power semiconductors. ASMC i. e.. is a dedicated analog foundry focusing primarily on the manufacturing of analog semiconductors and higher bipolar content-based mixed-signal semiconductors with the key focuses on Automotive Electronics, MEMS and IGBT. Besides investing in Silicon-based semiconductors, the Chinese government also gave significant funding to WBG semiconductor development and industrialization. The number of companies involved in the WBG area has grown continually since 2006. Chinese companies cover the entire value chain from WBG material to applications, both for GaN and SiC. As in other countries, different factors contribute to market dynamics and influence the market adoption of WBG power devices. "Therefore the Chinese WBG industry is targeting to have a strong position for next generation devices. The Chinese power electronics market is going through a rapidly changing period. In this unsettled market, all companies – both foreign and local – need to find their own position", Lin stated.

Clever Ideas Succeed in the Market

At APEC PEE discussed market challenges with Balu Balakrishnan, President and CEO of Power Integrations (PI), who acquired Swiss IGBT-driver CT-Concept and SiC company Semisouth around two years ago. The first deal turned out to be a success, the second failed. The company now plans to bring its Power IC technology into the IGBT world with the help of its successful acquisition.

While not satisfied with FY 2015 results, I believe we exited the year on an improving trajectory. The outlook we issued in February for the first quarter of 2016 called for two-percent year-over-year growth fueled particularly by new products such as InnoSwitch. While our revenues and earnings fell in 2015 against a challenging economic backdrop, cash flows increased from the prior year, and we returned a substantial amount of cash to investors while also making important investments to support future growth. We also demonstrated the high potential of our new InnoSwitch products, which have garnered a significant share of the "rapid" charger market for smartphones and are now making inroads in other applications. I believe not only that InnoSwitch will be our next flagship product family for the AC/DC power-supply market, but that the technological breakthroughs embodied in these chips will be the foundation of a mega product cycle, spawning products for a

"We will bring our patented FluxLink technology into IGBT driver and thus into high-power applications", PI's CEO Balu Balakrishnan promised at APEC Photo: AS

wider range of power-conversion applications and driving a significant expansion of our addressable market in the years ahead.

InnoSwitch was really driven by further integrating the power supply. Since we were integrating the high-voltage part of the power supply for almost 25 years, it became very clear that there is nothing more to integrate on the primary side. The only components left outside are the energy storage components such as inductors, capacitors and EMI devices, which all can not be integrated. That's why we set up a brainstorming week in the Caribians in order to find solutions for the secondary side isolation and coupling replacing an optocoupler which degrades over time, but more importantly also to save cost. Finally we came to the idea of using the "parasitic" inductance of the bond wires (which can be manufactured repeatable) and leadframe, in particular optimizing its physical layout. Our VP of development made a few calculations and confirmed that this approach of insulating the primary from the secondary side and also transmit signals between them might work, but it took a lot of hard work to make this now called FluxLink work reliably. In other words, to make innovations happen, you have to take risks!

InnoSwitch ICs are now being designed into higher-margin industrial and consumer-appliance applications, and we plan to introduce next-generations (see also our APEC review), which I believe will not only expand the market by addressing higher power applications, but also improve the cost-effectiveness by utilizing a new, higher-density process technology. Fueled largely by the success of InnoSwitch products in rapid-charging applications for smartphones, revenues from the communications market grew more than 20 percent in 2015.

I see this as an important harbinger for two reasons: First, I believe the growth in communications is more than a one-year story. Rapid-charging emerged as a disruptive force in the mobility market, creating a need for high-value integrated solutions in a market where commodity discrete designs had become predominant. InnoSwitch products fulfill the needs of this market, and we are winning a sizeable share, with designs now in production at many top-tier smartphone OEMs. We believe rapid-charging will be a growth driver for years to come as power levels continue to rise, charging speed becomes an important differentiator in mobile devices, and new technologies such as USB-PD and type-C connectors come to market. Second, as successful as we've been in chargers, we believe the technology may prove even more attractive in embedded power supplies, where efficiency specifications tend to be more challenging and where reliability is often the most important consideration due to the high repair and replacement cost of many end products. We now have designs in progress across dozens of applications, including appliances, consumer electronics and industrial applications.

Looking further ahead, we also have in our pipeline products that will bring InnoSwitch technology to other end markets such as lighting and even high-power IGBT-driver applications via our daughter company CT-Concept such as renewable energy systems and industrial motor drives. Whereas our current portfolio of IGBT-driver products is aimed primarily at very high-power applications, these new products will extend our reach to lower power levels, roughly doubling our served available market (SAM) for IGBT drivers and expanding our total SAM to more than $3 billion. We also continue to invest in longer-term R&D projects with the potential to expand our SAM even further, while maintaining focus on our core competency of high-voltage power conversion.

Taking risks some questions arise – why did PI failed with Semisouth? When we stopped our investment we already invested $65 million in a normally-off SiC JFET technology that in the end was not manufacturable on large scale – but our investors were not upset that we had taken this risk! The final reason for stopping our investment was – the founder left the company! Would you take a second chance for a risk i. e. with GaN? We will go after any technology that can give us an advantage in terms of a full solution, but we don't sell a technology. Our customers are not s much interested what is inside the chips, they are surprisingly pragmatic! What is the role of CT-Concept within PI's portfolio? This company is a perfect fit. With the integrated switch we can go up to 1 kW, above that most of the end applications use IGBTs. We as a small company are not in the position to develop IGBT technology, here you have the established manufacturers. For newer technologies such as SiC the situation is different – that's why we had taken this risk. But with our existing technology we can drive this high-power IGBT modules, we can combine CT's know-how and our inventions to bridge the gap in power levels and bring FluxLink technology into IGBT drivers – bridging the gap between 1 kW and 50 kW onwards! **AS**

www.power.com

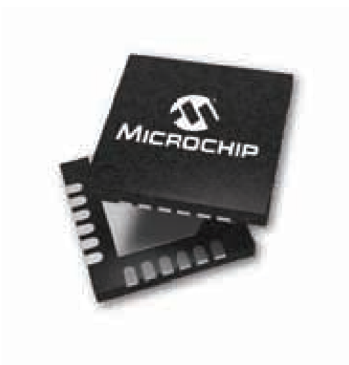
Wolfspeed Powers Gruppo PBM Battery Chargers

Wolfspeed (**www.wolfspeed.com**), a Cree company, announced that Gruppo PBM (**www.gruppopbm.it**) active in industrial battery chargers, is using Wolfspeed™ SiC MOSFETs in its new HF9 battery charger family to enable higher efficiency and power density at a lower overall system cost.

The HF9 product family is designed to provide the highest possible efficiency while achieving easy scalability for power ranging from 6 to 16 kilowatts. These benefits are made possible in part by Wolfspeed 1200V SiC MOSFET technology. "We selected Wolfspeed SiC Planar MOSFETs because they enabled us to improve our battery chargers while achieving operational savings, increased productivity and increased safety. This was not possible with the best IGBTs in the market," said both Marco Mazzanti and Giancarlo Ceo, who respectively serve as CTO and R&D engineer at Gruppo PBM. Based in Italy, Gruppo PBM specializes in rugged high-frequency battery chargers, dischargers, and testers. By using Wolfspeed SiC MOSFETs in its latest HF9 family, Gruppo PBM not only achieves improved efficiency, but also a reduction in component count, improving the overall reliability in the system by lowering the operating temperatures and most importantly reducing overall system cost. Wolfspeed SiC MOSFETs are commercially available in 900V, 1200V, and 1700V versions in TO-247 and SMD package options. The newly released surface-mount package, specifically designed for high-voltage MOSFETs, has a small footprint with a wide creepage distance of 7 mm between its drain and source. The new package also includes a separate driver-source connection, which reduces gate ringing and provides clean gate signals.

Advanced and Broad Power Management Portfolio

Microchip Technology has an expansive offering of power management solutions to fit virtually every type of design criteria. From the smallest form factor needed for mobile devices to complex industrial power management designs to automotive standards, you are sure to find a highly integrated solution to meet your needs. If you are looking for greater flexibility in your design, Microchip's digitally enhanced power analog devices integrate a microcontroller (MCU) or digital signal controller (DSC) for a fully programmable and flexible solution.



Applications:

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- Charge pump DC/DC converters
- Power MOSFET drivers
- Digitally enhanced and PWM controllers
- System supervisors
- Voltage detectors
- Voltage references
- Li-Ion/Li-Polymer battery chargers
- Power MOSFETs

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Ultra-compact 97 Percent Efficient EV Charger with GaN Transistors

German automotive electronics specialist HELLA (**www.hella.com**), in collaboration with GaN Systems (**www.gansystems.com**), and charging technology researchers at Kettering University's Advanced Power Electronics Lab (**https://my.kettering.edu/**), have developed a Level-2 electric vehicle (EV) charger prototype with efficiencies exceeding 97 % at an 2.6 kW/l power density.

Prior to this achievement, Level-2 EV chargers reached maximum efficiencies of 94 %. Using GaN Systems' 60 A, 650 V GS66516T switches in a two-stage architecture, the Kettering University research team, led by Associate Professor Kevin Bai, were able to increase the wall-to-battery efficiency to more than 3 % greater than previously obtained. "This is a significant milestone with important implications for charging electric vehicles, among other charging applications." Dr. Bai characterized this development as a 'game changer' for the EV charging industry. "The results of this collaboration are commercially important, because they provide us with a path to ultra-compact and lighter EV charger designs. This development also has a positive environmental impact, as it represents another step toward the global effort to reduce power consumption", added HELLA's Manager of Advanced Engineering, Matt McAmmond.

New Battery Concepts for Electric Vehicles

Development of a new Li-ion battery generation for the direct embedding into the chassis of electric vehicles – joint project "EMBATT" of Thyssenkrupp System Engineering GmbH, IAV GmbH and Fraunhofer IKTS starts.

Driving enjoyment and electric drive – two terms that are no longer contradictory. Today, hardly any automobile manufacturer goes without an "e-car" in its range of models. However, further full-scale research in the advancement of energy storage materials and concepts as well as the

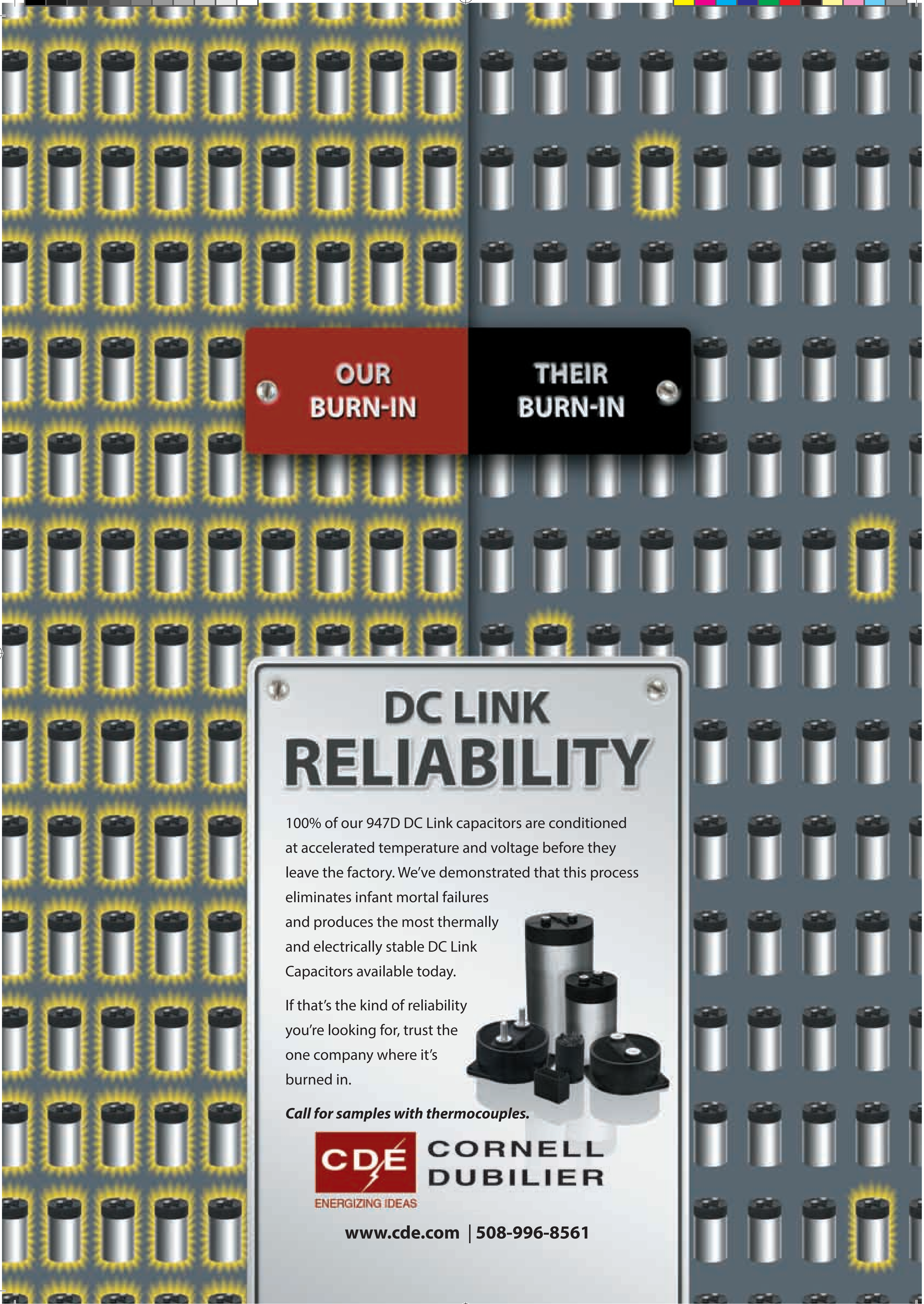
constant improvement of corresponding production technologies has to be conducted until electric vehicles become established in everyday life. On that point, Bernd Becker, chairman of the management board of Thyssenkrupp System Engineering (www.thyssenkrupp-system-engineering.com/) , says: "Production research contributes crucially to transferring intelligent battery concepts from the idea to the industrialization". Furthermore, optimal cost, performance and lifespan shall be achieved by means of intelligent system architectures and future-oriented lightweight housings.

The three project partners Thyssenkrupp System Engineering. IAV GmbH (www.iav.com), and Fraunhofer IKTS (www.ikts.fraunhofer.de) take this a vital step further. With EMBATT, they

develop the concept and specially tailored production technologies for lithium-based high-performance batteries set-up in a planar manner, which are directly integrated into the chassis of the vehicle. "Thereby, significantly more compact energy storage solutions with energy densities

of 450 Wh/l and therefore ranges of up to 1000 km are realizable", explains Wolfgang Reimann, division director "E-Traktion" of the IAV GmbH. IAV as one of the leading engineering partners of the automotive industry contributes its development expertise to the EMBATT project, from vehicle

conception, vehicle safety, battery design and construction to the application of the control unit software. Fraunhofer IKTS conducts research on the development of customized materials and specific methods for electrode manufacturing. Thyssenkrupp has expertise in manufacturing production plants and production equipment for vehicle construction and battery manufacturing. "Due to the promising connection of materials and technology know-how of the cooperation partners, system costs of Li-ion batteries are expected to be reduced to 200 €/kWh", says Dr. Mareike Wolter, group manager "Mobile Energy Storage Systems" at Fraunhofer IKTS.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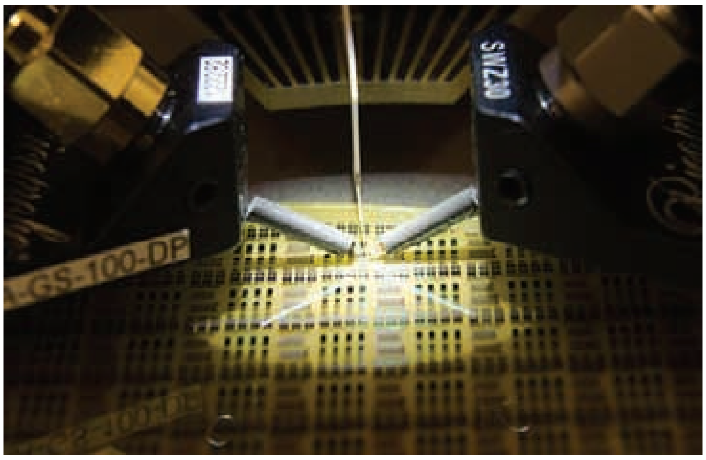
Breakthrough for GaN Power ICs

Researchers at HRL Laboratories (**www.hrl.com**), LLC, have achieved the first demonstration of gallium nitride (GaN) complementary metal-oxide-semiconductor (CMOS) FET technology, and in doing so have established that the semiconductor's superior transistor performance can be harnessed in an integrated circuit. This breakthrough paves the way for GaN to become the technology of choice for power conversion circuits that are made in Silicon today.

According to HRL Senior Staff Research Engineer and Principal Investigator Dr. Rongming Chu, GaN transistors have long excelled in both power switching and microwave/millimeter wave applications, but their potential for integrated power conversion has been unrealized. "Unless the fast-switching GaN power transistor is intentionally slowed down in power circuits, chip-to-chip parasitic



HRL GaN CMOS wafer based on sapphire

inductance causes voltage instabilities," he said. Chu and his colleagues in HRL's Microelectronics Laboratory have overcome that limitation, developing a GaN CMOS technology that integrates enhancement-mode GaN NMOS and PMOS on the same wafer. "Integration of power switches and their driving circuitry on the same chip is the ultimate approach to minimizing the parasitic inductance," Chu said.

Today, GaN transistors are being designed into radar systems, cellular base stations, and power converters like those found in computer notebook power adaptors. "In the near term, GaN CMOS IC applications could include power integrated circuits that manage electricity more efficiently while having a significantly smaller form factor and lower cost, and integrated circuits that can operate in harsh environments," he said. "In the long term, GaN CMOS has the potential to replace Silicon CMOS in a wide range of products. GaN CMOS IC was considered difficult or impossible, due to the challenge in making P-channel transistor and integrating an N-channel transistor. Our recent work opened up the possibility of making GaN CMOS IC's."

