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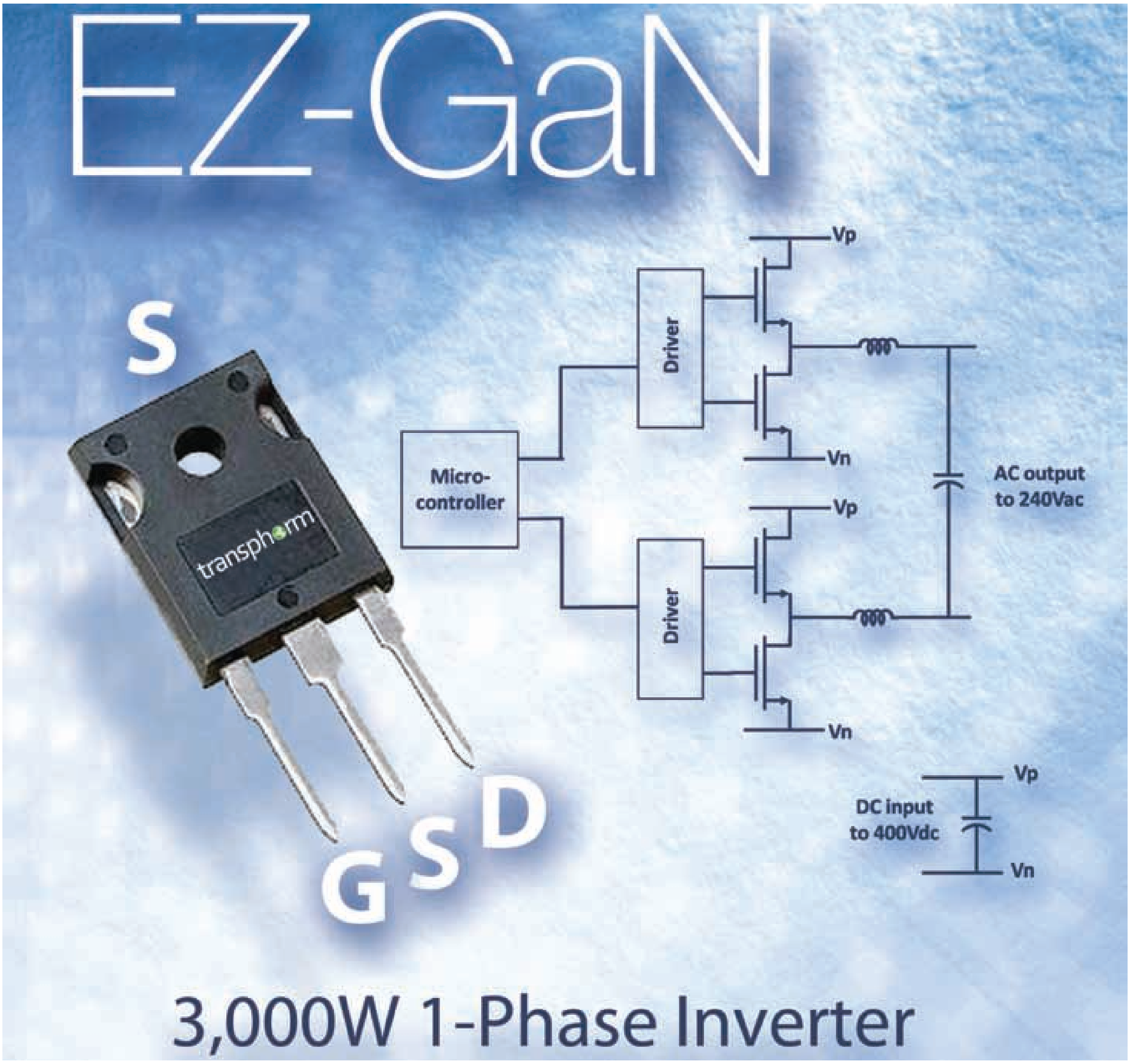
POWER GaN
Progress of GaN Transistors



THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

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Market News

PEE looks at the latest Market News and company developments

COVER STORY

Progress of GaN Transistors

Over the last several years, GaN semiconductors have emerged as a leading technology enabler for the next wave of compact, energy-efficient power conversion systems – ranging from ultra-small adapters, high-power-density PCs, server and telecom power supplies, to highly efficient PV inverters and motion control systems. Continuous progress has been made since the JEDEC qualification of Transphorm's 600 V-rated GaN-on-Si devices in 2013. Systematic voltage-accelerated off-state stress tests and temperature-accelerated on-state stress tests reveal an intrinsic Mean Time to Failure (MTTF) of 8x107 and 3x107 hours at the rated voltage and rated temperature respectively. The TPH3205WS is a first 600V GaN (Gallium Nitride) transistor in a TO-247 package. Offering 63 m? on-resistance and 34 A current rating, the device utilizes the source-tab connection design, which reduces EMI at high dv/dt to enable low switching loss and high-speed operation in power supply and inverter applications. An already demonstrated 2.4kW, bridgeless totem-pole PFC design exhibits near 99 % PFC efficiency at 100 kHz operation. There has been also strong interest in developing GaN power devices for automotive applications due to the physical arguments of their potential benefits for next generation vehicles. However, most previous reports have been consumed with discussion of device structures, characteristics and challenges in achieving reliability. In passing JEDEC qualification of 600-V rated GaN transistors, reliability can now be assessed to justify GaN's suitability for the stringent automotive applications. Although it will take more time to develop mature manufacturing of high current GaN devices for the main motor drive in an Electric Vehicle (EV), it is now attractive to employ present GaN switch products for auxiliary power blocks up to 6 kW. Full story on page 32.

Cover supplied by Transphorm Inc, Goleta, USA.