HRL's CMOS processing utilized metal-organic chemical vapor deposition (MOCVD) of the NMOS layers (GaN buffer, GaN and AlGaN) on sapphire substrate, sealed by a Silicon nitride (SiN) layer. PMOS were etched down to the GaN buffer and MOCVD re-growth. Details on HRL's GaN CMOS technology can be found under **http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7373586.**

High-voltage GaN at first

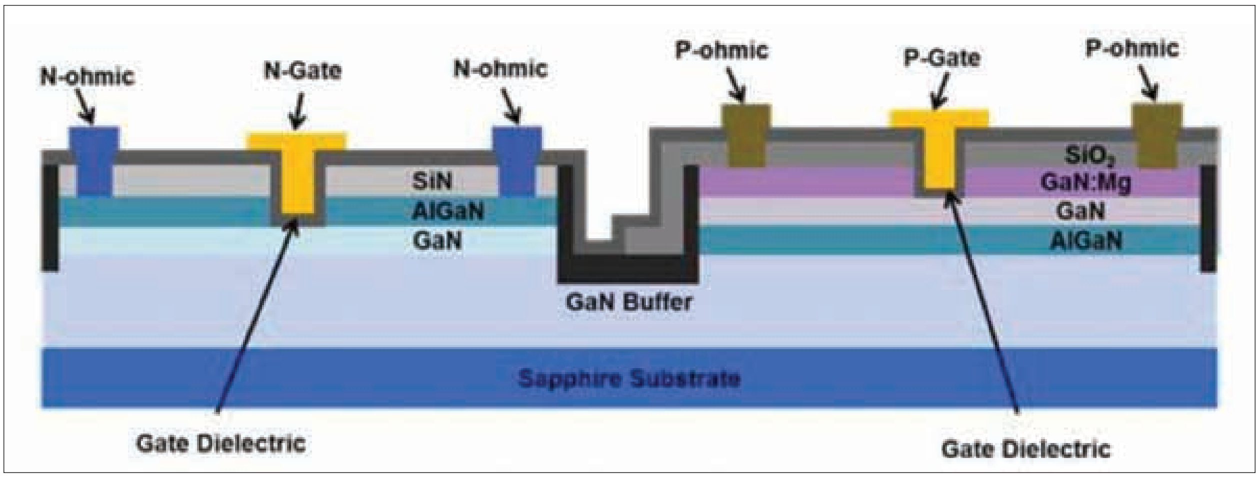
Power GaN is predicted to efficiently switch 100 x voltage of Si at the same frequency because the switching figure-of-merit $V_{sw}/(R_{on} \times C_{DS})$ is proportional to $\mu\epsilon^2$, where V_{sw} is switching voltage, R_{on} is on-resistance, C_{DS} is the effective output capacitance, μ is mobility and ϵ the breakdown field. Si power ICs are reported to switch 5V at 100 MHz by employing Si-on-insulator, SOI, lateral MOSFETs. Multi-phase point-of- load, POL, and VRM address a large consumer market. By employing a similar strategy, GaN power ICs have the potential for 100 MHz multi-phase 400 V PFC for power supplies and other applications. Increasing the switching frequency to 100 MHz has the potential to shrink converter weight by more than 10 times and to half the cost, and thus driving the adoption of GaN power ICs.

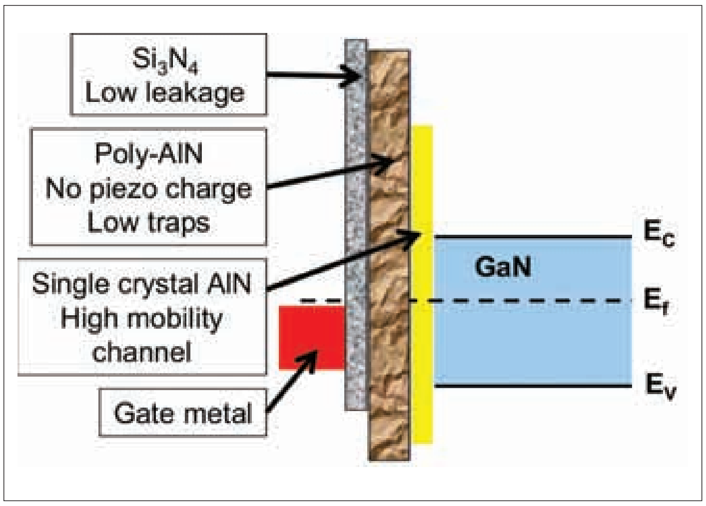
The breakdown field of GaN is about 10 x Si. GaN power ICs with lateral HFETs of same gate-drain spacing as lateral Si MOSFETs will have 10 x the breakdown voltage of Si. The small gate-drain spacing and high mobility of GaN result in ultra-low intrinsic R_{on} and output charge or effective, C_{DS}. GaN's lower $R_{on} \times C_{DS}$ can enable efficient hard and soft switching to high frequency. N+ Si substrates have biasing effects which increase R_{ov}, and therefore a not suitable for GaN power ICs. The GaN switches need short gate length to reduce channel resistance, low gate leakage for reliability, and e-mode for safe operation. D-mode GaN HFETs employ vertical ~ 30V Si MOSFETs in cascode for effective normally-off switches, but this approach is not suitable for GaN ICs.

Resistive-p-type gates have been employed in 200V and 650V e-mode GaN HFETs. HRL's approach for an e-mode is a native insulator, similar to Si02 on Si. The AlN-based gate has low IV hysteresis and gate leakage current of 2 nA/mm at 600 V.

A monolithic GaN power IC 400 V / 200 W ZVS converter is projected to be able to switch at 100MHz, with 50 x lower parasitic inductances by shrinking length of power loop 2.5 x and reducing distance between inductance

RIGHT: HRL's GaN-CMOS structure





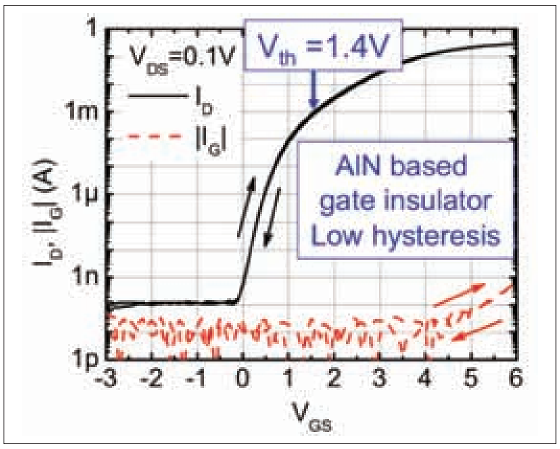
HRL's e-mode GaN HFET insulating gate structure illustrating key features

canceling currents by 50 x. The GaN-on-insulator power IC will be directly attached to heat sink to reduce thermal resistance and costs. The GaN-on-insulator power IC will have lower parasitic CDS and no substrate biasing. Interleaving converters will reduce current ripple and allow scaling to higher power. The 100 MHz GaN power IC converter should weigh 10 times less and consequently cost less than today's 100 kHz converters.

By the way, Navitas Semiconductor's (**www.navitassemi.com**) technology is based on HRL's high-volatage GaN-on-Si process, as CEO Gene Sheridan at APEC in an interview with PEE said. The fab-less company employs now 20 engineers and will introduce first integrated GaN half-bridges by mid 2016.

GaN at Imec

Imec's (**www.imec.be**) GaN-on-Si R&D program aims at bringing this technology towards industrialization. The Belgium-based research lab features a complete 200 mm CMOS-compatible 200 V GaN process line for e-mode devices. The program allows partners early access to next-generation devices and power electronics processes, equipment and technologies, and speed up innovation at shared costs. Current R&D focuses on improving the performance and reliability of e-mode devices, while in parallel pushing the boundaries of the technology through innovation in substrate technology, higher levels of integration and exploration of novel device architectures. "We are now working with our GaN partners to implement and transfer specific device customizations. in parallel, we are exploring alternative substrate technologies to further push the boundaries of the GaN technology", stated Rudi Cartuyvels, executive vice president of smart systems and energy technology.



Low hysteresis transfer IV for AlN-base gate dielectric

Automotive Grade Boost Controllers

While the 12-V lead acid battery is still the dominant power source in automobiles, there are new automotive applications that require higher voltages such as trunk audio power amplifiers and in-glass window defrosters. To address these high voltage applications, a new generation of AEC-Q100-qualified synchronous boost controllers has emerged. The controllers are designed to boost the 12-V battery, withstand voltage spikes as high as 60 V and deliver the robust reliability required in new car models.

Intersil now offers highly integrated boost controllers to simplify the design of high power automotive applications. Operating from a 12 V battery supply, these devices boost the output voltage to 24 V, 36 V or 48 V for premium 200 W to 800 W trunk audio amplifiers, start-stop systems, and headlamp LED strings. The controllers also address the demands of industrial and telecom applications where a step-up DC/DC converter must deliver high power in a small solution size.

The ISL78227 and ISL78229 enable a modular design for systems requiring power and thermal scalability. They support wide input and output ranges of 5V to 55 V and deliver greater than 95% efficiency. The ability to interleave two controllers for a four-phase application effectively doubles the output power and reduces input/output ripple, allowing power supply designers to use smaller capacitors.

The devices also offer an envelope-tracking feature that dynamically adjusts or scales the output voltage on the fly to meet all system load demands. For example, whenever the battery supply is low, power consumption of various components such as the audio amplifier must be limited, especially if the radio is on while the engine is off. Transient events such as the start-stop system restarting the engine also require on-the-fly voltage adjustments. And to simplify the task of attaining the ISO 26262 automotive safety integrity level (ASIL) rating, the ISL78229 offers a digital PMBus™ interface for advanced control, telemetry and diagnostics. Having the PMBus interface on-chip eliminates the need for dedicated telemetry circuitry required to configure fault types, system recovery and monitoring.

Operating principle

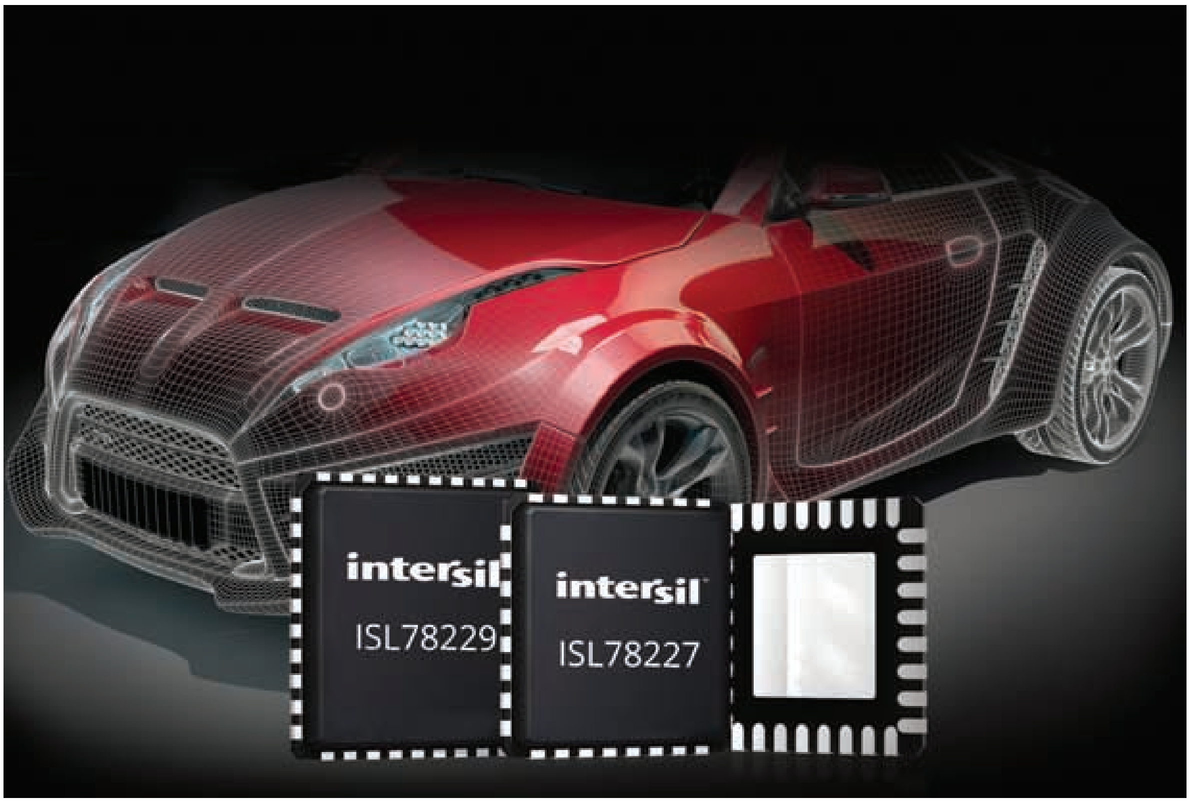
The ISL78229 as an example is a 2-phase synchronous boost controller with integrated drivers. It supports wide input and output ranges of 5 V to 55 V during normal operation and the VIN pin withstands transients up to 60 V.

The converter contains 2 A sourcing/3 A sinking strong drivers to support high efficiency and high current synchronous boost applications. The drivers have a unique feature of adaptive dead time control of which the dead time can be programmed for different external MOSFETs, achieving both optimized efficiency and reliable MOSFET driving. Selectable diode emulation and phase dropping functions support enhanced light-load efficiency.

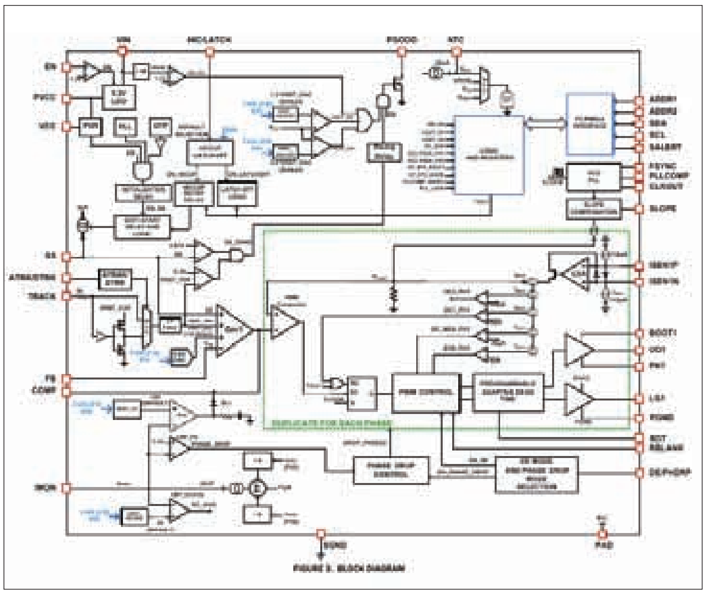
The PWM modulation method is a constant frequency Peak Current Mode Control (PCMC), which has benefits of input voltage feed-forward, a simpler loop to compensate compared to voltage mode control and inherent current sharing capability. A track function offers unique features of accepting either digital or analog signals for the user to adjust reference voltage externally. The digital signal track function greatly reduces the complexity of the interface circuits between the central control unit and the boost regulator. Equipped with cycle-by-cycle positive and negative current limiting, the track function can be reliably facilitated to achieve an envelope tracking feature in audio amplifier applications, which significantly improves system efficiency.

In addition to the cycle-by-cycle current limiting, the ISL78229 is implemented with a dedicated average Constant Current (CC) loop for input current. For devices having only peak current limiting, the average current under peak current limiting varies quite largely because the inductor ripple varies with changes of V_{IN} and V_{OUT} and tolerances of f_{SW} and inductors. The CC feature is able to have the average input current accurately controlled to be constant without shutdown. Under certain constant input voltage, this means constant power limiting, which is especially useful for the boost converter. It helps the user optimize the system with the power devices' capability fully utilized by well controlled constant input power.

With the PMBus compliant digital interface, the designer has access to a number of useful system control parameters and diagnostic features. It provides a means to remotely enable or disable the boost controller and to monitor and report variables such as input voltage, input current, and output voltage. In addition, the boost controller includes a pin to support the measurement of an external negative temperature coefficient (NTC) resistormonitor temperature. It



New highly integrated boost controllers to simplify the design of high power automotive applications



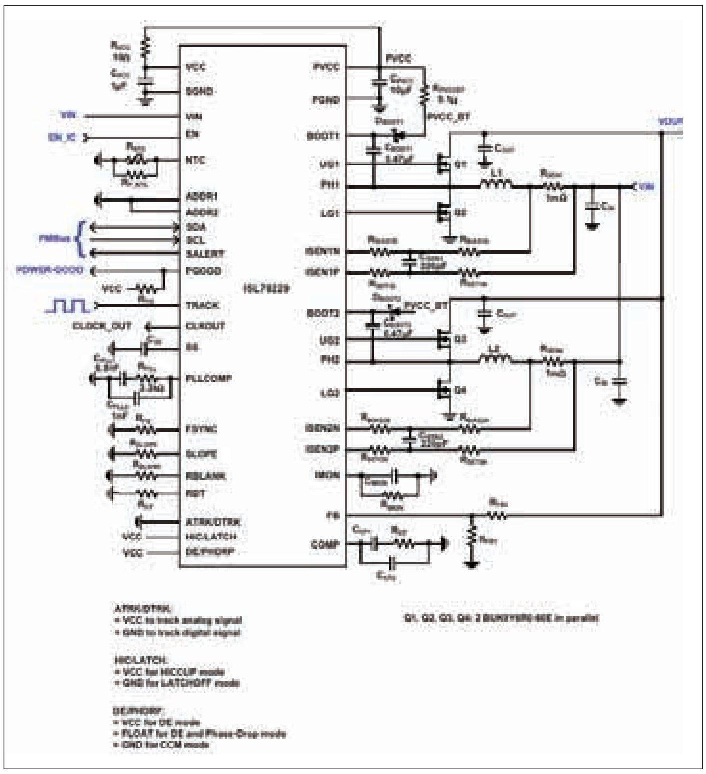
ISL78229 block diagram

then digitizes this signal and the reading can be reported over the PMBus. An over-temperature fault limit can be set for the external temperature monitoring.

Synchronous boost

It's common for buck converters to use a FET in place of a diode for the output rectifier function because most buck converters deliver low output voltages. In this configuration, the voltage drop across the rectifying element represents a high proportion of the power lost to produce the output voltage. Replacing the output rectifier diode with a sync FET that switches on and off at the right time greatly enhances efficiency. This is because the FET losses are typically a fraction of the loss in the rectifier diode. In the buck converter, the sync FET is ground referenced and therefore the drive circuitry is relatively simple.

The sync FET brings several benefits also to the boost configuration. In a boost converter application, the output voltage is usually several times greater than the



Typical application - 2-phase synchronous boost input voltage so the losses in the output rectifier element are not as high of a percentage of the total output power. While the boost converter benefits from the sync FET efficiency improvements, the sync FET provides bidirectional current flow, which allows continuous mode operation, even at light loads – a key benefit for applications that require low electromagnetic interference (EMI). Bidirectional current flow is also a key capability required to implement an effective envelope tracking function. Additionally, the use of a sync FET does not preclude operation in discontinuous mode. The boost controllers can detect negative current flow and can optionally disable the sync FET to emulate the function of the synchronous rectifier diode.

Thus the ISL78229 employs synchronous boost architecture as shown in the typical application schematic. The UGx output drives the high-side synchronous MOSFET, which replaces the freewheeling diode and reduces the power losses due to the higher voltage drop of the freewheeling diode.

While the boost converter is operating in steady state Continuous Conduction Mode (CCM), each phase's low-side MOSFET is controlled to turn on with duty cycle D and ideally the upper MOSFET will be ON for (1-D).

The upper side UGx drivers are biased by the C_{BOOTx} voltage between BOOTx and PHx (where "x" indicates the specific phase number). C_{BOOTx} is charged by a charge pump mechanism. PVCC charges BOOTx through the Schottky diode D_{BOOTx} when LGx is high pulling PHx low. BOOTx rises with Phx and maintains the voltage to drive UGx as the DB_{OOTx} is reverse biased.

At start-up, the charging to C_{BOOTx} from 0 to ~4.5 V will cause PVCC to dip a little. So a typical 5.1Ω resistor RPVCCBT is recommended between PVCC and DBOOTx to prevent PVCC from falling below VPORL_PVCC. The typical value for CBOOTx is 0.47 μF.

The BOOTx to PHx voltage is monitored by UVLO circuits. When BOOTx-PHx falls below a 3V threshold, the UGx output is disabled. When BOOTx-PHx rises back to be above this threshold plus 150 mV hysteresis, the high-side driver output is enabled. For standard boost application when upper side drivers are not needed, both UG1 and UG2 can be disabled by connecting either BOOT1 or BOOT2 to ground before part start-up initialization. Phx should be connected to ground.

Programmable adaptive dead time control

The UGx and LGx drivers have an adaptive dead time algorithm that optimizes operation with varying operating conditions. In this algorithm, the device detects the off timing of LGx (UGx) voltages before turning on UGx (Lgx). Furthermore, the dead time between UGx ON and LGx ON can be programmed by the resistor at the RDT pin. The typical range of programmable dead time is 55 ns to 200 ns, or larger. This is intended for different external MOSFETs applications to adjust the dead time, maximizing the efficiency while at the same time preventing shoot-through. The dead time is smaller with a lower value RDT resistor, and it's clamped to minimum 57 ns when RDT is shorted to ground. Since a current as large as 4mA will be pulled from the RDT pin if the RDT pin is shorted to ground, it is recommended to use 5 kΩ as the smallest value for the RDT resistor where the current drawing from the RDT pin is 0.5 V/5 kΩ = 100 μA.

Summary

The ISL78227/29 multi-phase 55V synchronous boost controllers offer a combination of features that accommodate many different power system requirements. Individually, the capabilities may seem trivial, but when put together, the whole exceeds the value of the sum of the parts. Voltage quality modules for start-stop systems, trunk audio amplifiers, and in-glass window defrosters are just a few of the high voltage applications that require a robust boost controller solution.

The ISL78229 55V synchronous boost controller with PMBus is available now in a 6mm x 6mm, 40-lead WFQFN package and is priced at $3.95 in 1k quantities. An ISL78229EV1Z evaluation board can be purchased for $172.

www.intersil.com/products/isl78229

Special Conference on Power Electronic Packaging and Integration

The bi-annually Conference on Integrated Power Systems (CIPS) was held 18 years ago in Bremen/Germany featuring 40 delegates. Now the conference from March 8 to 10 has grown up to almost 300 delegates, making it to one of the most important events for power electronics packaging.

CIPS is focussed on some main aspects such as: Integration with ultra high power density, of hybrid systems and mechatronic systems; systems and components operational behavior and reliability; basic technologies for integrated power electronics systems as well as upcoming new important applications which will be presented in interdisciplinary invited papers. Since 2010, CIPS is a IEEE sponsored conference. All accepted papers are avaible in IEEE Xplore.

GaN again

Prior to CIPS the ETG hosted a workshop entitled 'Design Techniques for Gallium Nitride Devices in Power Electronics' featuring nearly 50 attendees. As expected GaN was the subject, but more on evaluation on current devices rather than introduction of new products.

In the first presentation 'GaN Devices between Expactation and Reality' Thomas Heckel from Fraunhofer IISB (**www.iisb.fraunhofer.de**) in Erlangen expressed his expectations:"We expect a normally-off characteristic, better performance than Si and even SiC, and more vendors"! At IISB a test system has been set up for the evaluation of various GaN transistors. A 200-V transistor switched at 100 V exhibited dynamic on-resistance (120 mΩ to 80 mΩ) which was not specified in the datasheet; a 650 V/150 mΩ cascode was opened which needs external gate resistor, this type exhibited poor controllability; a 650 V/45 mΩ with four GaN transistors showed better controllability – but is commercially not more available; a 650 V/50 mΩ normally-off device had better dynamic on-resistance but reached not the datasheet specifications. Only Panasonic's 600 V GIT device exhibited no dynamic on-resistance!

"In contrast the Cree 900 V/65 mΩ SiC MOSFET featuring low-inductive package (Kelvin contact) has the ability to serve as future benchmark for GaN transistors, though this device has a poor body diode", Heckel stated. "In general many questions are still unsolved, thus future research is necessary".

Regarding the GaN GIT (Gate Injection Transistor) Panasonic's (**https://eu.industrial.panasonic.com/**) German represetative Francois Perrault explained: "A carrier injection into the gate creates holes beneath the gate which in turn create electrons which are forming the electric current from Source to Drain. Thus the mechanism is a conduction-modulation due to change of the conductive channel. A GIT is therefore driven by current as well as voltage!" The turn-on depends on the gate resistor. The possible reverse operation could eliminate a freewheeling Schottky diode.

Having listened to these two presentations PEE raised the question: "Since IISB judged all examined GaN cascodes as not easy to control - but Infineon have with the IR GaN acquisition a cascode topology and by licensing the Panasonic GIT an e-mode technology in house – what is Infineon's preference for the future? Gerald Deboy, Senior Principal Power Semiconductors and System Engineering at Infineon (**www.infineon.com/**) stated: "We now have our focus on normally-off topology, an official statement will be released later at APEC!" This statement can be interpreted that the company will skip the GaN cascode and switch to e-mode – what was the general trend at APEC 2016 (see our APEC report).

In his presentation 'Performance of GaN HEMTs vs Next-Best Silicon Alternative' Deboy underlined that improvements in efficiency from 96 to 98 percent in data center power supply losses could be halved. "Next Silicon CoolMOS generations could in terms of typical resistance compete with SiC and GaN, but not with the capacitancies which are by a factor of 10 lesser. The turn-off losses of CoolMOS C7 are already near equal to GaN", Deboy said. Jens Friebe from Germen PV inverter manufacturer SMA (**www.sma.de**) described some of the experiences the company has gained in the joint project 'Neuland' ended 2013 together with Infineon and German GaN company MicroGaN. "With GaN we achieved in DC/AC inverters at turn-off half the losses of SJ MOSFETs and the body diode was usable!"

CIPS keynotes on integration trends

So far some results of the GaN workshop, but the subject was continued at the next day with ETH Zurich Prof. Johann Kolar's CIPS keynote on Googles Little Box Challenge, which is also a challenge in PE integration. The ETH along with Fraunhofer IZM and the Slovenia Fraza team applied for this $1 million-contest (see details in PEE 6-2015, pages 14-15).

The total volume of the inverter is 14.22 in^3 resulting in a power density of 140.60 W/in^3. The inverter stage of the system consists of two output phases, each of which is formed by two interleaved bridge leg stages in buck-configuration. Each of the four bridge legs is operated with an triangular current mode (TCM) modulation scheme controlled by an FPGA, whereby the (variable) switching frequency is in the range of hundreds of kilohertz for reducing the volume of inductors.

The volume of the inductors has been minimized additionally by a novel type of multiple air gap foil winding inductor with extremely thin isolation layers. The volume of the DC link capacitor has been minimized by using a novel and highly compact type of ceramic capacitor.Normally-off GaN GITs from Infineon, which are driven by a novel gate driver are used for implementing the four bridge legs.

French Schneider Electric's (**www.schneider-electric.com**) inverter (20 cm^3) topology deploys full bridge operating at PWM mode, consisting of two half-bridge legs and an LC output filter. Wide band-gap semiconductors are selected in order to reach high efficiency. Different GaN and SiC components with various package forms such as QFN, TO220 and TO247 were tested and the final choice was to use SiC MOSFETs in TO247 package, which proved to be best in terms of component ruggedness, thermal management, gate driving and EMI.

Unfortunately these design did not win the Google Little Box Challenge, but came into the finalists round. It was a helpful experience of what can be

ETG's GaN Workshop 2016 was opened by Nando Kaminski/Univ. Bremen (left) and Andreas Lindemann/OvGU Magdeburg Phot: AS

Eckart Hoene, business development manager at Fraunhofer IZM, presented the team's LBC design covering four GaN GITs in the power stage Photo: AS

achieved with new ideas on packaging and new power transistor technologies. The winning team also utilized e-mode GaN transistors rated at 650 V (see our APEC report in this issue).

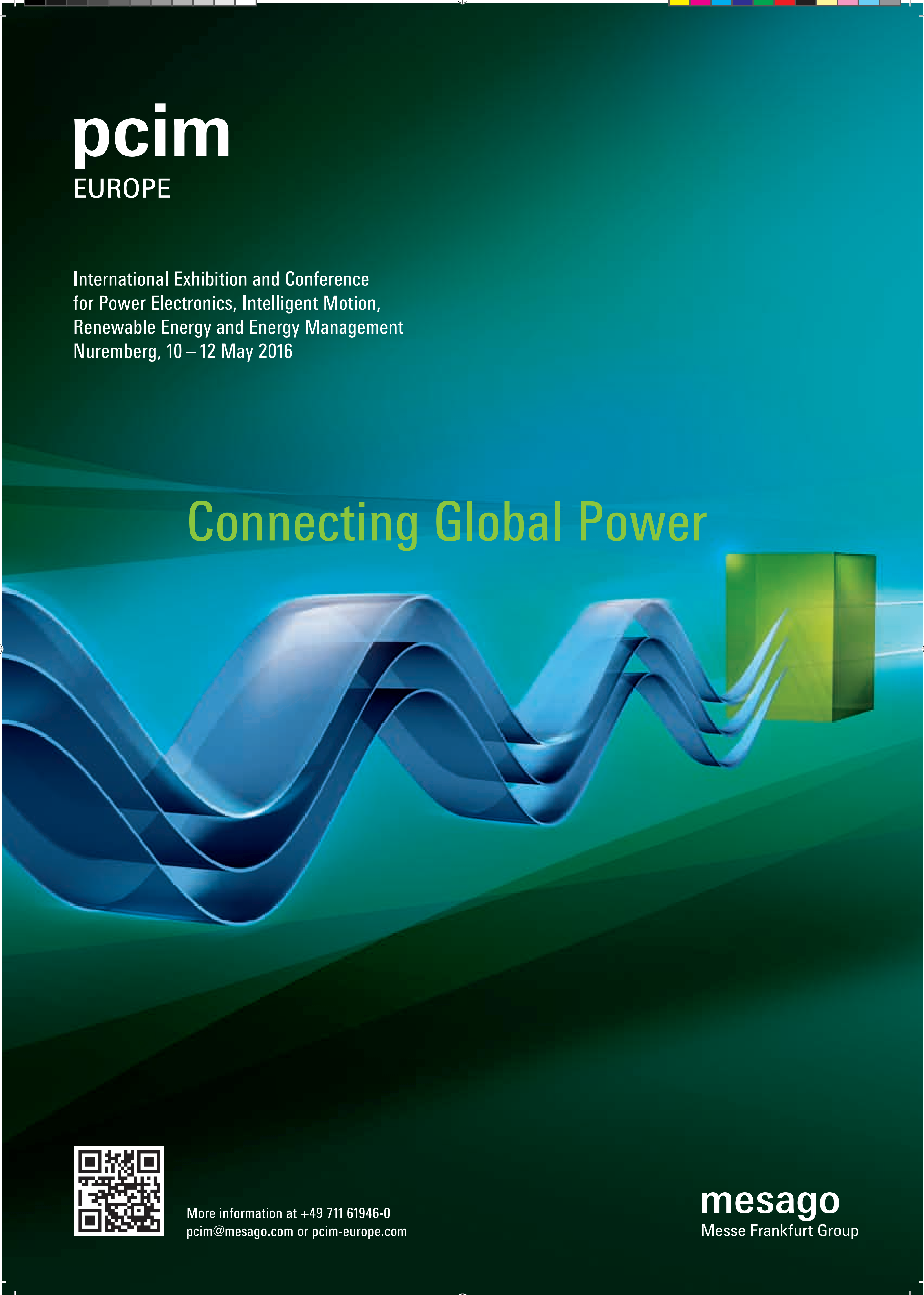
A review of the integration trend in power module technology has been made in the keynote by Mitsubishi Electric's (**http://www.mitsubishielectric.com/**) fellow Gourab Majumdar. Since the invention of bipolar transistor power module as a controllable active high power switching element, the power module technology has contributed extensively in elevating power density of power electronics based power conversion systems centering IGBT technology as its core component. On the other hand, higher integration of the power module has progressed by incorporating system functionalities driven by the motivation of contributing to miniaturization and performance improvement of overall systems. IPM, which was invented in the 1980s, integrated dedicated drive and protection circuitry along with power switching elements (IGBTs and diodes) in an optimized module structure and provided a leaping progress in terms of easing usability in applications. Furthermore, direct-fin-attached type power modules have been made available recently providing dramatic improvement in thermal conductivity improvement and system cooling design. Recently, a highly integrated smart module concept combining almost all functions of an inverter together with its heat dissipating cooling heat-sink has appeared. This trend of integration is expected to move forward toward higher technological level basing on the so-called application-specific approach.

Last but not least the SEMIKRON Foundation (**www.semikron-stiftung.com**) and ECPE (**www.ecpe.org**) honoured Dr. Patrick Berwian and his team with the Innovation Award (includes prize money of EUR 10,000) and Mr. Erik Lemmen for his work with the Young Engineer Award (EUR 3,000).

The Innovation Award team includes Dr. Michael Schütz (Intego GmbH), Larissa Wehrhahn-Kilian (Infineon Technologies AG), Dr. Patrick Berwian (Fraunhofer IISB) and Dr. Michael Krieger (Friedrich-Alexander University). They have developed and evaluated a new technology for quality assurance during SiC device manufacturing using UV photoluminescence imaging in order to detect harmful material defects in SiC on a full wafer scale. This novel inspection technique detects material defects which are the root cause for later device degradation at an early stage in a fast, contactless and non-destructive way. This innovation significantly contributes to SiC device reliability which is an important topic in industry. The method has been successfully proven and it is on the way to be adopted by industry. The economic impact and societal benefit of the innovation is related to the energy efficient power electronics based on SiC power devices. The innovation was developed within the SiC-WinS joint project funded by the Bavarian Research Foundation.

The SEMIKRON Young Engineer Award was given to Mr Erik Lemmen from University of Technology Eindhoven, The Netherlands for his contributions to the development of an ´Extended Commutation Cell - A Path Towards Flexible and Reliable Multilevel Power Conversion´. **AS**

Semikron Foundation Awardees Bettina Martin (SEMIKRON foundation), Prof. Leo Lorenz (ECPE), Dr. Patrick Berwian (Fraunhofer IISB), Larissa Wehrhahn-Killian (Infineon Technologies AG), Dr. Michael Krieger (Friedrich-Alexander-University Erlangen-Nürnberg), Dr. Steffen Oppel representing Dr. Michael Schütz (Intego GmbH), Prof. Dr. Elena Lomonova representing Erik Lemmen (left to right) Photo: Semikron Foundation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Next Push for Gallium Nitride

The Applied Power Electronics Conference (APEC) from March 20 – 24 in Long Beach/California was with 4,670 pre-registered delegates (5,000+ in total), 408 exhibitor booth, and 563 accepted technical papers out of 1212 proposals the by far largest event since its inauguration in 1986. As in the past this year's conference was a great opportunity to get the latest news and rumors in terms of technologies, products and last but not least companies within the power electronics industry.

The plenary session covered the key power electronics technologies, components, and innovations affecting industry and finally society. The Challenges of VHF Power Conversion explained CTO Anthony Sagneri, Finsix Corp (**www.finsix.com**). FINsix meams 'Frequency INnovation in power', and six, or VI in Roman numerals, is the electrical formula for Power. Founders were MIT graduate students with the goal to build the smallest and lightest power electronics with a laptop adapter as first product to make VHF power ready for commercial production. "Until the year 2013 laptop adapters did not charge so well due to its poor 89 percent maximum efficiency at full load at around 60 watts. Now higher switching frequency leads to smaller inductors and capacitors, lower weight and volume. GaN and VHF power conversion are a natural marriage, though dynamic on-resistance or other minor problems have to be solved. In magnetics we favor the air-core approach with geometrically defined inductance. Actual designs feature greater 95 percent efficiency a 4 x smaller size", Sagneri stated.

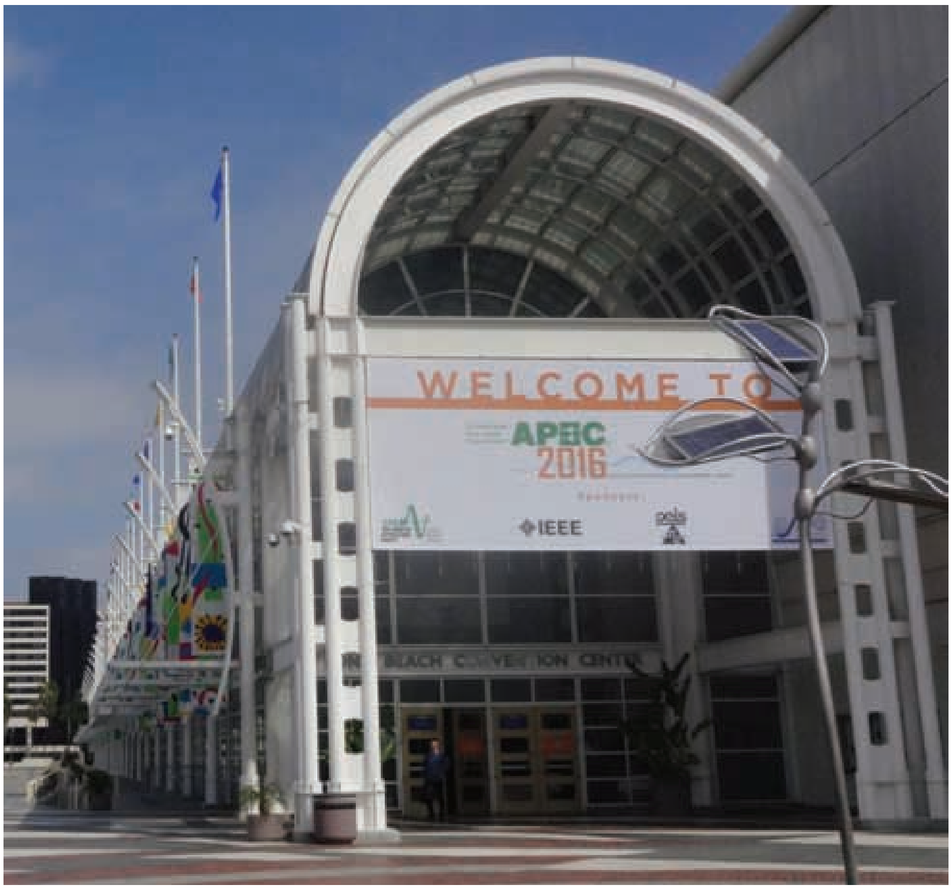
The Future of Power Electronic Design was predicted by Enphase Energy (**www.enphase.com**), a Solar microinverter company in Petaluma/CA. "With the 1979 patented IR HEXFET power electronics came to reality. Prior to that were the first PWM controller in 1976 and the switched power supply technique in 1977. Since then power conversion efficiency increased from 50 to 97 percent. Thus the question is still how to make power converters even more efficient and lighter. Wide bandgap devices offer 100 – 1000 x better performance than Silicon devices, particularly with bidirectional GaN HEMTs", ?Michael Harrison, Senior Director, Power Conversion Strategy, underlined.