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PCIM Europe 2015

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GaN FET Module Performance Advantage over Silicon

Gallium Nitride (GaN) FETs are increasingly finding use as next-generation, high-power devices for power electronics systems. GaN FETs can realize ultra-high power-density operation with low power loss due to high carrier mobility in the two-dimensional electron gas (2DEG) channel, and high breakdown voltage due to large critical electric field. GaN FETs are a majority carrier device, therefore, the absence of reverse recovery charge creates a value proposition for high-voltage operation. **Narendra Mehta, Senior Systems Engineer GaN products, Texas Instruments, Dallas, USA**

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Gallium Nitride Transistors Drive Automotive Applications

Enhancement-mode gallium nitride transistors have been in production for over five years. As the technology has matured it has been adopted into a number of automotive applications such as cockpit wireless charging, LiDAR sensing, and EV charging with many more to follow. **Alex Lidow, CEO Efficient Power Conversion Corporation, USA**

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DC/DC Converter Modules Replace Discrete Designs

The decision to 'make or buy' a DC-DC converter has never been straightforward with many factors to consider. More low power applications can now be satisfied with new generations of low cost modules. **Paul Lee, Director of Business Development, Murata Power Solutions, UK**

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Products

Product update.

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Website Product Locator

Emerging Silicon Substitutes

The power semiconductor market is growing again and has reached $11.5 billion in 2014, a growth rate of 8.4 percent and will surpass $17 billion by 2020. In line events such as PCIM Europe (May 18-21 in Nuremberg) are also growing. Market growth will be driven by a significant increase in electric and hybrid vehicle sales, as well as the ramp-up of renewable energy and more smart-grid technology implementation. Power modules, and more precisely IGBTs, will lead this growth. Modules are expected to reach a CAGR 2014-2020 of 10.3 percent, compared to 5.1 percent growth for discrete components, according to market researcher Yole. The new wide band gap device market will also drive growth, SiC and GaN have proved to be powerful solutions. Ready to be implemented in numerous applications, WBG solutions will represent around 5 percent of the overall market by 2020, even though in terms of units their presence will still be limited. Due to the growing and important role of WBG semiconductors efficient packages will become mandatory, so that devices' high frequency, high voltage or high temperature capabilities can be best exploited.

The emerging market for SiC and GaN power semiconductors is forecast by market researcher IHS to grow by a factor of 17, during the next 10 years, energized by growing demand for power supplies, hybrid and electric vehicles, photovoltaic inverters and other established applications. Worldwide revenue from sales of SiC and GaN power semiconductors is projected by IHS to rise to $2.5 billion in 2023, up from just $150 million in 2013. The key factor determining market growth will be how quickly SiC and GaN devices can achieve price parity with - and equivalent performance of - Silicon MOSFETs, IGBTs or rectifiers. Price and performance parity is forecast to occur in 2020, and the SiC and GaN power market is subsequently expected to experience tremendous growth through 2023.

Just after the $3-billion acquisition of International Rectifier with a focus on their GaN-on-Silicon technology and intellectual property Infineon expands its GaN-on-Silicon technology and product portfolio. The company now offers both Panasonic's enhancement mode and IR's cascode configuration GaN-based platforms for applications requiring high levels of energy efficiency including Switch Mode Power Supplies (SMPS) used in server, telecom, mobile power and consumer goods such as Class D Audio systems. GaN shall complement the portfolio of MOSFETs and SiC active devices. Infineon will start by developing a portfolio of discrete switches, but will soon also offer integrated solutions; leveraging the fact that GaN is a viable alternative technology. Infineon recognizes that GaN switches will enable the next level of system efficiency, energy saving and power density and, therefore, decided to invest a significant amount of its R&D effort to pursue this challenge. And Transphorm Inc. announced in partnership with ON Semiconductor the introduction of two co-branded 600 V GaN cascode transistors and a 240 W reference design that utilizes them. This introduction builds on the partnership between Transphorm and ON Semiconductor announced in September 2014. The Transphorm GaN HEMT devices are in mass production at the Fujitsu Semiconductor group's CMOS-compatible, 150 mm wafer fab in Aizu-Wakamatsu, Fukushima, Japan. The large-scale, automotive-qualified facility will allow expansion of GaN power device production according to the growing demand. According to EPC, also one of the early vendors, enhancement-mode gallium nitride transistors have been commercially available for over five years and have infiltrated many applications previously monopolized by the aging Silicon power MOSFET. At ISPSD 2015 CEO Alex Lidow will discuss the state-of-the-art and the expected progress of GaN technology over the next few years, showing that Moore's Law is alive and well in the world of power semiconductor technology. He will also enumerate the advantages of GaN over silicon in terms of performance, cost, and reliability – as he will do at PCIM Europe some days later. Recently the automobile industry has begun to show its vision of the future for the fully-mobile lifestyle. The dashboard is being taken over by the smartphone, the car is being taken over by sensors and computers to become semi, and eventually, fully autonomous. And, our cars are going semi, and eventually fully electric. Power devices made with Gallium Nitride are an integral part of every aspect of this mobility trend. These new generation power devices have already carved out a significant position in the next generation automobile, Lidow will point out on occasion of PEE`s Special Session "Power GaN for Automotive Applications" at PCIM on May 20. According to Transphorm there has been strong interest in developing GaN power devices for automotive applications due to the physical arguments of their potential benefits for next generation vehicles. Although it will take more time to develop mature manufacturing of high current GaN devices for the main motor drive in an Electric Vehicle, it is now attractive to employ present GaN switch products for auxiliary power blocks up to 6 kW. GaN devices built upon Silicon substrates will meet the needs of the automotive industry in terms of voltage and current rating, will GaN Systems underline in this Special Session. The suggested ratings for a GaN e-Mode power transistor are a voltage blocking capability 600 V and minimum single-die current rating of 100 A. To directly compete with Silicon, and allowing no premium for higher performance (efficiency), the GaN transistor would have to be priced at less than $10/cm^2 – and this will be feasible. To complement this Session, PEE also has organized a panel discussion "Quo Vadis Power GaN" scheduled May 20, 2:00-3:00 pm, in the PCIM Industry Forum featuring panelists from EPC, GaN Systems, Infineon, Transphorm and Texas Instruments.

These activities underline our mission to penetrate new and promising technologies throughout our readership in print and online. Hope to welcome you there.

Achim Scharf
PEE Editor

Power Semiconductors - Back to Growth

The power semiconductor market is growing, after two years of stagnancy. According to Yole's market research, the power semiconductor devices market reached $11.5 billion in 2014, a growth rate of 8.4 percent and will surpass $17 billion by 2020.

The outlook for the years ahead is also optimistic. Market growth will be driven by a significant increase in electric and hybrid vehicle (EV/HEV) sales, as well as the ramp-up of renewable energy and more smart-grid technology implementation. The market will surpass $17 billion by 2020, representing a compound annual growth rate (CAGR) of 6.9 percent for the period 2014-2020.