Breaking Speed Limits with GaN Power ICs was the plenary subject by Dan Kinzer, CTO of California-based start-up Navitas Semiconductor (**www.navitassemi.com**). "GaN is ready for the market and we are integrating things which have not been integrated before", he stated. The company has designed a fully integrated GaN IC with integrated gate drive in QFN 5 mm x 6 mm package. "This e-mode device features 20 times lower drive loss than Silicon, the driver impedance is matched to the power stage. Also almost zero inductance leads to low switching losses – and our 650-V process allows switching frequencies of up to 27 and 40 MHz! The switch is not the limit, it is the magnetics". According to Kinzer this device can also be used as a 500-V synchronous rectifier and it makes no sense to put a GaN switch into a TO220 package! Also a cascode makes it difficult to control the lower MOSFET (gate drive).

Residential Nanogrids With Battery Storage – Is This Our Future? This question was raised by Antonio E. Ginart from the College of Engineering of University of Georgia (**www.uga.edu/**). "PV can cover 100 percent of the energy demand in the US south, whereas due to the different climate conditions in Germany around 50 percent can be reached. Nanogrids will cover up to 25 kW, residentials up to 25 kW. DC nanogrids will operate from 12 to 400 V, they are more efficient than AC nanogrids but more critical to control. For energy storage in nanogrids only batteries and capacitors (supercaps) are useful, and for feeding energy back into the grid bi-directional inverters are a precondition".

The Future of Magnetic Design for Power Electronics was covered by Ray Ridley, Ridley Engineering (**www.ridleyengineering.com/**). "Magnetic fields move in the speed of light, thus there is no limitation in switching frequency. And there is no theoretical limit that transformers can reach 99 percent efficiency, thus transformers are used for a century and will be used in the future as well! Faraday designed the transformer back in 1831. You cannot get rid of the magnetic core since it shields the magnetics from the other components", so Ridley's main conclusions.

Why Do Power Supplies Fail? David Hill, from Dallas-Based Power Clinic (**www.powerclinicinc.com/**) analyzed many power supplies and came to the conclusion that fans are the main source of failures since overheating destroys most of the power semiconductors. An other failure mechanism are dried-out electrolytic capacitors, also a consequence of overheating.



Long Beach's Convention Center hosted this year's APEC attracting more than 5,000 delegates

E-mode or d-mode?

As already outlined in the plenaries GaN played a major role within the conference sessions as well as on the exhibition floor. There were 106 technical papers and presentations that referenced GaN in one way or another. GaN was the talk of the show by far.

"In the digital arena Moore's law - doubling the transistor count on chip every 18 month – has now been broken, but in power electronics we are just in the beginning with the role of GaN", EPC's (**www.epc-co.com**) CEO Alex Lidow pointed out. "GaN is the logical technological successor to Silicon for power conversion and analog devices, and possibly also for digital components as well. We are away by the factor of 800 of the theoretical GaN limits, this technology is able to be integrated up to the level of NMOS. GaN technology enables applications such as wireless charging, higher resolution MRI imaging, micro satellites, high resolution and low cost LiDAR, and higher bandwidth wireless communications. The recent sluggishness of the end markets for semiconductors is somewhat a by-product of the end of Moore's Law; Silicon cannot keep pace with the need to double performance while lowering cost. GaN is on track to re-establish that "go-go period" when consumers could count on new products and applications that year after year delivered higher performance and a constantly reducing price".

E-mode characteristics are achieved by special doping of the gate electrode. EPC uses a Taiwan-based foundry that makes also DMOS and other devices. Just for comparison – 150 mm wafers contain up to 20,000 GaN devices, with Silicon MOSFETs this number is around 5,000, because device size is much smaller. Additionally, up to 200 V breakdown voltage e-GaN switches up to 8 x faster than the best Si MOSFETs by offering up to 4 x lower output capacitances (resonant applications).

Regarding cost – Lidow claims that EPC has beaten already Silicon because EPI (which was more expensive in the past) now comes to equal. And since EPC uses no conventional packaging which covers the same cost as the Silicon – devices are glass-sealed already on the wafer level – another major cost driver is eliminated. "I hate packaging due to its disadvantages in cost, added parasitics and failures, that's why we stay on low voltage up to 200 volts maximum", Lidow underlined. In terms of integration half-bridges are just the beginning.

EPC's APEC demonstrations showcased wireless power systems that span the full power range of Qi and AirFuel standards and a multi-mode solution, a single stage 48 V – 1 V DC/DC converter, 3-D real-time LiDAR imaging camera, and an LTE compatible envelope tracking power supply.

Canadian GaN Systems (**www.gansystems.com**) also offers e-mode devices with its so-called island technology. "Smart mobile devices, slim TVs, games consoles, automotive systems and other mass volume items have been designed with GaN transistors as the enabling power technology, so it is imperative that devices are available in correspondingly large quantities", said President Girvan Patterson. "After three years of working together, we formally announced our collaboration with TSMC as our foundry in December last year". Delivering large volumes of GaN transistors in near-chipscale packaging is the result of designs beginning in 2008.

Certainly the most impressive design based on GaN System's devices (GS66508P e-mode GaN power transistor) was the winning team of Google's Little Box Challenge. Google and the IEEE Power Electronics Society awarded the $1 million prize to Belgiums CE+T's Red Electrical Devils for designing, building and demonstrating an inverter with the highest power density and smallest volume. The key goal of the challenge was to reach an inverter power density in excess of 50 W/cubic inch in a volume of under 40 cubic inches – a feat which had never been done before. Their winning inverter design produced a power density of 143 W/cubic inch in 14 cubic inches, outperforming the Little Box Challenge power density goal by nearly a factor of 3 thanks

GaN again was the topic in the conference and on the show floor as seen at the EPC booth

GaN System's President Girvan Patterson proudly showcased the winning inverter of Google's Little Box Challenge

to GaN power, which, according to Google, "is 10 times more compact than commercially available inverters".

During APEC, Texas Instruments (**www.ti.com/gan**) announced that they have leveraged existing manufacturing infrastructure and capabilities to qualify a 600-V e-mode GaN process (see also the feature 'Optimizing GaN Performance with Integrated Driver').

Transphorm (**www.transphormusa.com**) introduced the 650 V TPH3207WS cascoded GaN FET with low on-resistance (41 mΩ) in a TO-247 package that reduces system volume by 50 % and low reverse recovery charge of 175 nC. Hard-switched bridges and CCM bridgeless totem-pole PFC in on-board chargers, solar inverters, telecom power supplies and other power conversion applications can benefit from these new devices. Transphorm's GaN FET portfolio is also strengthened with the introduction of the TPH3208 family (130 mΩ) in industry-standard TO-220 and PQFN packages. Regarding some GaN problems mentioned in the plenaries Marketing Director Zan Huang stated: "Dynamic on-resistance is not a problem of cascode or e-mode, it is a problem of the wafer structure. Nevertheless we are forcing our e-mode GaN technology acquired from Fujitsu to come to market early next year". And the company is expanding into Europe with a near Frankfurt-based office within this year.

Vishay Siliconix (**www.vishay.com**) showcased its Si MOSFET portfolio, particularly in the lower voltage range. "Later this year we will launch a C7-compatible SJ family, and we are also working on a GaN cascode", Roy Shoshani, VP ICs, stated.

And by the way, Infineon (**www.infineon.com**) who has acquired International Rectifier for $3 billion in 2014 mainly due to its d-mode GaN (cascode) expertise and patent portfolio will according to informal informations skip this technology in order to favor Panasonic's e-mode (GIT) technology, which has been licensed also in 2015. This turn obviously marks an industry change to support e-mode or normally-off devices in the future.

Besides all the GaN news Silicon Carbide (SiC) still plays a major role in the higher voltage range (650 V onwards). Though there were rumors at APEC to have 650-V SiC MOSFETs (as Rohm already introduced in October 2015 the SCT2120AF device) Wolfspeed (**www.wolfspeed.com**) denied to have such plans. At APEC the company focused on their 900/1200/1700 V MOSFETs and on power modules which are footprint and pin-compatible to standard IGBT modules. Though the internal design is optimized to minimize parasitic stray inductance, these standard power modules employ Al wire-bonds limiting switching frequency and thermal performance, "thats why we are working with our recent acquisition APEI on low-resistance and low-inductance packages to maximize the performance of our power modules", stated Guy Moxey, Director Product Marketing by showing a prototype power module and gate driver.

Power Management

Power Integrations, an APEC newcomer, announced a 900-V device to its InnoSwitch™-EP

Wolfspeed's Director Product Marketing Guy Moxey showing a prototype of new power module design and gate driver

family (see PEE 6-2015, pages 22-24 for basic technology) of off-line CV/CC flyback switcher ICs (**www.power.com/innoswitch-ep**). The new device targets power supplies operating from high-voltage DC and three-phase power sources found in industrial, motor-drive, metering and renewable energy applications, and standard mains-voltage applications where continuous operation during line swells and surges is required. The 900-V EP ICs feature typically 85 percent efficiency for a dual output 18 W design – eliminating optocouplers and heat sinks. InnoSwitch employs the FluxLink™ magneto-inductive coupling technology which utilizes the well-defined inductance of the bond pads and includes synchronous rectification with secondary-side regulation. It features an properly designed 900-V power MOSFET which provides an operating margin for 450 V AC industrial systems. Working continuously with an input voltage of up to 450 V AC, an optional layer of protection - line UV/OV – prevents the IC from switching and protects the circuit up to 650 V AC. Devices are UL1577 and TUV (EN60950) safety-approved and

Power Integration's VP Marketing Douglas Bailey introduced new 900 V InnoSwitch-EP devices which simplify the design of reliable power supplies operating from commonly available industrial voltages

EN61000-4-8 (100 A/m) and EN61000-4-9 (1000 A/m) compliant. Explains Douglas Bailey, VP Marketing "The new 900 V InnoSwitch-EP devices drastically simplify the design of reliable power supplies operating from commonly available industrial voltages, i. e. for medical, industrial and even appliances."

Intersil announced two new PMBus™ compatible, single-phase digital hybrid DC/DC controllers that provide point-of-load (POL) conversions for FPGAs, DSPs, ASICs, processors and general purpose system rails. The ISL68200 with integrated MOSFET drivers (**www.intersil.com/products/isl68200**) and ISL68201 with PWM output simplify power supply designs for data center routers, servers and storage. The ISL68200 can drive external MOSFETs directly, while the ISL68201 is paired with Intersil's DrMOS power stage to create a complete voltage regulator solution. The ISL68200 and ISL68201 leverage proprietary R4 modulation technology, which provides a compensation-free control loop

Intersil's Brandon Howell, Lead Product Marketing Engineer, introduced new "hybrid" DC/DC controllers with a digital interface that allows to monitor power supply health, output current/voltage, and change output voltage on the fly

that eliminates external compensation resistors and capacitors. The R4 modulator includes energy saving light-load efficiency modes of operation, and adjusts both duty cycle and switching frequency in response to load transients. The R4 control loop's fast response time significantly reduces the amount of output capacitance. The ISL68200/01 has been demonstrated with PowerNavigator™ software simplifiing power supply set up and configuration, including all device parameters and telemetry. "We see an increasing need for DC/DC controllers with a digital interface that allows to monitor power supply health, output current/voltage, and change output voltage on the fly," said Brandon Howell, Lead Product Marketing Engineer. "The ISL68200 and ISL68201 digital hybrid controllers deliver higher PoL performance than analog controllers, while offering a familiar design flow and the PMBus functionality found on high-end full digital products".

Infineon introduced its Integrated Power Stage family (**www.infineon.com/integrated-powerstages**). With power efficiency rating reaching 96 percent, the new Si devices can be combined with Digital PWM Power management controllers to provide a full multiphase voltage regulation (VR) solution. Maximum current rating of 70 A in a 5 mm x 6 mm PQFN SMD package supports phase reduction in multiphase systems. The Integrated Power Stage family also offers smart self-protection with both over-current and over-voltage protection, temperature and current information to the application.

For high-power inverters Rogers Corporation's Power Electronics Solutions (PES) group showed examples of busbar power management technology. ROLINX® CapEasy and ROLINX® (**www.rolinx.com/index.aspx**) CapPerformance capacitor-busbar assemblies and their high current and low inductance capability have been combined with Power Ring Film Capacitor™ technology from SBE (**www.sbelectronics.com**), resulting in capacitor-busbar assemblies with extremely low inductance and high power density capabilities. The integrated capacitor-busbar assembly is developed for critical DC link applications for automotive HEV/EV powertrains and also for solar and wind inverters. The typical voltage ranges from 450 V – 1500 V DC and capacitance ranges from 75 – 1600 µF. IGBT interconnection is made via a low inductance laminated busbar allowing inverter systems to maximize performance, increase lifetime and reduce size and cost. "The addition of the metalized polypropylene film capacitors, with their low ohmic resistance and outstanding heat-transfer capabilities, brings a significant reduction in equivalent series inductance (ESL) and equivalent series resistance (ESR) to the capacitor-busbar assemblies", said PES Sales Director Dirk Maeyens.

Rogers' Konrad Aicher (left) and Dirk Maeyens showing new integrated film-capacitor busbar assembly developed for critical DC link applications

pcim
EUROPE
Nuremberg, 10 – 12 May 2016

More Exhibitors Confirm International Importance

With 61 first-time exhibitors from 14 nations – including renowned companies like General Electric, Marschner Tabuchi, Murata or Siemens – PCIM Europe (**www.pcim-europe.com**) proves its status as the international meeting point, as well as information and knowledge platform for power electronics once again this year.

From 10 – 12 May 2016 more than 400 exhibitors, both from Germany and abroad, present themselves at the exhibition and conference for power electronics, intelligent motion, renewable energy and energy management and thereby introduce trendsetting innovations and product developments to an international expert audience.

On the two days prior to the official beginning of the conference, well known experts will share their knowledge in seven half-day seminars and ten full day tutorials on topics such as “Design Challenges for High Frequency Magnetic Circuit Design for Power Conversion“, “Reliability Engineering in Power Electronics – from Components to Systems” or “Exceeding 99 % Efficiency for PFC and Isolated DC-DC Converters. GANs versus Silicon”.

With two visitor forums, PCIM Europe 2016 offers a diverse and attractive supporting program in the field of power electronics: On the one hand, experts will highlight what currently drives the industry and exchange views which challenges academia is facing lately at the industry forum, an exclusive discussion and presentation platform for research and development topics. On the other hand, individual companies introduce recent product developments at the exhibitor forum in more than 50 presentations.

Furthermore, the association TERA of the Technical University in Graz, Austria, will reveal its progresses and approaches in the field of efficient vehicle technology for the first time by illustrating

The poster session on SiC and Gan are open for exhibition staff and visitors the purely electrically operated research vehicle IBEX at a special area.

High-level conference: program

With more than 300 oral and poster sessions covering topics like new materials, concepts, construction techniques, system integration and reliability issues, the conference of PCIM Europe 2016 offers a varied program at the highest level. The highlights include, amongst others, three keynote speeches on "Welcome to the Post-Silicon World: Wide Band Gap Powers Ahead", "Smart Transformers – Concepts, Challenges, Applications" and "Trends of Solar System Integration Electricity Networks", as well as special sessions on: "Passive Components", "Smart Lighting" and "E-Mobility".

Poster session for all

A novelty is the Poster Session on SiC and GaN at the Wednesday from - 17:00 within the PCIM foyer and thus open also for exhibitor staff and visitors not having a ticket for the conference.

Topics include: Integrated SiC MOSFET-Gate Driver Module With Ultra Low Parasitic Inductance for Noise Free Ultra High Speed MHz Switching by Liqi Zhang, NC State University, Raleigh, USA;

An integrated module is designed, fabricated, and tested. Due to the low stray inductance and parasitic capacitance, the gate resistor is chosen as zero to further increase switching speed. A half bridge inverter utilizing this module is designed and tested under the conditions of 3.38 MHz, 700Vds and 9.2A pk-pk.

An Insightful Evaluation of a 650V High-Voltage GaN Technology in Cascode and Stand-Alone Transistors by Dr. Jaume Roig, On Semiconductor Belgium BVBA, Oudenaarde, Belgium;

A switching performance comparison between 650V power transistors is carried out in this work by assembling identical GaN DHEMTs as Stand-Alone and Cascode in TO-220 and SMD packages. Our investigations are focused on hard-switching also including best-in-class Super-Junction MOSFETs. It is experimentally proven that waveform ringing and power loss are significantly reduced with respect to previous GaN technologies. Additional physics-based simulations help to elucidate power loss mechanisms and define suitable operating conditions.

Characterisation of Discrete State-of-the-Art SiC Power Transistors by Michael Meisser, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Deutschland; Silicon-Carbide transistors in TO247 packages are wide-spread despite of their limitations regarding parasitic inductance and power dissipation. This digest publishes a comprehensive study on the static performance of commercially available SiC discrete transistors. The device-specific differences regarding RDSon stability over current and temperature in forward and reverse operation were investigated. The full paper will furthermore encompass the dynamic properties by means of double-pulse measurements.

Analytical Losses Model for SiC Semiconductors dedicated to Optimization Operations M.Sc. Gnimdu Dadanema, Laboratoire SATIE, Cachan, Frankreich; An analytical model for semiconductor losses prediction in wide Band-gap devices is presented. We use the clamped inductive load test circuit to determine the typical switching waveforms and to establish current and voltage equations for the different switching steps. Our final objective is to integrate this model in an optimization routine. Therefore, our analytical losses model which is more accurate than the traditional piecewise linear model can easily be used for optimization purpose.

Current Measurement and Gate-Resistance Mismatch in Paralleled Phases of High Power SiC MOSFET modules by Roman Horff, University of Bayreuth, Bayreuth, Deutschland; This paper deals with the problems of current measurement in paralleled phases. A solution based on low inductive shunts is proposed. The influence of gate-resistance mismatch on the switching behaviour and the resulting switching losses will also be analysed for high power SiC MOSFET modules.

Gate Drive Strategies of SiC Cascodes by Dr. Xueqing Li, United Silicon Carbide, Inc., Monmouth Junction, USA; SiC cascode has a much more complex switching processes because LV Si MOSFET may be driven into avalanche during turn-off and the parasitic inductances of bond wires and capacitances of MOSFET and JFET may cause large oscillations. All of these issues must be carefully considered in the design to ensure reliable and stable operations of SiC cascode. These issues can be mitigated or even eliminated by using proper gate drive approach. This work will discuss the impact of the different gate drive strategies on SiC cascode.

State-of-the-art of HF Soft Magnetics and HV/UHV Silicon Carbide Semiconductors Geraldo Nojima, Eaton Corporation, Arden, USA; High Voltage and Ultra-high Wide Bandgap devices rated from 10kV to 27kV and hard switching between 5kHz and 10kHz have been developed, tested and the results are presented here. This paper addresses the new challenges brought about by the superior performance of these post silicon devices. The second part of this presentation addresses the new soft magnetic materials and processes under development at the Carnegie Mellon University that are fundamental to fully utilize the advantages of these new HV and UHV wide bandgap semiconductors.

Comparison of Unipolar Silicon Carbide Power Transistors Used in High Switching Frequency Inverter Topologies by Dipl.-Ing. Sebastian Fahlbusch, Helmut Schmidt Universität Universität der Bundeswehr Hamburg, Deutschland; Unipolar silicon carbide SiC power transistors are a promising alternative in power electronic applications at DC-link voltages above 600 V, in which IGBTs are predominantly used. SiC enables a significant increase of switching frequencies in such applications. The objective of this paper is to analyse potentials of commercially available unipolar SiC power transistors and their suitability for high frequency operation. For this, SiC-MOSFETs and SiC-JFETs are investigated in a hard switching inverter half-bridge topology.

ST SiC MOSFETs in 1MHZ DC-DC Converter by Dr. Luigi Abbatelli, STMicroelectronics s.r.l., Catania, Italien; Today power electronics designers know that 1200V SiC MOSFET can replace 1200V Silicon IGBTs allowing frequency range enlargement up to dozens of kHz. What will happen in the power conversion field if new SiC MOSFET technologies, featuring extremely low RDS(on)xQg Figure-of-Merit, will be released into the market? In the present work the SiC MOSFET potential to afford very-high-frequency power conversion (at least 1MHz) will be investigated by looking at the results of the latest ST SiC devices.

Switching Performance Comparison of Latest SuperJunction and SiC MOSFETs Dr. Andrew Lemmon, The University of Alabama, Tuscaloosa, USA by This paper presents a side-by-side switching performance comparison of the latest Silicon SuperJunction (SJ) MOSFET s and SiC MOSFET s in the newly-released 900 V blocking class. The results presented here indicate that the two device types demonstrate very similar dynamics and nearly identical voltage slew rates. However, a difference in the turn-off current slew rate results in a 32% reduction in total per-cycle switching energy in favor of the SiC MOSFET.

Towards a One Nano-Henry Power Module for SiC and GaN by Prof. Jacques Laeuffer, Dtalents, Paris, Frankreich; Decreased commutation times, especially with SiC and GaN, requires much reduced inductances inside power modules. This paper proposes an optimal geometry of strip line layout everywhere inside the power module. Return conductors are made of copper foils mounted face to face in front of chips boundings. Increased width of conductors, and decreased thickness of insulation, leads - for a half bridge including six paralleled MOS - to an inductance around only one Nano-Henry.

Scalable SiC Cascode Power Blocks by Matt Grady, United Silicon Carbide, Monmouth Junction, NJ, USA; A design methodology that leverages the performance and reliability of SiC cascodes in TO-247 packages to cost effectively implement high performance, high power converters is described and demonstrated. By paralleling complete converter legs, which include gate drive, DCBus capacitance, and cascodes in TO-247 packages, high switching speed with minimal ringing and well balanced power dissipation can be easily achieved. The design principle is introduced and test results from a hard switched half bridge converter are presented.

The conference also broaches the issue of the role of power electronics in regard to important future topics. In the panel discussion on "The Smart Future of Power Electronics", available free of charge for exhibitors, visitors and conference attendees, the meaning and challenges of Industry 4.0 for power electronics will be analysed and discussed by experts who provide interesting impulses as well.

For the keynotes and more general informations see PEE 1-2016, pages 16-17.

GaN Matures for Industry with Monolithic Power ICs

Power GaN has come of age with high performance, high frequency and high reliability. It has taken over 15 years for the material to mature from university curiosity to industry-qualified product, from the early days of dMode (normally-on, depletion) to eMode (normally-off, enhancement) devices. Now, manufacturing issues have been resolved and lateral 'GaN-on-Si' devices have been qualified on 6" wafers using conventional, low cost Si fabrication equipment. Now, the introduction of GaN Power ICs – with monolithically-integrated gate drive, logic and FET in low-cost, high volume packaging – enables power systems to run at multi-MHz switching frequencies simply, predictably and with high device and system reliability. **Dan Kinzer, CTO, COO; and Stephen Oliver, VP Marketing, Navitas Semiconductor, El Segundo, USA**

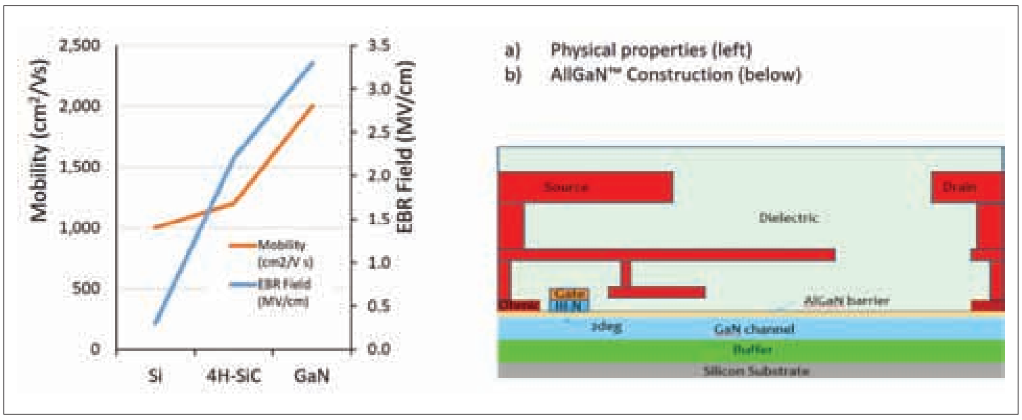
Superjunction Silicon (SJ Si) is no longer the best solution for off-line power supplies. Power Gallium Nitride (GaN) manufacturing processes are mature and devices are operating with higher frequencies, higher efficiencies, higher power densities and lower system costs.

Gallium Nitride (GaN) is a wide bandgap (WBG) material, even wider than SiC. As GaN can be formed with a two-dimensional electron gas (2-DEG) by using anAlGaN/GaN heteroepitaxy structure, It can have very high mobility and very high carrier density in the channel and drain drift region. This gives GaN a big resistance advantage compared to existing devices in the 650 V class. (see figure 1a).

On the way to maturity

The earliest GaN power devices were d-mode (depletion mode) which are turned on with zero gate-to-source voltage (V_{GS}), and require a negative V_{GS} to turn off – not a practical solution for off-line applications. This unwanted "always on" characteristic of d-mode devices was mitigated by the addition of a second, low voltage 'cascode' silicon FET that is used to turn the GaN power device on and off. This essentially converts the depletion-mode into an "always off" device, required to block high bus voltages when a power converter is first turned on.

The cascode FET allows for a standard gate drive signal to be used (0 V = OFF) where zero volts turns the device off and a positive gate drive voltage turns the device on. Cascoding results in a two-switch module that presents a variety of concerns including complex (multiple and/or stacked die) packaging, high parasitic inductance, ceramic interposers for isolation, tendency for oscillation and



RIGHT Figure 1: Comparison of Si, SiC, GaN physical properties, plus AllGaN lateral 'GaN-on-Si' construction

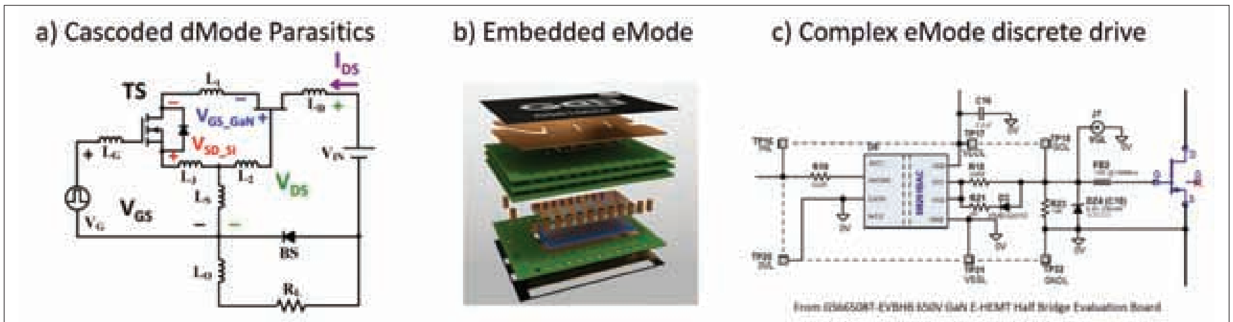


Figure 2: Early dMode & eMode GaN packaging and gate drive

internal over-voltage stress, reduced overall yield, and ultimately a higher cost (see figure 2a).

Early enhancement (e-mode) devices have been implemented in wafer-level chipscale packaging up to 200 V. Others have been offered in standard low performance through-hole packages, but these require on-state gate current and still need a negative gate to ensure they are fully off. Still others more recently have been offered in expensive, non-standard PCB-embedded packaging (figure 2b).

In all of these cases, a high level of sensitivity exists at the gate due to a very low threshold voltage, so tightly regulated gate voltage is required and the devices are very susceptible to noise and voltage spikes that can easily occur due to high-frequency and high-dv/dt noise from the surrounding switched-mode converter circuit. To mitigate these problems, a complex external gate drive circuit (Figure 2c) may be required that includes a voltage regulator circuit, a Zener clamp, an additional gate capacitor, and a ferrite bead. Also, since the gate drive circuit is placed and routed with PCB traces, much care is needed for layout design to reduce parasitic inductance such as cross-coupling of devices and PCB layers.

Dealing with all of these issues by adding components and PCB layers, while trying to increase switching frequency and increase power density, can be a major roadblock to bringing a product out of the lab and into production. A simpler and more reliable solution is needed without adding additional concerns or difficulties.

AllGaN and GaN Power ICs

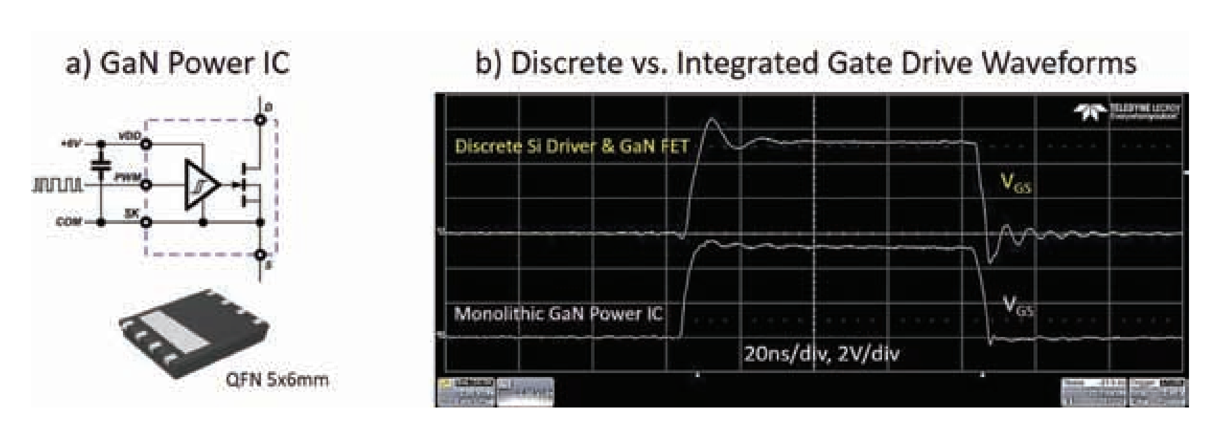
AllGaN™ is the first platform which allows monolithic integration of 650 V GaN IC circuits (drive, logic) with GaN FETs. It is based on a very high density, lateral e-mode device structure with extremely high speed switching capability. The result is a device which liberates the performance of e-mode GaN using a simple digital signal, with the previously vulnerable gate now safely protected.

This 'GaN Power IC' contains features such as hysteretic input, voltage regulation and ESD protection – all integrated in the same GaN layer as the main power device (see figure 1b). This monolithic integration of drive and switch is impractical using d-mode GaN, vertical GaN or SiC. Lateral 'GaN-on-Si' construction means immediate high volume capability using existing foundry processes.

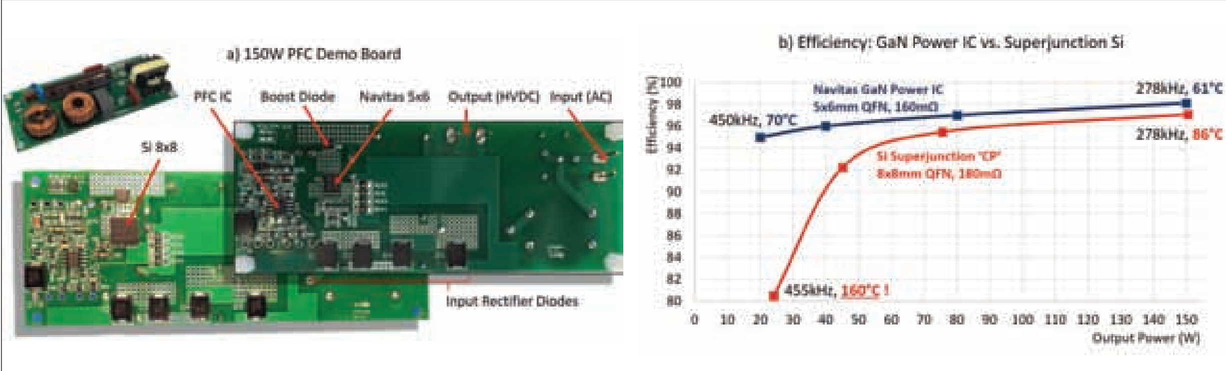
Within the AllGaN solution, the GaN FET gate is driven safely, precisely and efficiently by the upstream integrated GaN driver. Standard 3.3 V, 5 V or 15 V PWM signals are fed directly into the GaN Power IC for an easy, low component count design (Figure 3a). Integrating the driver also reduces ringing and enables tight control of turn-on, turn-off for high-frequency half-bridge applications (Figure 3b).

Practical PFC application

A 150W PFC boost converter was used as a test case for the 650 V GaN Power IC and also the benchmark Si FET (650 V 'CP' SJ, Figure 4). The circuit uses a standard L6562 controller running in Critical Conduction Mode (CrCM), with switching frequency varying with load and AC line. At full power (~280 kHz), the 5 mm x 6 mm GaN Power IC runs 25°C cooler than the 8mm x 8 mm 'CP' SJ, with 33 % lower loss. This circuit highlights one frequency limitation with Silicon – high capacitance. As the load is reduced, the highly non-linear output capacitance of Si (C_{OSS}) at low V_{DS} creates a lossy, non-ZVS condition as frequency increases. Silicon reaches an unsustainable 160°C case temperature while the GaN C_{OSS} is so low that it runs very cool at only 70°C for the same conditions. A single CrCM PFC circuit can be comfortably designed up to 250 W,



ABOVE Figure 3: **GaN Power IC schematic, gate switching waveforms**



ABOVE Figure 4: **PFC boost application example (demo board, GaN Power IC vs. Superjunction Si)**

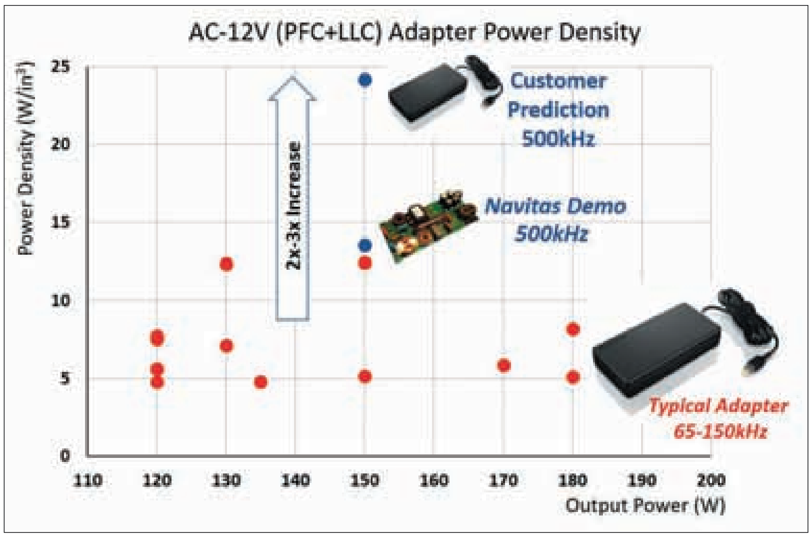


Figure 5: LLC application example: power density increase with frequency

then may be interleaved for higher power applications while maintaining a very low profile.

Switching frequency plays a major part in converter size and cost due to the effects on magnetic components. A study of EMI chokes (common mode, differential mode) and PFC boost inductors showed that magnetics costs could be reduced by 40 % and size reduced by 75 % by increasing switching frequency 5x from a nominal 200 kHz to 1 MHz.

Higher power density with high frequency

High specification 'gamer' laptops, all-in-one PCs and 38"-50" TVs use AC-DC adapters in the power range 120-180 W. Today, the majority of adapters run at 65 kHz/100 kHz with typical power densities around 8 W/in³ with a few benchmark adapters at 12 W/in³. Customer estimates, based on a non –optimized, 500 kHz 150 W PFC+LLC demonstration board using GaN Power ICs indicate that 24 W/in³ will be achieved. This is a 2x–3x increase on today's designs (Figure 5). This simple example showing that the higher frequency enabled by GaN Power ICs shrinks magnetics and enables high efficiency, higher power density solutions.

Conclusions

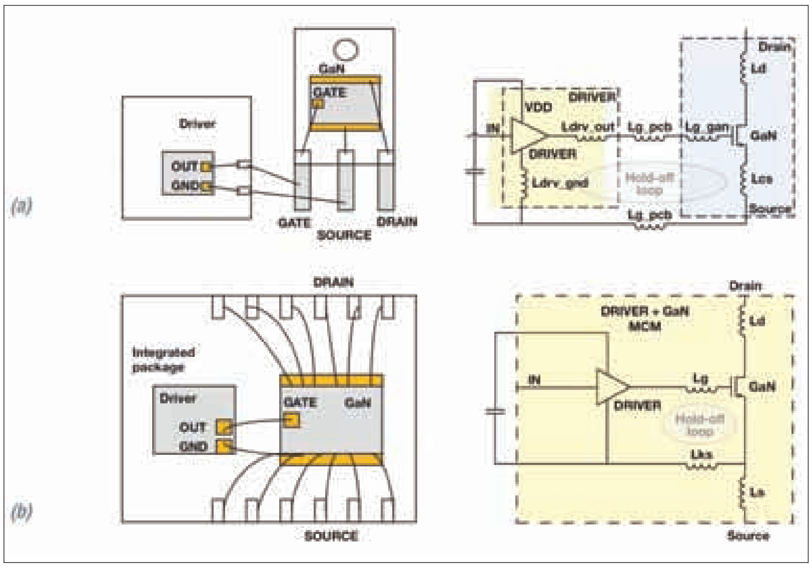
For power system designers, GaN Power ICs represent breakthrough - yet mature - technology, which brings new benchmarks in switching speed, efficiency and power density to a broad array of applications at a wide range of power levels. Unlike other, earlier wide bandgap proposals, GaN Power ICs also represent a simple, fast, scalable and dependable building-block approach to system design, to minimize risk / respins and maximize chance of success. With the AllGaN lateral 'GaN-on-Si' platform qualified on 6" wafers using conventional, low cost Si fabrication equipment, and with products assembled using high volume, industry-standard QFN packaging, monolithic GaN Power ICs are ready for industry.