"Power modules, and more precisely IGBTs, will lead this growth. Modules are expected to reach a CAGR 2014-2020 of 10.3 percent, compared to 5.1 percent growth for discrete components", explains Mattin Grao Txapartegi, Technology & Market Analyst. "This growth in the demand of IGBT modules is due to their improved overall performance in terms of efficiency and thermal conductivity management".

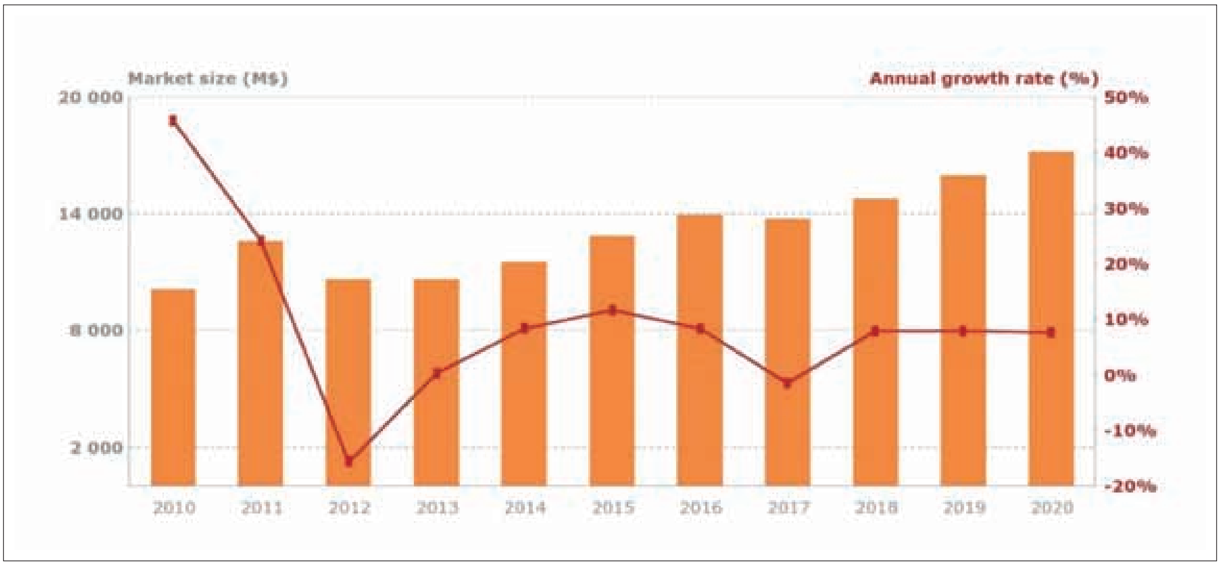
"The new wide band gap device market will also drive growth", expects Pierric Gueguen, Business Unit Manager for Power Electronics & Compound Semiconductor activities. According to Yole's report, lot of industrial companies has been focusing its development on WBG technologies. And today, both solutions, SiC and GaN have proved to be powerful solutions. Ready to be implemented in numerous applications, WBG solutions will represent around 5 percent of the overall market by 2020, even though in terms of units their presence will still be limited.

Due to the growing and important role of WBG semiconductors efficient packages will become mandatory, so that devices' high frequency, high voltage or high temperature capabilities can be best exploited.

In order to increase power module yield and reliability, companies are working on new products for power packaging, especially for the common failure locations, die and substrate attach, interconnection and encapsulation. Both new designs and new materials can be used, whether to eliminate levels of connection or to improve interfaces. In die attach, for instance, soldering is progressively losing market share, which benefits silver sintering. Although the basic material is more expensive, taking into account cheaper equipment and manufacturing costs and improved reliability, this technology is seducing ever more players. Standard wire bonding is evolving as well, with solutions increasing contact surface, such as ribbon or ball bonding. Encapsulation technologies must evolve to handle high operating temperatures: standard silicone gel or epoxy are limited in terms of temperature, and so new materials such as parylene are being developed.

Thus the power packaging market is also growing, pulled by the interconnection and substrate segments, respectively 14 and 13 percent between 2014 and 2020. And global growth for raw material is expected to reach 12 percent between 2014 and 2020, with a global market of $1.7 billion in 2020.