Optimizing GaN Performance with Integrated Driver

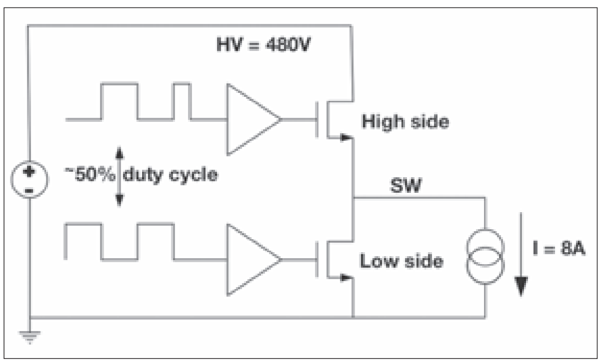
Gallium Nitride (GaN) transistors can switch much faster than Silicon MOSFETs, thus having the potential to achieve lower switching losses. At high slew rates, however, certain package types can limit GaN FET switching performance. Integrating the GaN FET and driver in the same package reduces parasitic inductances and optimizes switching performance. Integrating the driver also enables the implementation of protection features. **Yong Xie, IC design engineer; Paul Brohlin, Design and system manager, GaN and Next team, Texas Instruments, USA**

GaN transistors have switching performance advantages over Silicon MOSFETs given their lower terminal capacitances for the same on-resistance and lack of a body diode with reverse-recovery loss. Because of these features, GaN FETs can switch at higher frequencies, improving power density and transient performance while maintaining reasonable switching losses.

GaN devices are packaged as a discrete device and driven with a separate driver, because GaN devices and drivers are based on different process technologies and may come from different manufacturers. Each package will have bond wires and/or leads that introduce parasitic inductance, as shown in Figure 1a. When switching at high slew rates of tens to hundreds of volts per nanosecond, these parasitic inductances can cause switching loss, ringing and reliability issues.



ABOVE Figure 1: **A GaN device driven by a driver in a separate package (a); and an integrated GaN/driver package (b)**



RIGHT Figure 2: **Simplified diagram of the half-bridge circuit for simulations**

Integrating the GaN transistor with its driver (Figure 1b) eliminates common-source inductance and significantly reduces the inductance between the driver output and GaN gate, as well as the inductance in driver grounding. package parasitics. Optimizing these parasitics in an integrated package reduces parasitic issues and enables excellent switching performance at slew rates higher than 100 V/ns.

Simulation setup

To simulate the effects of parasitic inductances, we used a depletion-mode GaN half-bridge power stage in a direct-drive configuration (Figure 2). We set up the half bridge as a buck converter, with a bus voltage of 480 V, a 50 percent duty cycle with 50 ns of dead time (V_{OUT} = 240 V) and an inductor current of 8 A. The GaN gate is directly driven between the on and off voltage levels. A resistive drive sets the turn-on slew rate of the GaN device. A current source emulates an inductive load attached to the switch (SW) node in a continuous-conduction-mode (CCM) buck converter.

One of the most important parasitic elements in high-speed switching is the common-source inductance (L_{cs} in Figure 1a), which limits the slew rate of the device's drain current. In a conventional TO-220 package, the GaN source is brought out through bond wires to a single lead, where both the drain current and gate current flow. This common-source inductance modulates the gate-source voltage as the drain current changes. The common source inductance – including bond wire and package lead – can be higher than 10 nH, limiting the slew rate (di/dt) and increases switching losses.

With the integrated package shown in Figure 1b, the driver ground is wire-bonded directly to the source pad of the GaN die. This Kelvin source connection

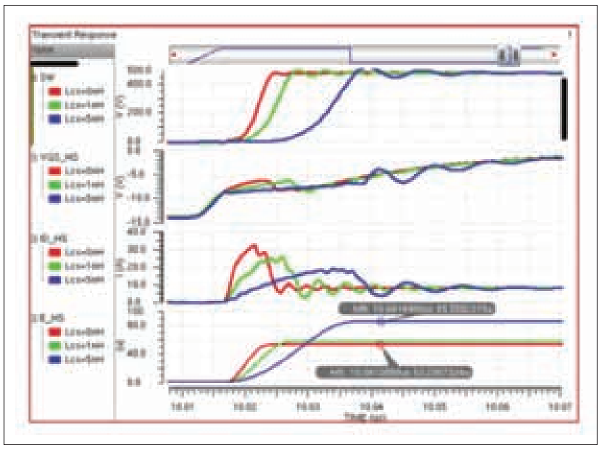


Figure 3: High-side turn on with different common-source inductance (red = 0 nH, green = 1 nH, blue = 5 nH). E_HS is the integration of V_{DS} and I_{DS} of the high-side device over time (energy consumption)

minimizes the common-source inductive path shared between the power loop and gate loop, allowing the device to switch at much higher current slew rates. A Kelvin source pin can be added to a discrete package; however, the additional pin makes it a nonstandard power package. The Kelvin-source pin also must be routed on the PCB back to the driver package, increasing gate-loop inductance.

Figure 3 shows hard-switching waveforms when a high-side switch turns on. With a 5-nH common-source inductance, the slew rate is cut in half due to the source degeneration effect. A lower slew rate translates to a longer transition time and leads to higher cross-conduction losses, as seen in the energy consumption plots. With a 5-nH common-source inductance, the energy loss increases from 53 µJ to 85 µJ, a 60 percent increase. Assuming a 100-kHz switching frequency, the power loss increases from 5.3 W to 8.5 W.

Gate-loop inductance includes both gate inductance and driver ground inductance. The gate inductance is the inductance between the driver output and GaN gate. With separate packages, gate inductance includes the driver output bond wire (L_{drv_out}), the GaN gate bond wire (L_{g_gan}) and the PCB trace (L_{g_pcb}), as illustrated in Figure 1a. Depending on package size, gate inductance can range from a few nH for a compact surface-mount package (for example, a quad flat no-lead) to more than 10 nH for a leaded power package (for example, the TO-220). If the driver is integrated with the GaN FET on the same lead frame (Figure 1b), the GaN gate is directly bonded to the driver output, which can reduce the gate inductance to less than 1 nH. Package integration also can significantly reduce driver ground inductance (from $L_{drv\_gnd} + L_{s\_pcb}$ in Figure 1a to L_{ks} in Figure 1b).

The reduction of gate-loop inductance has a great impact on switching performance, especially during turn-off when the GaN gate is pulled down with a resistor. The resistor needs to be low enough so that the device does not turn back on when its drain is pulled high during switching. This resistor forms an inductor-resistor-capacitor (L-R-C) tank with the gate-source capacitance of the GaN device and the gate-loop inductance. Equation 1 expresses the Q factor as:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} \qquad (1)$$

With a larger gate-loop inductance, the Q factor increases and ringing becomes higher. This effect is simulated with a 1-Ω pull down to turn off the low-side GaN FET, which appears around 9.97 µs in Figure 4 where the gate-loop inductance is varied from 2 nH to 10 nH. In the 10-nH case, the low-side V_{GS} rings 12 V below the negative gate bias. This significantly increases the stress on the GaN transistor gate.

Gate-loop inductance also has a significant impact on hold-off capability. When the gate of the low-side device is held at the turn-off voltage, and the high-side device is switched on, the low-side drain-gate capacitance sources a large current into the gate's hold-off loop. This current pushes the gate up through the gate-loop inductance. Figure 4 illustrates this event at around 10.02 µs. As inductance increases, the low-side V_{GS} is pushed higher increasing the shoot-through current, which is visible from the high-side drain current plots (ID_HS). The shoot-through causes the cross-conduction energy loss (E_HS) to increase from 53 ?J to 67 µJ.

One way to mitigate gate stress is to increase the pull-down resistance which in turn reduces the Q factor of the L-R-C tank, according to Equation 1. Figure 5 shows simulations with a 10-nH gate-loop inductance and pull-down resistance (R_{pd}) swept from 1 Ω to 3 Ω. Although the gate undershoot is limited to within a few volts below the negative bias with a 3-Ω pull down, hold-off capability becomes worse, causing larger shoot-through current. This

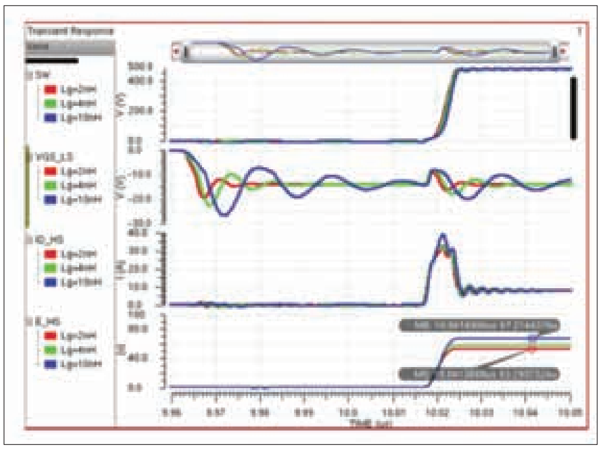


Figure 4: Low-side turn-off and high-side turn-on waveform at different gate-loop inductances (red = 2 nH, green = 4 nH, blue = 10 nH). E_HS is the high-side energy consumption

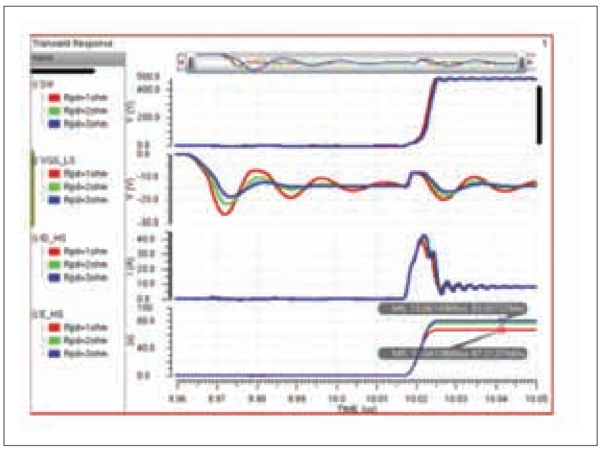


Figure 5: Simulation with 10-nH gate-loop inductance and pull-down resistance (R_{pd} = 1 Ω (red), 2 Ω (green) and 3 Ω blue). E_HS is the high-side energy consumption

is evident in the drain current plots. The E_HS energy plots show an additional 13-µJ loss in each switching cycle, an almost 60 percent increase from 53 ?J compared to a 2-nH gate-loop inductance and 1-Ω pull down (Figure 4).

Assuming a 100-kHz switching frequency, the power loss on the high-side device increases from 5.3 W to 8 W due to shoot-through caused by both high gate-loop inductance and high pull-down resistance. This additional power loss can make it very difficult to manage heat dissipation in the power devices and increases packaging and cooling costs. area An integrated GaN/driver package provides low gate-loop inductance and minimizes both gate stress and shoot-though risks.

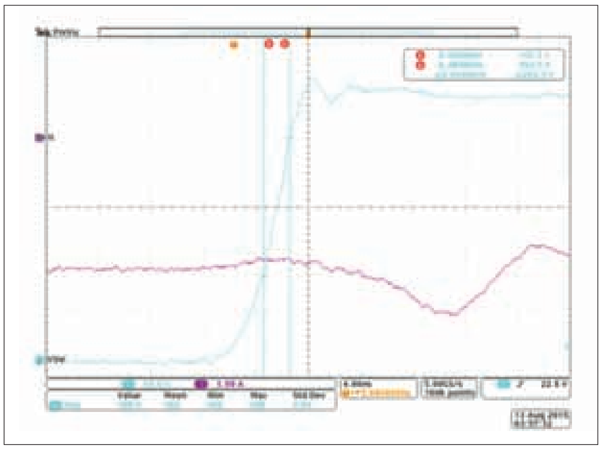


Figure 6: SW-node waveform of high-side turn on in a half-bridge buck (channel 2)

GaN device protections

Having the driver mounted on the same lead frame as the GaN transistor ensures their temperatures are close, since the lead frame is an excellent heat conductor. Thermal sensing and over-temperature protection can be built within the driver that shuts the GaN FET down when the sensed temperature goes beyond the protection limit.

A series MOSFET or a parallel GaN sense FET can be used to implement over-current protection. Both require low-inductance connections between the GaN device and its driver. Since GaN is usually switched very fast with large di/dt, extra inductance in the interconnection can cause ringing and requires a long blanking time to keep the current protection from misfiring. Integrating the driver ensures minimal inductive connections between the sensing circuit and the GaN FET so that the current-protection circuit can react as fast as possible to protect the device from over-current stress.

Figure 6 is the switching wave of a half-bridge created with two GaN devices in 8-mm by-8-mm quad flat no-lead (QFN) packages with an integrated driver. Channel 2 shows the SW-node when the high-side device is hard-switched at a slew rate of 120 V/ns at a bus voltage of 480 V. The optimized driver-integrated package and PCB limits the overshoot to under 50 V (waveform was captured with a 1-GHz scope and probes).

Conclusion

The package integration of a GaN transistor with its driver eliminates common-source inductance, thus enabling high current-slew-rates. It also reduces gate-loop inductance to minimize gate stress during turn-off and improves the device's hold-off capability. Integration further allows designers to build effective thermal- and current-protection circuits for GaN FETs.

Literature

"48 V GaN Point-of-Load Converter", Michael Seeman, Texas Instruments, Dallas, USA, Power Electronics Europe, July 2015, pages 29-31

TI showcased 600 V discrete GaN power FET and driver

At APEC, TI announced that they have leveraged existing manufacturing infrastructure and capabilities to qualify a 600-V GaN process. First product is an E-GaN FET with integrated driver in 8x8 QFN package. Building on years of expertise in manufacturing Silicon process technologies, TI has established a GaN-specific qualification methodology and application-relevant testing. With this 600-V process, TI will build out the portfolio of companion parts that will support high-voltage applications and new topologies such as UCD digital controller enabling 99 + percent efficient PFC – demonstrated at APEC. This 1 kW Totem-Pole PFC at 100-kHz frequency enables 30 percent lower volume vs. traditional designs and feature adaptive deadtime control due to UCD digital controller.

The TPS53632G is an analog controller, optimized for GaN in a 48 V/ 1 V POL application. Paired with TI GaN power stages and drivers, the controller can switch up to 1 MHz to minimize magnetic component size and reduce overall board space. The LMG5200 GaN power stage is designed specifically for this controller to achieve high frequency and efficiency as high as 92 percent with 48-V to 1-V conversion. Emerging applications such as 48 V-POL had a lot of interest. Google joined the Open Compute Project a few weeks ago and proposed a computer server-rack architecture based on a 48 V power-distribution bus to improve overall system efficiency. While the 48 V bus has been around for a long time, the push (and challenge) is for high-efficiency 48 V voltage regulators. EPC showcased TI's 48V-to-1V EVM which uses the LMG5200 GaN module (driver and FETs), announced at APEC last year, and the new TPS53632G.

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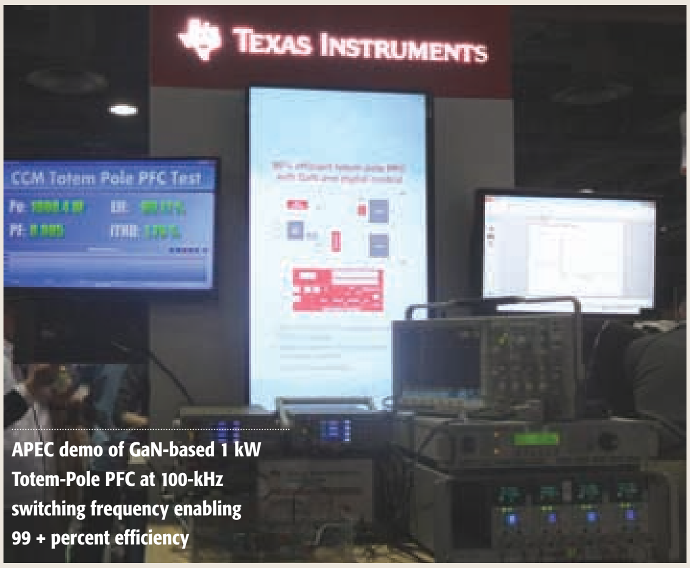


APEC demo of GaN-based 1 kW Totem-Pole PFC at 100-kHz switching frequency enabling 99 + percent efficiency

Digital Power-Converter Architecture and Applications

Complex and power-hungry computing applications used in manufacturing, Cloud services and telecoms to name a few, must continue to improve energy efficiency to meet customer demands cost effectively and minimise environmental impact. Digital power converters are an important part of the solution, and the latest generation of devise deliver extra advantages such as higher current density, enhanced thermal performance and improved reliability. **Bob Cantrell, Senior Applications Engineer, Ericsson Power Modules, Plano, USA**

The general rising trend of energy prices continues to drive demands for more energy-efficient computing in applications such as industrial control, cloud services, enterprise computing, and telecom. Among responses to these demands, digital power conversion effectively minimizes the energy lost throughout the power supply architecture, from the AC/DC front end to point-of-load converters on the server boards.

Digital power concepts

Traditional analogue power converters, such as point-of-load modules, are designed according to a fixed set of parameters. They can only deliver "best-fit" performance as the computing load and therefore power demand varies from minimum to maximum. Today's digital converters, on the other hand, sense and digitize the output voltage, and feed the digitized value to an algorithm executed in a microcontroller that generates the necessary control signals. The control strategy can be changed dynamically to optimize performance depending on the operating conditions at any given time.

A number of valuable advantages arise from this extra adaptability of digital power converters. Converter efficiency can be much more consistent across the load range, particularly at light loads where analog converters are often less efficient. In addition, the output voltage can be adjusted to optimize system efficiency. Moreover, for an application with a specific input voltage, output voltage, and capacitive load, the control loop of a digital converter can be optimized for a robust and stable operation and with an improved load transient response. This optimization will minimize the amount of required output decoupling capacitors for a given load transient requirement yielding an optimized cost and minimized board space.

Dynamic Loop Compensation (DLC) featured in PoL converters such as the new 60-A BMR466 converter (Figure 1), measures the characteristics of the power train and calculates the proper compensator PID coefficients. Once the output voltage ramp up has completed, the DLC algorithm will begin and a new optimized compensator solution (PID setting) will be found and implemented.