www.yole.fr



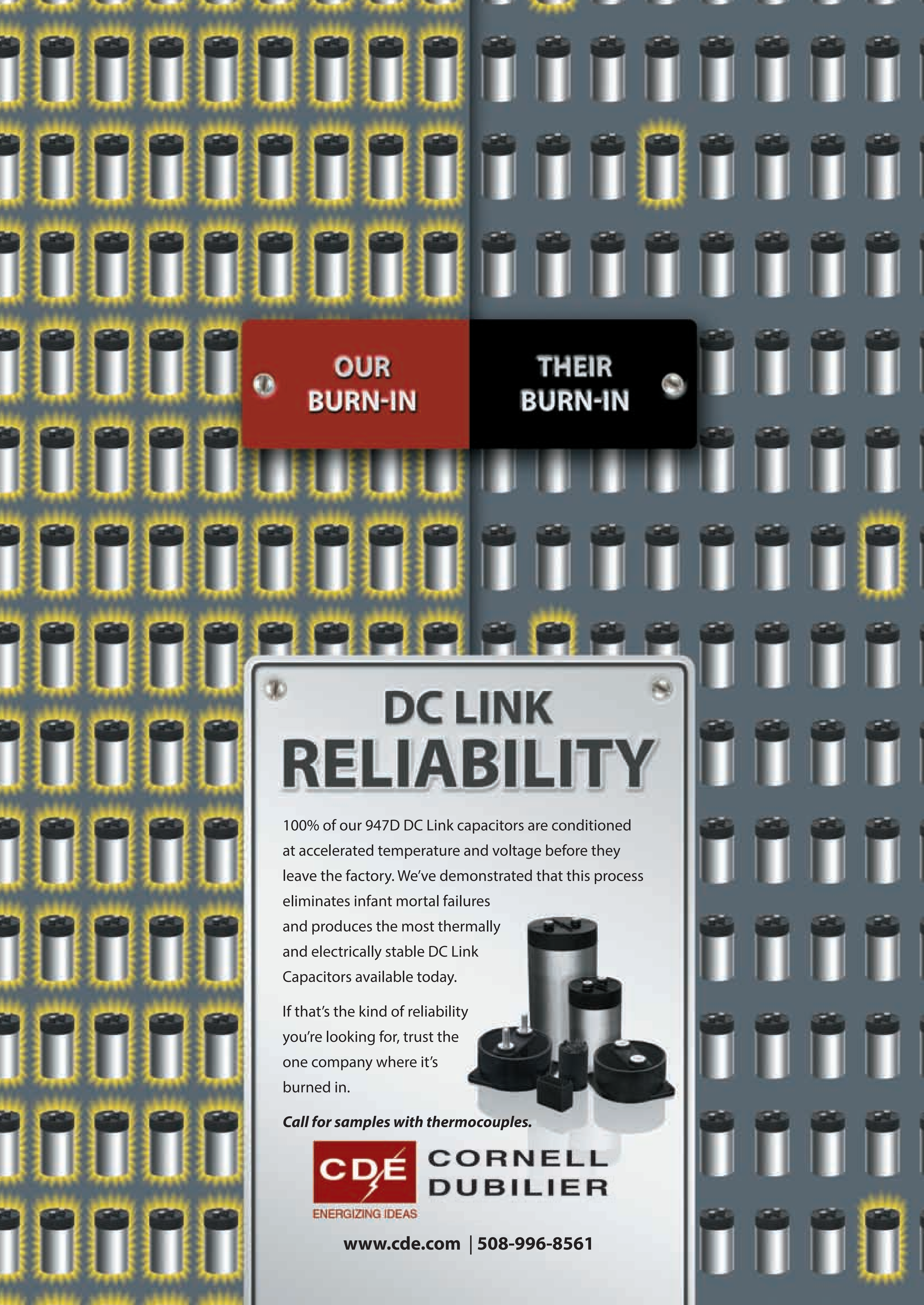
Power semiconductor market development 2010 – 2020
Source: Yole

New Applications Set to Propel the SiC and GaN Power Semiconductors Market

The emerging market for Silicon Carbide (SiC) and Gallium Nitride (GaN) power semiconductors is forecast to grow by a factor of 17, during the next 10 years, energized by growing demand for power supplies, hybrid and electric vehicles, photovoltaic (PV) inverters and other established applications. Worldwide revenue from sales of SiC and GaN power semiconductors is projected by IHS to rise to $2.5 billion in 2023, up from just $150 million in 2013.

"SiC and GaN power semiconductors have been trying to establish themselves in key applications, for a few years now; however, approximately 15 percent of the eventual market could be made up of new applications using these device technologies that are still two or three years away from production. In addition to the market the hybrid and electric vehicles themselves, it is now apparent that the electric vehicle charging infrastructure market - including battery charging stations for plug-in hybrid and battery-electric vehicles - is also a potentially interesting area for SiC and GaN power devices, stated Richard Eden, Senior Analyst - Power Semiconductors, IHS Technology.

There is no agreed global standard for hybrid-electric vehicle (HEV) charging infrastructure, so there are various competing standards describing the various levels or modes for AC and DC charging. All of the assorted AC levels can be considered to be for electromechanical systems, which require few, if any, power semiconductors.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The IHS report ("The World Market for SiC & GaN Power Semiconductors - 2014 Edition"), therefore only considers DC or "fast charging," because these systems are AC/DC power supplies, converting power from the mains (typically three-phase) into very high currents of up to 125 - 400 A at voltages up to 480 to 600 V DC, delivering a maximum power of 240 kW. Wireless power charges battery-powered appliances by transmitting power through the air instead of through power cables. Although proximity within a specified range is required, this technology is gaining in popularity in mobile phones, game controllers, laptop computers, tablets, electric vehicles, and other commodity products.

The adoption of SiC and GaN power semiconductors will be negligible in inductive charging solutions, which are designed to comply with the Wireless Power Consortium (WPC's) Qi or Power Matters Alliance (PMA) standards, because Silicon MOSFETs are adequate for the low frequencies involved. In contrast, the fast switching capabilities of SiC and GaN power semiconductors are ideal for magnetic-resonance power-transfer applications, which perform well at the higher frequencies of the Alliance for Wireless Power (A4WP) standard. As numerous consumer-electronics applications use fairly low voltages, they will be more suitable for GaN devices. The only area of this application thought suitable for SiC power devices is wirelessly charging battery-powered electric vehicles, such as plug-in hybrid vehicles (PHEVs), etc.

"Two more applications that could potentially use SiC power modules are wind turbines and traction. In both cases the biggest barriers to SiC power module adoption are their high cost; unproven reliability; and a lack of availability of high current-rated modules, in general, and of full SiC modules, in particular. Both applications typically require 1700 V modules; a voltage at which few SiC transistors have already been developed. Trials are underway, but commercial production is not expected to start until 2016 or 2017. For high-voltage SiC technologies, there are a host of new medical applications and other potential industrial applications. For low-voltage GaN devices, the new applications include many emerging technologies that will drive significant growth in the future, such as wireless envelope tracking, light detection and ranging (LIDAR), Class-B audio amplifiers, or medical devices", Eden expects. "The key factor determining market growth will be how quickly SiC and GaN devices can achieve price parity with - and equivalent performance of - Silicon MOSFETs, IGBTs or rectifiers. Price and performance parity is forecast to occur in 2020, and the SiC and GaN power market is subsequently expected to experience tremendous growth through 2023."

www.technology.ihs.com

Infineon Expands its GaN Portfolio

Infineon Technologies AG and Panasonic Corporation will jointly develop Gallium Nitride (GaN) devices based on Panasonic's normally-off GaN on Silicon transistor structure integrated into Infineon's SMD packages. In this context Panasonic has provided Infineon with a license of its normally-off GaN transistor structure.

Just after the acquisition of International Rectifier (IR) with a focus on their GaN-on-Silicon technology and intellectual property (see PEE 1/15 page 6, PEE 2/15 page 8) Infineon expands its GaN-on-Silicon technology and product portfolio. The company now offers both Panasonic's enhancement mode and IR's cascode configuration GaN-based platforms for applications requiring high levels of energy efficiency including Switch Mode Power Supplies (SMPS) used in server, telecom, mobile power and consumer goods such as Class D Audio systems. GaN technology significantly reduces the size and weight of power supplies which will open up new opportunities in end-products such as ultra-thin LED TVs. According to an IHS market research report, the GaN-on-Silicon market for power semiconductors is expected to grow at a compound annual growth rate (CAGR) of more than 50 percent, leading to an extension of volume from $15 million in 2014 to $800 million by 2023.