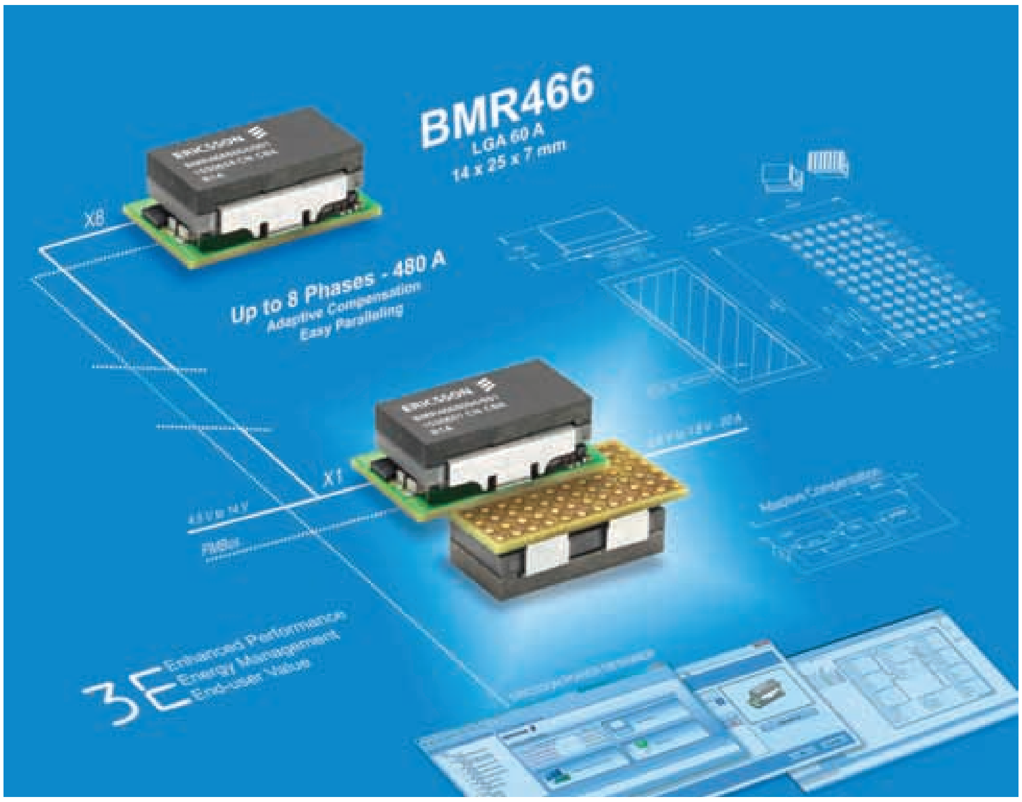


Figure 1: Digital converters measures the characteristics of the power train and calculates the proper compensator PID coefficients

DLC eliminates any need to design circuitry to stabilise the converter, and minimizes demand for filtering capacitors.

Digital technology not only simplifies design but also reduces the converter component count, which can accelerate time to market and save space on server boards. This real-estate is at a premium on expensive, multi-layer main boards, particularly in some of the more complex systems that may have 10, 15 or more PoL converters supplying multiple power domains and multi-rail devices like processors, FPGAs or ASICs. The BMR466 can run at up to up to 94.4 % efficiency with a 5V input and a 1.8V output, at half load.

The reduced component count of a digital converter also helps boost reliability. The MTBF of the BMR466 is calculated at 50 million hours based on the industry-standard Telcordia method. In addition, the BMR466 has an advanced thermal design that ensures the module can maintain extremely high reliability without temperature derating.

PoL construction

The LGA package platform enable to dissipate heat very efficiently. The internal layout has been optimized to promote dissipation from the power FETs, which are a major heat source in any PoL.

The PoL has a compact footprint so it can easily be placed near its load, which is helps to improve transient performance at the load. For systems that require power in excess of 60 A, up to eight BMR466s can be connected in parallel to supply up to 480 A to the load. Where multiple modules are used, two or more of the single-phase BMR466 PoL converters can be synchronized with an external clock to enable phase spreading, which reduces input ripple current and corresponding capacitance requirements and efficiency losses.

In addition to greater efficiency, enhanced simplicity and increased reliability, digital point-of-load power converters like the BMR466 also allow input and output voltage and current, internal temperature, duty cycle, and switching frequency to be monitored more easily than conventional analog converters can allow. This not only facilitates fast and accurate adjustment of converter settings, but also allows the supervising host system to identify any problems with the power supply or the board and determine any maintenance requirements.

The BMR466 is supported in the Power Designer software toolchain. These tools address the requirements both of development and prototyping and configuration of modules in a production environment. Engineers can build systems offline before buying any hardware, and can also use the tools in conjunction with an evaluation board.

Power Designer simplifies setup and initialization of digital power modules, for example by allowing access to the converter's control loop to optimize load transient response and stability, and by optimizing the input and output filters using the minimum possible number of capacitors to ensure the lowest BOM cost. Simple systems or multi-module/multi-phase systems can be configured, and the designer can take control of current sharing, sequencing and tracking, synchronization and phase spreading. In addition, real-time status monitoring of key parameters such as temperature, current and voltage helps identify and fix any faults. Once the design is complete, users can generate configuration files that can be applied directly to units on the production line.

Software-defined power

The BMR466 excels in applications that require increased power delivery within a reduced footprint without compromising reliability, without demanding significant extra provisions for cooling, such as fan or cold plate. The enhanced thermal performance allows these devices to operate reliably at high current for extended periods. The BMR466 has been shown to be capable of delivering 60 A to a 1.8V load, with ambient air temperature of 70°C and airflow of 1.0 m/s. The derating graph of Figure 2 shows that this part will be able to deliver improved thermal performance and reliability compared to conventional digital PoLs for the same amount of airflow.

The BMR466 is compliant with PMBus commands, making the device ready for the coming generation of software-defined power architectures. These will take advantage of the adaptability of digital converters to introduce new and versatile operating modes, under software control to achieve levels of adaptability and responsiveness never seen before.

Now that modules such as the BMR466 have raised efficiency to yet higher levels, software-defined power takes the search for further gains up to the system level. Features such as dynamic bus-voltage adjustment and phase spreading are a couple of techniques that can be applied by manipulating converters in real-time

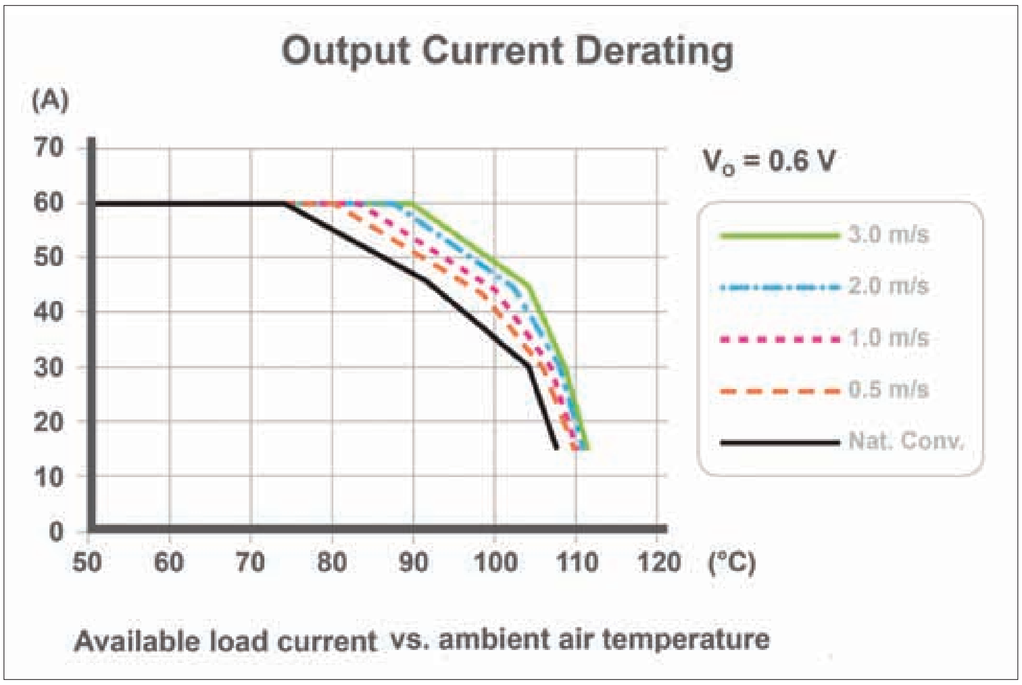


Figure 2: Enhanced thermal performance helps enhance reliability compared to conventional converters, without increasing cooling demands

using PMBus commands, to further increase the efficiency, reliability and controllability of tomorrow's distributed power architectures.

The most recent PKB4313D is a low-profile, 12 V-output, digital DC/DC converter module that offers up to 25 A current handling and 300 W of power to deliver tightly regulated voltages to point-of-load DC/DC regulators. Compatible with the DOSA (Distributed-power Open Standards Alliance) 5-pin eighth-brick footprint standard and offering an input range from 36 V to 75 V, this bus converter is suited for intermediate bus conversion in ICT (Information and Communication Technologies) applications.

PMBus Enables Standardized Digital Power

The PMBus protocol has enabled the electronics industry to standardize communications to their power conversion circuits. Controlling, configuring, and monitoring of AC/DC power supplies, isolated DC converters ("bricks"), and non-isolated point-of-load (PoL) converters has proliferated across the power supply industry.

The original idea of a standardized digital power management protocol, soon deemed PMBus, was conceived in 2004. Several power supply manufacturers and IC suppliers collaborated together as the original promoters of PMBus. With business and technical persons from these contributors, the Special Interest Group (SIG) was created, and the original PMBus specification was developed and released in March 2005. The specification continues to be driven by the System Management Interface Forum (SMIF). The new AVSBus addition in Part III of the latest PMBus revision is creating a lot of interest with board-level system designers. It enables real-time, dynamic control of high-power, high-speed, complex digital logic devices like ASICs, FPGAs, memory and processors with multi-rail voltage requirements. These capabilities will gain support in data center and other computing applications, and certainly spread to other industry segments. This will serve to accelerate broader adoption of PMBus 1.3, which will in turn increase demand for PMBus-compliant power conversion solutions.

At APEC 2016 PMBus support options for the Linux platform (in particular Ubuntu on the Raspberry hardware platform) has been presented within an industry session. This session addressed the needs of power engineers from the perspective of design, debug and manufacturing, mainly the tradeoffs when choosing between Linux sysfs, /dev/i2c, and kernel drivers. According to presenter Michael Jones the Raspberry and Linux platform are open and SMBus is built-in into the Ubuntu kernel, thus PMBus will be supported across various Linux versions and might enable the path towards software defined power.

www.pmbus.org

Robustness Against Parasitics By SOI

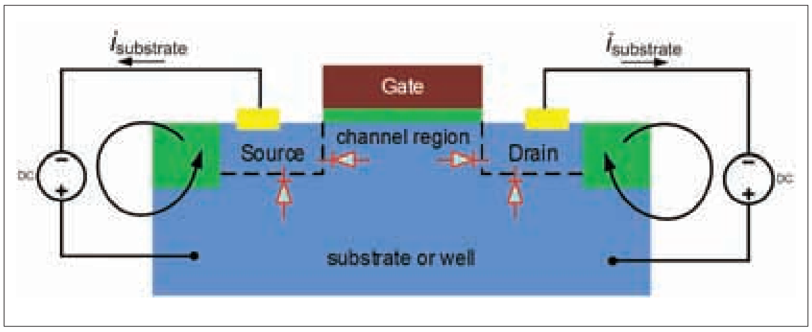
Monolithic level shifting gate driver ICs suffer heavily from the negative voltage which can occur at the high side reference pin, when standard IC technologies are used. Silicon-on-insulator (SOI) technology, however, provides the robustness to address this behavior. Three half bridge level shifter gate driver ICs are tested under static and transient negative voltage condition. This article discusses the test method and points out the performance of each gate driver IC under the negative voltage condition.
Wolfgang Frank, Jinsheng Song, Infineon Technologies, Neubiberg, Germany

ICs based on standard Silicon technology exhibit low tolerance to negative voltages presented to their inputs and outputs. A small negative voltage in the range of -0.8 to -1 V at one of the IC pins may result in uncontrolled substrate currents. The substrate currents are injected for instance by a forward biased PN junction from substrate to active area according to Figure 1. This usually triggers an undefined IC behavior.

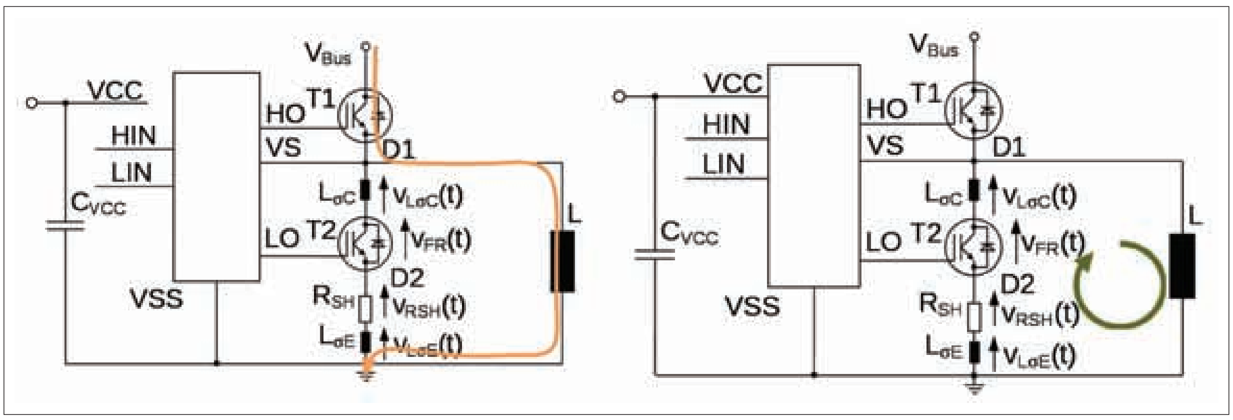
This effect caused by negative voltage transients is particularly pronounced in gate driver ICs. Gate driver ICs are used to control power transistors which operate at high voltages and currents. The switching mode operation of power transistors injects di/dt- or dv/dt-transients. This stimulates resonant circuits consisting of parasitic elements such as stray inductances or coupling capacitances. Oscillations in both, currents and voltages, are the consequence which often exposes gate driver IC terminals to a negative voltage. This can lead to uncontrolled changes of the output states of the gate driver. A latched turn-on state of the gate driver IC can even damage the system. Figure 2 shows examples of a half bridge configuration including its parasitic elements and the voltage which is induced by them.

The half bridge consists of two IGBTs T1 and T2 accompanied by the freewheeling diodes D1 and D2. The half bridge energizes loads such as transformers or electric machines. The load is receiving power from the DC link power supply, when the high side transistor T1 is on according to the left part in Figure 2. When T1 is off, the load current commutates onto the low side portion of the half bridge so that diode D2 conducts the load current as sketched in the right part of Figure 2. Parasitic elements are visible for the low side commutation path only. Similar stray inductances are physically present in the high side path as well.

It can easily be seen that there will be a transient voltage drop over the elements $L_{\sigma C}$, $L_{\sigma E}$, the shunt R_{SH}. Also there is a forward recovery effect of the freewheeling diode D2. All voltage drops result in a negative voltage at terminal VS of the gate driver IC. The amplitude of such negative voltages can reach several 10 V in the system and therefore requires a high robustness of the gate driver IC. Other aspects, such as ground bouncing, also require a high robustness of the IC against



RIGHT Figure 1: **Cross section of a transistor structure in bulk technology**



BELOW Figure 2: **Half bridge configuration with indication of the current path for energizing the load (left) and freewheeling of the inductive load current (right) including the parasitic elements of the low side path**

	Infineon 2EDL05N06PF [1]	Device 2	Device 3
Technology	Silicon-On-Insulator	Bulk silicon	Bulk silicon
Isolation level	600V	600V	600V
Isolation method	Level shifter	Level shifter	Level shifter
V_{s_tran} (t < 500ns) [V]	-50	Unknown*	Unknown*
V_{static} [V]	-0.5	-0.3	-0.3
Bootstrapping	Internal diode	Internal FETs	External diode
I_{Opk+} [A]	0.36	0.4	0.35 (min 0.25)
I_{Opk-} [A]	0.70	0.65	0.65 (min 0.5)

* Not specified within the respective product datasheet

LEFT Table 1: Tested half bridge drivers

negative voltages at other terminals such as the signal input terminals LIN and HIN. The duration of such transients is related to the time it takes to commutate the current from the high side IGBT T1 into the freewheeling diodes D2. Usually, these negative voltage transients disappear quickly after this period.

This study was performed on various half bridge gate driver ICs. The tested gate drivers and their main operating parameters are listed in Table 1. The parameter list shows that each of the devices is tolerant to negative voltages of various amplitudes and durations. The tests were designed in order to push the tested ICs to their limits and to discover possible anomalies in gate driver operation induced by static and dynamic or pulsed negative voltages.

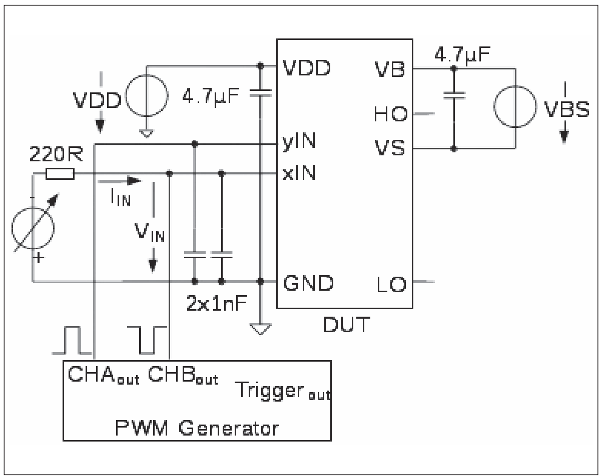


Figure 3: Simplified test circuit for static tests

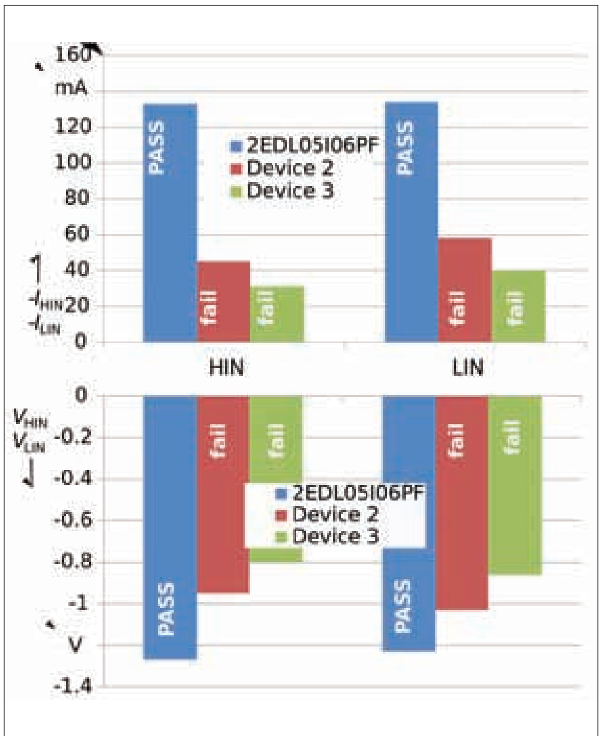


Figure 4: Test results of static test with negative voltage applied to signal input terminals

Static tests

The ICs can be exposed to negative voltages statically in case of a malfunction of other circuits. As mentioned above, the driver ICs can also be regularly exposed to short negative pulses as a consequence of transient phenomena. These can have high amplitude up to several tens of volts and usually have a short duration of a few hundreds of nanoseconds. Such pulses can repetitively appear at the terminal VS of the gate driver during a normal circuit operation due to existing parasitic elements as explained in Figure 2. In both cases the driver ICs should be able to maintain a normal operation without a malfunction in order to prevent damage to the power devices.