"Infineon's GaN-on-Silicon portfolio combined with the acquisition of International Rectifier's GaN platform together with our partnership with Panasonic clearly positions Infineon as the technology leader in this promising GaN market," stated Andreas Urschitz, President of the Power Management & Multimarket Division of Infineon Technologies AG.

Infineon's expanded offering will include dedicated driver and controller ICs which enable the topologies and higher frequencies that fully leverage the benefits of GaN. The offering is further enhanced by a broader patent portfolio, GaN-on-Silicon epitaxy process and 100-600 V technologies resulting from the IR acquisition. Additionally, Infineon and Panasonic will jointly introduce devices utilizing Panasonic's normally-off (enhancement mode) GaN-on-Silicon transistor structure integrated into Infineon's SMD packages, providing dual sourcing of highly efficient 600V GaN power devices.

"Through the acquisition of International Rectifier's GaN platform together with our partnership with Panasonic Infineon is clearly positioned as the technology leader in the promising GaN market," stated Andreas Urschitz, President of the Power Management & Multimarket Division of Infineon Technologies AG

Both device concepts have specific advantages depending on the target application. The cascode configuration is fully compatible with existing drivers for low-voltage MOSFETs and offers an integrated body diode with low forward voltage drop for reverse operation. The enhancement mode concept is a single-chip solution and hence facilitates further integration either on the chip or package level. For most early GaN applications so far identified either cascode or enhancement mode GaN devices will suffice. Therefore, early applications will be chosen around the maturity of the solution including availability of appropriate on-resistance switches, drivers and controllers. As enhancement mode-based solutions reach maturity, ease-of-use and solution costs will very likely make them the more prominent solution. to minimize voltage and current peaks, and gain the most benefit out of the fast switching devices. Regarding drivers, the cascode switch is compatible with standard FET gate drivers. The enhancement-mode devices can be driven with conventional gate drivers plus an external R-C network. But a dedicated driver IC will ultimately provide higher performance using lower power. For either type of GaN, new controller ICs will be necessary to take full advantage of the topologies and higher frequencies enabled by GaN.

"In line with our 'Product to System' approach, our customers can now choose enhancement mode or cascode configuration technologies according to their application/system requirements. We also are developing SMD packages and ICs that will further leverage the superior performance of GaN in a compact footprint. As a real world example, using our GaN technology, a laptop charger found on the

Broad Range of Solutions for Power Conversion Designers

The power conversion market is constantly evolving, with a focus on increased efficiencies and higher integration.

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market today could be replaced by one that is up to four times smaller and lighter". Urschitz commented.

"Infineon is committed to serve its customers with a broad product and technology portfolio including reliable power devices based on Gallium Nitride. We are convinced that enhancement mode GaN switches, together with our corresponding driver and optimized driving scheme, will provide high value to our customers, while the dual sourcing concept will help them manage and stabilize their supply chains," Urschitz stated. Thus GaN will complement the existing portfolio of CoolMOS™, OptiMOS™ and SiC active devices. "We will start by developing a portfolio of discrete switches but, we will soon also offer integrated solutions; leveraging the fact that GaN is a viable alternative technology. Infineon recognizes that GaN switches will enable the next level of system efficiency, energy saving and power density and, therefore, decided to invest a significant amount of its R&D effort to pursue this challenge. Infineon's GaN-on-Silicon product portfolio will support energy efficiency through further minimizing losses compared to Silicon. In addition, we expect that GaN will play a role in the automotive market - not only due to higher efficiency but also because GaN enables smaller form factors. However, we expect GaN will take off in the automotive market once its reliability under adverse conditions has been fully proven. Regarding our SiC strategy we see applications more in the 600 V and above range, whereas GaN will be covering the range below and up to 600 V."

www.infineon.com/gan

Transphorm and ON Semiconductor Start Production of GaN Power Devices

Transphorm Inc. announced in partnership with ON Semiconductor the introduction of two co-branded 600 V GaN cascode transistors and a 240 W reference design that utilizes them. This introduction builds on the partnership between Transphorm Inc. and ON Semiconductor announced in September 2014.

With typical on-resistances of 150 and 290 mΩ, the two new GaN products, TPH3202PS (ON Semi equivalent: NTP8G202N) and TPH3206PS (ON Semi equivalent: NTP8G206N), are offered in an optimized TO-220 package for easy integration with customers' existing circuit board manufacturing capabilities.

The two-stage evaluation board NCP1397GANGEVB (Transphorm equivalent: TDPS250E2D2) is offered as a complete reference design so that customers can implement GaN cascode transistors in their power designs. The evaluation board is representative of a production power supply that has been re-designed for smaller size and higher performance systems, and it highlights the capability and potential of GaN transistors in this power range. The boost stage delivers 98 % efficiency and utilizes the NCP1654 power factor correction controller. The LLC DC-DC stage uses the NCP1397 resonant mode controller to offer a 97 % full load efficiency. This performance is achieved while running at 200+ kHz and – impressively – is also able to meet EN55022 Class B EMC performance. Full documentation is available at the Transphorm and ON Semiconductor websites.

The Transphorm GaN HEMT devices are in mass production at the Fujitsu Semiconductor group's CMOS-compatible, 150 mm wafer fab in Aizu-Wakamatsu, Fukushima, Japan. The large-scale, automotive-qualified facility, which is providing exclusive GaN foundry services for Transphorm and its partners, will allow expansion of GaN power device production according to the growing demand.

www.transphormusa.com, www.onsemi.com

GaN Systems Expands in Asia

Ottawa-based GaN Systems Inc. has signed an agreement with Japanese semiconductor and electronic component distributor, Value Integrated Technology (Vitec) to distribute power GaN devices to its customer base in Japan, Taiwan, and China, including many well-known consumer brand and enterprise equipment manufacturers.