The static tests were performed using the circuit given in Figure 3. The IC is supplied from a 15 V source to enable the operation of the gate driver outputs. The acceptance criterion of the test is the uninterrupted transmission of the continuous PWM input signals to the related output. Any kind of latch state of any output will lead to "fail".

The static test injects a voltage to the input signal terminals for the low side output or the high side output according to Figure 3. The negative voltage opens a path from ground to the input terminals either by means of forward biased PN-junctions in case of bulk technologies or by discrete clamping diodes in case of SOI. The clamping therefore has a diode characteristic.

Figure 4 shows the fail conditions at the end of the test. The 2EDL05I06PF is the only part, which achieved “PASS” in this test. The negative voltage for this part is approximately V_{IN} = -1.25 V for terminal HIN and LIN. The injected input current exceeds I_{IN} = -130 mA. The test had been stopped in order to avoid a thermal overstress of the clamping diode structure.

Device 2 shows faulty behavior once the negative voltage at the inputs reaches about V_{IN} = -1.0 V. The failure mode observed can be both, latch-on and latch-off. It is important to note that the latch states are occurring randomly. Even more critical is the fact that even the not tested channel can latch as well. Thus, the high side output HO latches when the low side input LIN is under test and vice versa. The device 3 also shows unstable behavior. This occurs at approximately V_{IN} = - 0.8 V. The injected current is only about I_{IN} = -40 mA. The result also is a latched output similar as with device 2; the outputs may latch either on or off.

Dynamic tests

The dynamic tests were performed using the circuit given in Figure 5. The negative pulses were applied directly at terminal VS of the device under test as these are most likely the ones where such a high amplitudes and short durations of the negative pulses occur. The input side of the DUT was supplied by signals from a PWM generator.

The IC is supplied from two 15 V power supplies V_{DD} and V_{BS} to establish a normal circuit operation. The second power supply V_{BS} is required since the bottom switch in the phase arm is not available for bootstrapping and the IC is not affected by any bootstrapping activity. The bottom switch was replaced by a pull down resistor in order to enable suitable injection of negative voltages to the terminal VS during intervals when the bottom switch is supposed to be on. The PWM generator was manually triggered to generate a sequence of nine pulses. The fifth pulse in the sequence is triggering the second pulse generator which is used to drive the negative voltage. This synchronization is done to maintain the negative pulse generation to the time interval when the upper switch is turned off. During the on-state of IGBT T1 in Figure 5, the voltage on VS is clamped to the DC link voltage of 100 V. The injection of negative voltages is therefore restricted. The amplitude of the negative pulse is controlled by the voltage supply -VN whereas the duration of the pulse is controlled by settings of the pulse generator. The amplitude of the pulse is varied from -10 to -60 V; the duration of the pulse varies between 50 and 600 ns.

The test pulse configuration is shown in Figure 6. The negative pulse is applied in the moment just after the turn-off of the upper switch. This pulse configuration was chosen because in a practical application it is most probable that negative voltage pulses would be injected into terminal VS in this instant due to changes of the power devices’ switching states and freewheeling effects. The delay Δt as well as the pulse width T_{PW} of the negative pulse are varied in a wide range when the DUT revealed sensitivity to negative pulses further away from the switching transitions. This is done to include cases when the negative pulses are generated in rather remote locations within the power circuit, for example in other circuit phases.

The acceptance criteria for all the tests is the undisturbed transmission of the input PWM signal from the input terminals LIN and HIN to the outputs LO and HO, respectively.

Test results

The 2EDL05I06PF performed in the tests without any critical observation. The high side output reacts after the IC´s turn-off propagation delay $t_{pd(off)}$. This is followed by the decrease of the emitter voltage due to the pull-down resistor being connected to the emitter of transistor T1 according to

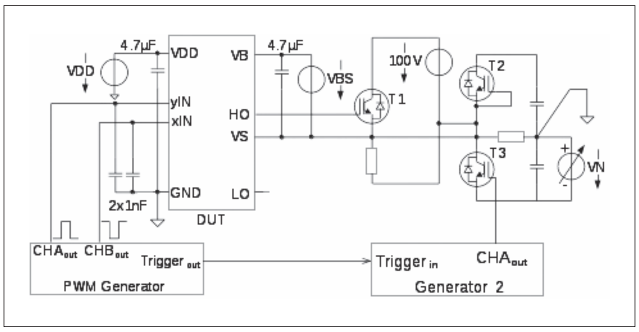


Figure 5: Simplified test circuit for dynamic tests

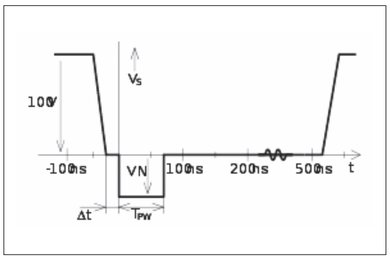


Figure 6: Test pulse configuration, negative pulse at turn-off of the upper switch

Figure 5. The negative pulse of the duration T_{PW} is applied after the interval Δt right after the turn-off of T1. There are no anomalies detected in the driver function.

Device 2 behaves as expected at negative pulses with amplitudes higher than –20 V respectively pulses shorter than approximately 400 ns. In case of pulses with lower amplitude or longer duration, the high side output HO tends to change from Low state to High state even if not requested by the input signal.

Device 3 performed well in the test. Anomalies were detected in the driver function when the negative pulse exceeds -50 V and 500 ns.

Conclusion

Three level shifter half bridge driver ICs with focus on the negative voltage influence were compared in this article The executed tests include static tests and dynamic or pulse tests in order to cover various situations which can occur in practical applications. The Silicon-On-Insulator (SOI) technology is stable during operation even under statically applied negative voltages. From the test results presented, it can be concluded that the SOI-based 2EDL05I06PF gate driver IC outperforms other driver ICs based on conventional bulk silicon technology regarding negative voltage immunity. SOI-Technology eases the designers challenge to create robust power electronic devices and inherently leads to more reliable designs.

Literature

Frank W., Song J., SOI technology provides robustness against parasitic elements injecting negative voltages, Proceedings PCIM Europe 2015

Latest Current Probes from PEM

Motor installers and design engineers can deal more effectively with high frequency (hf) common-mode currents caused by variable-frequency drives, using the latest non-contact current probes from Power Electronic Measurements (PEM) Ltd.

The new CMC series of current probes, using Rogowski technology, empower engineers to assess the magnitude of the threat posed by hf common-mode currents, that can damage motor bearings and interfere with nearby electrical equipment. The current measurements can help determine suitable corrective action, such as fitting brushes, insulated bearings, or choke coils, and with further measurements assess the effectiveness of the chosen remedy.

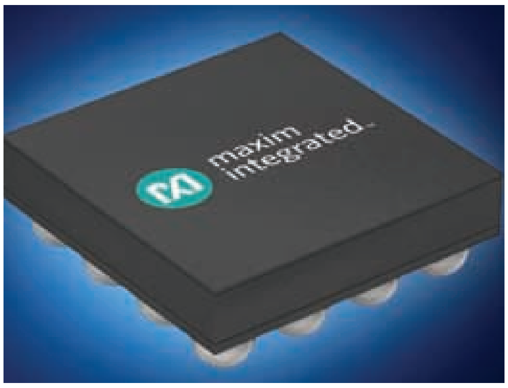
The screened coils have excellent immunity to voltage disturbances and a low frequency (-3dB) bandwidth that attenuates unwanted 50/60Hz magnetic fields while maximising the SNR of the measurement of the high frequency common mode currents. Available in coil sizes from 300 to 1000mm, and longer if required, making them ideal for use with a wide range of motor shafts. Even with a coil circumference of 1000mm the CMC probes can achieve a high frequency (-3dB) >10MHz.

The probes are available in three sensitivity grades for measuring bearing currents up to 37.5A, 75A or 150A peak. The peak detected current corresponds to a maximum output voltage of ±7.5V when connected to an oscilloscope input via the BNC output provided.

Further information can be found at www.pemuk.com/products/cmc-probe.aspx

Accurate Current, Voltage and Power Monitoring IC

Mouser Electronicss is now stocking the MAX44298 low-side current, voltage and power monitoring IC from Maxim Integrated. The MAX44298 offers power, current, and voltage monitoring plus reference with precise measurement and programmable current-sensing of full-scale voltages of 5 mV, 10 mV and 2 0mV. With its wide single supply voltage range from 3 V to 5.5 V, the MAX44298 allows simple sharing of supplies with either an ADC or a microcontroller, and is an ideal solution to improve measurement quality while saving cost and space in a variety of power monitoring applications.



The MAX44298 IC offers instantaneous power with accurate power measurement of less than 1.1 % of reading total error. Itfeatures three outputs, all of which are scaled to a full-scale current of either 100 µA or 50 µA, with the full-scale current option set through a simple pin-strap. The device's reference output allows an additional output current of either 100 µA or 50 µA, and this current can be used to create a reference voltage for the ADC being used to measure power, voltage, and current signals. Having the MAX44298 use currents rather than voltage to convey the measured signals to the ADC also avoids any errors caused by voltage drops across the parasitic resistance of the PCB - a significant factor for high-current systems. The 16-bump, 2.4 mm × 2.4 mm MAX44298 IC is specified at a temperature range from 0 to +85 degrees Celsius, and is ideally suited for many power monitoring applications.

www.mouser.com/new/maxim-integrated/maxim-max44298-monitor/

DC/DC Controller for 65-V Operation

Texas Instruments introduced a 2.2-MHz, dual-channel synchronous buck converter with a unique set of features designed to significantly reduce electromagnetic interference (EMI) and high-frequency noise in high-voltage DC/DC step-down applications such as automotive infotainment and high-end cluster power-supply systems. The LM5140-Q1 controller includes dual outputs with phase interleaving and is offered in wettable flank packaging that speeds manufacturing. Together with TI's WEBENCH® Automotive Design tool, the LM5140-Q1 enables engineers to get their automotive designs to market faster. The LM5140-Q1 uses external MOSFETs to support up to 10-A dual-channel loads for high-end infotainment systems and other noise-sensitive systems. The LM53600-Q1 and LM53601-Q1 support 650-mA and 1-A load current, respectively, for emerging advanced driver assistance (ADAS) systems. The LM53602-Q1 and LM53603-Q1 deliver 2-A and 3-A loads, respectively, for higher-current ADAS and infotainment systems.

www.ti.com/lm5140q1-pr

Longer Life Expectancy for PFC Capacitors

TDK Corporation offers with EPCOS PhaseCap® Energy two new series of high power capacitors for power factor correction. These components are available with gas or resin-filled housings. They are designed for voltages of 230 V AC to 690 V AC and offer a reactive power of between 5 kvar and 33 kvar. The life expectancy of the B25674* series of gas-impregnated capacitors has been possible to extend by nearly 40 % from 130,000 to 180,000 hours. The maximum permissible inrush current was also increased by 25 percent to 500 x I_R. The maximum number of switching cycles per year has been doubled from 7500 to 15,000. The maximum permissible operating temperature as per IEC 60831-1 has also now been raised by 5 K to 60°C. The B25675* series of resin-filled capacitors features an even longer life expectancy of 200,000 hours and is likewise designed for a maximum operating temperature of 60°C and a maximum permissible inrush current of 500 x I_R. A further significantly improved feature of both series is their increased energy density in comparison with the existing types.

www.epcos.com/pfc_phasecap_energy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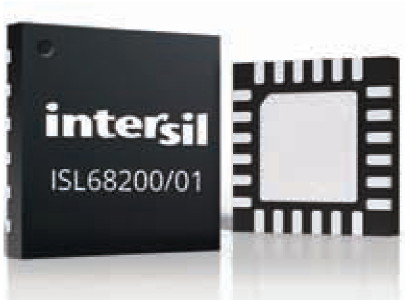
Power Modules for Railway Applications

Powerbox launches two products in its Railway DC/DC power converters ENAR150D series. The products perform at 93% high efficiency, saving energy, reducing power dissipation and allowing more power available in confined environment. The new series includes an extensive set of accessories, simplifying power integration into trains and related vehicles. Combining high efficiency power switching and optimized topology to reduce component count by 25% compared to conventional topologies, contribute to improve the MTBF and to the long-term reliability. Developed for low profile applications and efficient conductive-cooling, the ENAR150D series employs the latest planar-on-board technology, improving power dissipation and robustness towards shocks and vibration. The two new products, ENAR150D24 and ENAR150D110 deliver 150 W output power, with a typical efficiency of 93 % and are housed in slim packaging of 18.5 mm (0.73") width, making possible to integrate the power modules in tight and confined environments. Designed to operate from 24 VDC (16.8 – 30 VDC) or 110 VDC (77 – 137.5 VDC), the ENAR150D24/2x12 and ENAR150D110/2x12 feature dual isolated 12 V outputs that can be combined in four different modes, independent, parallel, serial and symmetrical.

www.prbx.com

Digital Hybrid PWM Controllers with PMBus

Intersil announced two new PMBus™ compatible, single-phase digital hybrid DC/DC controllers that provide point-of-load (POL) conversions for FPGAs, DSPs, ASICs, processors and general purpose system rails. The ISL68200 with integrated MOSFET drivers and ISL68201 with PWM output simplify power supply designs for data center routers, servers and storage, as well as wireless infrastructure equipment. The ISL68200 can drive external MOSFETs directly, while the ISL68201 is paired with Intersil's DrMOS (Integrated Driver and MOSFET) power stage to create a complete voltage regulator solution. The ISL68200 and ISL68201 digital hybrid controllers provide the performance of R4™ control loop with the benefits of a digital PMBus interface. Both controllers are fully configurable with external pin-strap resistors, which provide a familiar engineering design flow and eliminate the need for non-volatile memory. Designers can use the PMBus interface and PowerNavigator GUI software to read back input and output voltages or temperature telemetry, monitor fault reporting bits, and conduct on the fly changes to the output setpoint. For systems where PMBus functionality is not required, the interface can be used to debug the power supply during board bring-up, and then left disconnected in final production. This feature speeds development by allowing designers to quickly modify important parameters like switching frequency, output voltage and loop gain to fine-tune power supply performance without using a soldering iron to change components.



www.intersil.com/products/isl68201

The Rectiverter combines rectifier, inverter and transfer switch in a box

Eltek in Norway launches the Rectiverter, a power conversion box combining the functions of a rectifier, an inverter and a "static transfer switch". The Rectiverter is a 3-port bidirectional converter that simplifies solutions providing both AC and DC power to critical loads in telecom, data center and industrial applications. It features a power conversion efficiency of 96% in mains mode and 94% when operating as an inverter. First product is the Rectiverter HE, delivering 230 V/1500 W AC and 48 V/1200 W DC. It features high power conversion efficiency, and is controlled by a single controller. Rectiverter systems are available as single or 3 phase, input and output, and can be scaled to meet any power demand.

The Rectiverter combines the functions of a rectifier and an inverter, and eliminates the need for a static transfer switch. The Rectiverter has three ports - one AC input, one AC output and one bidirectional DC port for both input and output. During normal operation, the Rectiverter provides both AC and DC power with a total load of up to 2000 W per cabinet. The AC input is first rectified, then fed to a built-in inverter for AC output. The rectified AC input is fed to a DC/DC converter for appropriate DC load output, and to batteries for charging. In case of AC (mains) failure, the DC flow is reversed from the batteries to feed the inverter for conversion to AC, and to take over the DC load. The transition from AC to DC feed is instantaneous and with no load disturbance. The Rectiverter is a combined AC UPS and DC power supply, but can also be used as a pure inverter. "To integrate a rectifier and an Inverter in the same box, with bidirectional power flow and still maintain high efficiency is an impressive achievement," commented Dr. Tore M. Undeland, Prof Emeritus of Electrical Engineering at Norwegian University of Science and Technology (NTNU).

www.eltek.com/rctvpr

MLCCs Specified at 175°!C

Knowles Dielectric Laboratories (DLI), has announced a number of specification extensions to their Ultra-low ESR and High Q MLC capacitors. In both cases DLI have taken the temperature performance to a higher level of 175°C. These new improved TCC (temperature coefficient of capacitance) figures apply to DLI's UL ceramic dielectric capacitors in case size C07 (0711) and AH porcelain dielectric capacitors in case size C17 (1111) – both with SMD compatibility. Applications range from Impedance Matching, Power Handling, DC Blocking, Bypass, Coupling, Tuning and Feedback. UL is an EIA Class I Stable TC, NP0, Ceramic dielectric, with Ultra Low ESR; High Q, and Low Noise. Parts can now be operated up to +175°C with TCC of 0 ± 60 ppm/°C (limited to +125°C at 0 ± 30 ppm/°C). The AH EIA Class I Positive TC, P90 Porcelain dielectric now achieves the +175°C rating with a TCC of 0 ± 20 ppm/°C. Applications are where High Q, coupled with Low ESR, is a priority. They have a dielectric constant that increases with temperature (90ppm/°C). Capacitance range starts at 0.3 pF and climbs to 1000 pF over the voltage range 50 V, to a high working voltage of 1 kV.

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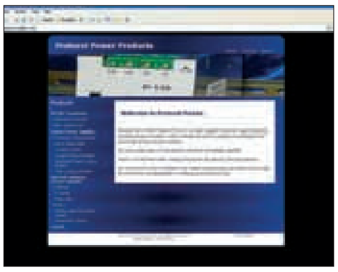

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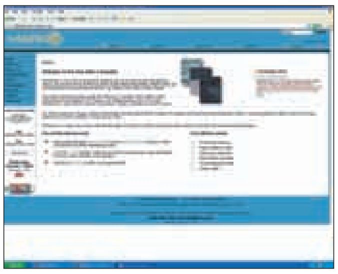

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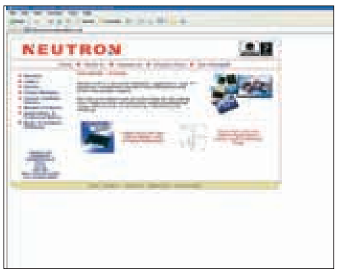

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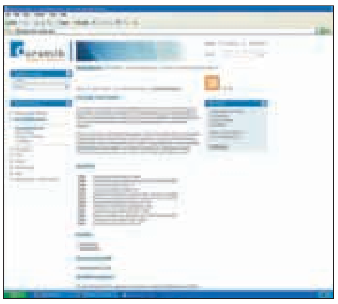

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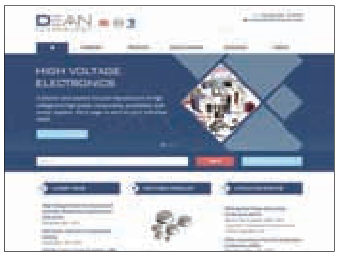

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