Announcing the deal, Jim Witham, CEO, GaN Systems said: "Vitec has a strong presence in the consumer and enterprise segments and has links with major brand name manufacturers. Demand for our GaN power switching transistors is growing very rapidly. Multiple consumer and enterprise products designed with our GaN devices will be launched starting in 2015, and we're excited that Vitec and GaN Systems will expand this reach substantially." GaN Systems have developed and productized a comprehensive portfolio of GaN E-HEMT power devices with current ratings from 7 A to 220 A, in both 650V and 100V ranges. "Vitec is expanding into industrial and automotive markets and GaN Systems has a very strong portfolio of higher-current GaN power switches for high-power applications in these sectors. GaN Systems' product portfolio also complements our existing businesses in solar inverter and infrastructure power. Together, we will have very strong business growth for next-generation high-efficiency power designs", commented Osamu Komaki, Vitec's VP of Marketing.

www.gansystems.com, www.vitec.co.jp

Winds of Change in Automotive Industry

The days of car companies controlling the future of the automotive industry are numbered. Indeed, waves of creative destruction and globalization are shaking the industry due to electrification of cars.

Current rumours suggest Google has been working on a “super battery” for the last 3 years and Apple on an electric car whilst vacuum manufacturer Dyson is reportedly sinking $15 million of investment into new battery technology for electric vehicles. “Indeed pure electric, hybrid electric and fuel cell cars are positioned to take $188 billion of the whole $1 trillion market by 2025 and that is just the start - autonomous vehicles come next taking almost $77 billion by 2030”, expects Franco Gonzalez, Senior Research Analyst IDTechEx in the report “Future Technologies for Hybrid and Pure Electric Cars 2015-2025”. The stakes at play in this sector have never been so high with 2015 so far seeing more pieces of the puzzle taking strategic steps towards electrification of the car industry. “The most recent is the billionaire lawsuit of BASF against Umicore in relation to alleged infringement of the later into Argonne Lab NMC patents. On the other hand Toyota announced the most recent highlights about the Mirai fuel cell car and how it represents the beginning of a new era, with the support of the Japanese government. VW on the other hand is not so sure about this “new era” and reportedly acquired a stake in a new solid state battery start-up. The latest news suggest the Renault-Nissan Alliance is tense in relation to Carlos Ghosn’s consideration to source batteries from other sources.”

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Annual Meeting of Solar Power

This year's Intersolar Europe Conference/Exhibition in Munich (June 9-12) offers expert insights into the solar markets and technologies of the future. It will run alongside Intersolar Europe, the world's largest exhibition for the solar industry attracting around 1,100 attendees and 200 speakers.

Worldwide PV module capacity grew by an average of 44 % each year between 2000 and 2013, according to the current Photovoltaics Report published by Fraunhofer Institute for Solar Energy Systems (ISE). Analysts expect a further 55 GW to be added in 2015, which would correspond to an increase of 20 % from the 46 GW recorded in 2014. This growth is partly attributed to ongoing technological advances in photovoltaics, which have continuously improved solar cell and module efficiency, while better production technologies have reduced material consumption. Technology and economies of scale also caused prices to drop rapidly. With solar energy continuing to expand, the industry is faced with a number of questions, such as how technological innovations can be used to optimize on-site consumption, how grids can be designed to accommodate for the growing share of solar energy and how energy can be stored efficiently and economically.

For businesses to be successful, they require knowledge of the various international photovoltaics markets and their different political, economic and legal conditions. Currently, more than half of the world's photovoltaics capacity is installed in Europe, where a steady annual growth of 10 GW is expected over the next few years. Growth rates are considerably higher in markets like China, the USA and Japan, however. During several sessions at the Intersolar Europe Conference, experts will take a detailed look at the markets in Europe, Asia, North and South America, the Middle East and Africa, as well as their political, legal and financial conditions.

In Europe, the era of feed-in tariffs is drawing to a close, making new financing models more important than ever and an essential component of new business models. Several presentations shed light on current trends in financing and managing solar installations, focusing in particular on new forms of financial cooperation between local energy suppliers, project developers and financial service providers.

Bottleneck energy storage

ees Europe, the international exhibition for batteries, energy storage systems and innovative production, will open its doors for the second time on June 10. With around 250 exhibitors, last year's ees Europe, which was organized in conjunction with Intersolar Europe, was already a success. Between them, the two exhibitions played host to a total of around 1,100 exhibitors and welcomed 42,380 visitors. This year, exhibition space is set to increase considerably – the organizers expect the exhibition to span an area of around 9,000 sqm, four times larger than the previous year. Industry leaders, such as LG Chem, VARTA Storage, HOPPECKE, Deutsche ACCUmotive, Samsung SDI, Saft, Sonnenbatterie and Sharp Electronics, already view ees Europe as a leading industry platform.

Technical advances and increased demand are driving forward the market for battery storage systems, which, in turn, is reducing prices. According to a current survey by the German Solar Industry Association (BSW-Solar) and Intersolar/ees Europe, electricity storage systems had already considerably reduced in price in the second half of 2014 compared with the previous year. The costs of lead-acid batteries dropped by 27 %, while lithium storage devices became 22 % cheaper. As such, storage solutions are becoming increasingly important for the mass market and may hold the key to one of the biggest challenges facing the energy transition – storing volatile renewable energy until it is needed.

ISPSD 2015 www.ispsd2015.com

Power Electronics Conference in Hong Kong

The 27th IEEE International Symposium on Power Semiconductor Devices and ICs (ISPSD), sponsored by the IEEE Electron Devices Society and technically co-sponsored by the IEEE Power Electronics Society, will be held at Kowloon Shangri-La, Hong Kong, May 10– 14, 2015.

ISPSD's topics include: Device Physics, Device Design, High Frequency Devices, High Power Devices, Smart Power Devices, RF Power Devices, Safe-Operating Area, Reliability, and ESD; Process Integration, Doping Technology, Lifetime Control, Passivation, and Crystal Growth; Device Modeling and Circuit Simulation, Layout, and Verification Tools; Si, GaAs, SiC, GaN, and Diamond Materials; Isolation Techniques, SOI, Power IC Design, Device Technology, Energy Capability and SOA, Reliability, Power SoC, and Monolithic vs Hybrid Integration; Novel Packaging Concepts, Power SiP, Stress and Thermal Analysis, and Thermal Management; Hybrid Vehicles, Computer and Telecom Power, Motor Drives, and Utility Applications.

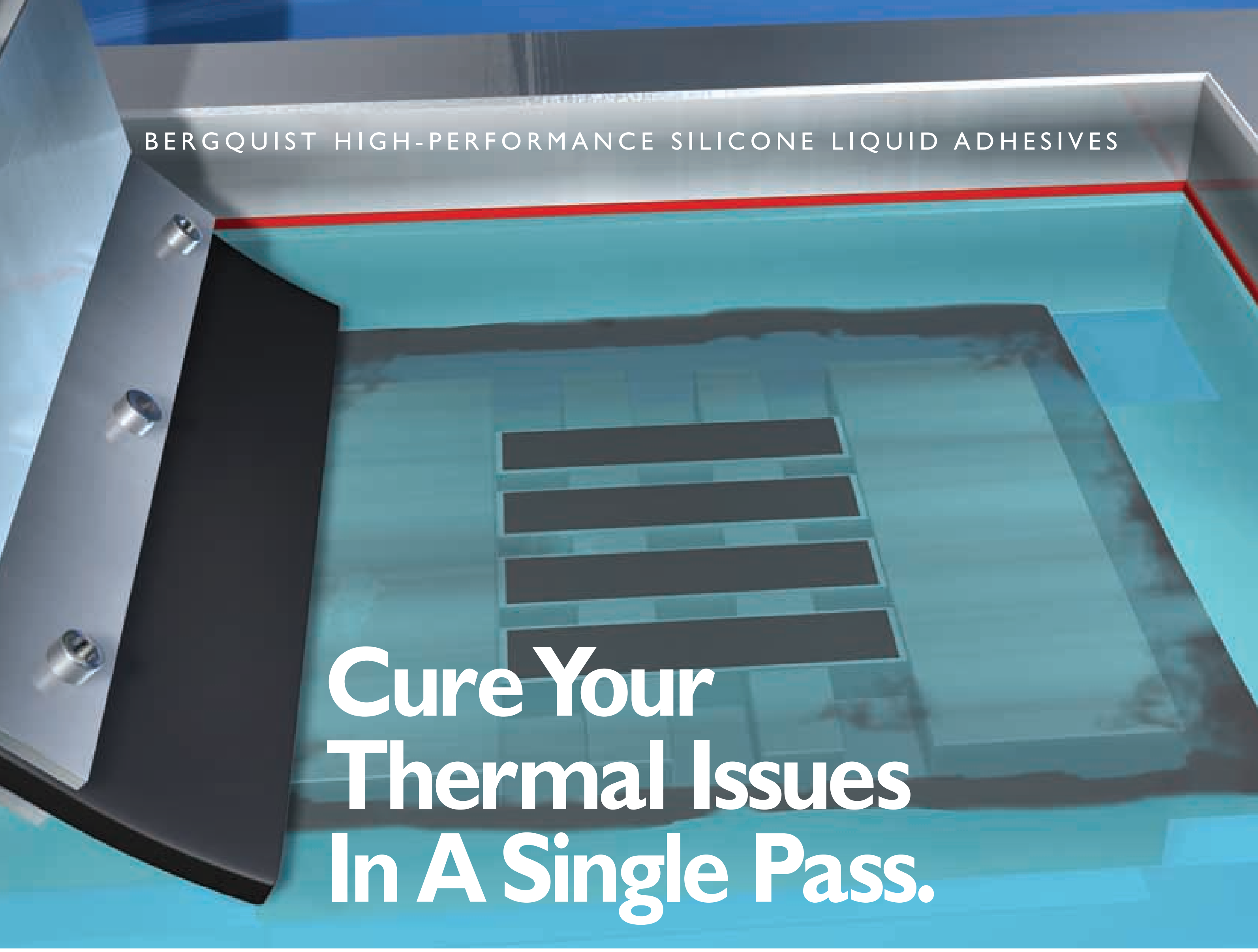
With the Society's awareness in renewable energy and energy efficiency, power semiconductor devices and power ICs have become a focal point as a key enabling device technology to help solve the world's energy challenge. ISPSD 2015 will have an expected attendance of 400–500 researchers from industries, universities, and research institutions all over the world. Traditionally more than 70 % of ISPSD attendees are engineers and technical managers from the power semiconductor industry. More recently, representatives from CMOS foundries and power electronics design firms are also drawn to the conference.

ISPSD 2015 will commence with a one-day tutorial program on topics such as WBG devices in harsh environment, power ICs for use in automotive applications, high temperature packaging technologies, impact of power grid and connection of renewable energy sources, and advances in power conversion for mobile computing.

The conference will feature several plenary talks given by world renowned experts and a collection of high quality technical presentations, along with a poster session to offer a closer interaction among the attendees.

The plenary talk "GaN Transistors – Giving New Life to Moore's Law", features Alex Lidow, CEO Efficient Power Conversion Corporation (EPC). Enhancement-mode gallium nitride transistors have been commercially available for over five years and have infiltrated many applications previously monopolized by the aging silicon power MOSFET. He will discuss the state-of-the-art and the expected progress of GaN technology over the next few years, showing that Moore's Law is alive and well in the world of power semiconductor technology. He will also enumerate the advantages of GaN over silicon in terms of performance, cost, and reliability – as he will do at PCIM Europe some days later.

Other plenaries will cover the power semiconductor market (Yole), Traction (CSR Zhuzhou Institute), nd LED Lighting (Panasonic).



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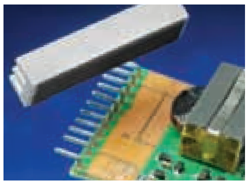

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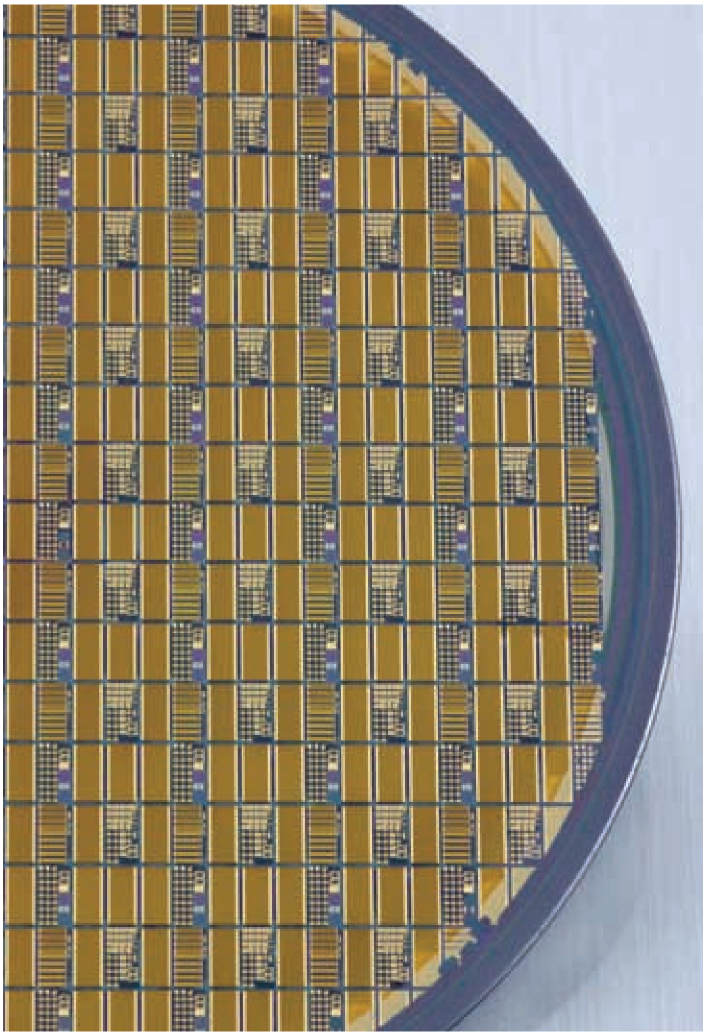
Power GaN Made in Europe

In the recently completed EU group-project called HiPoSwitch eight European institutional and industrial project partners led by the Ferdinand-Braun-Institut, Leibniz-Institut fuer Hoechstfrequenztechnik (FBH) have successfully developed prototype power transistors that use Gallium Nitride (GaN) in enhancement mode.

Highly efficient power electronics is needed for low volume and low weight future power conversion systems. The project aimed for the exploitation of novel (GaN transistors for advanced switched mode power supplies. High voltage normally-off GaN power devices on Si substrates in vertical device architecture are to be developed and its technology transferred to an European industrial environment. The devices are planned to reliably operate at elevated junction temperatures up to 225°C. The project covers the full value added chain from substrate technology and epitaxy to complete power electronic system prototypes, from experienced partners in automotive technology, power electronic system and circuit design, power semiconductor technology, high temperature packaging technologies, GaN power device technology including GaN on Si epitaxy as well as sophisticated device characterization and reliability evaluation techniques

One percent efficiency increase saves one power plant

Power converters using these novel GaN transistors have less than half the losses of existing technologies and make conversion efficiencies of over 98 % practical. A great deal of primary energy consumption can be saved with their widespread use. "More than 3000 terawatt-hours (TWh) of power are generated in Europe annually," said Joachim Würfl, head of both the HiPoSwitch project and the GaN Electronics Business Area at FBH. "If you only converted a quarter of the electricity produced annually in Europe to a different level and increase the efficiency level by two percentage points, you can turn off at least two coal-fired plants," Würfl explained.

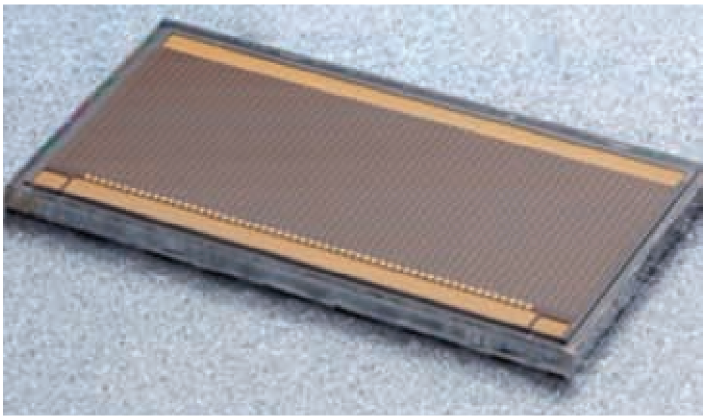


HiPo Switch 200-mm GaN-on-Silicon wafer

Gallium nitride possesses ideal physical properties for a semiconductor. "GaN components are therefore very efficient and very fast power switches. And this is because of their low on-state resistance with negligible losses," Würfl emphasized. "At the same time, higher switching frequencies mean that passive elements of the power converter, i.e. the inductive coils and capacitors, can be considerably smaller in size – a definite improvement on the systems side."

GaN has already been utilized in microwave transistors for a long while and applied in thin layers mostly on silicon carbide (SiC) substrates. This technology has been further developed by FBH over the last few years for 600 volt-rated power transistor switches. "This works well, but it is too expensive for mass markets. As an alternative, the processes developed for SiC can be transferred to considerably more cost-effective, but technologically more challenging silicon substrates," Würfl explained. The advances made in the HiPoSwitch project fit hand-in-glove with FBH's collaboration partners. Among other accomplishments, FBH was so successful in optimizing the processing of GaN switching transistors on SiC and silicon (Si) that nearly ideal components became feasible. Among others, comprehensive investigations of drift and degradation effects carried out by University of Padua and University of Vienna provided the foundation for this.

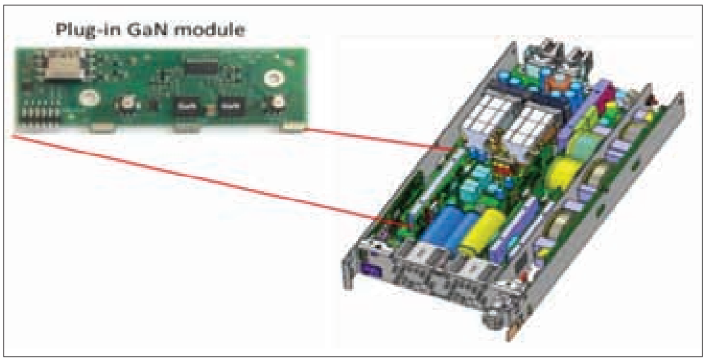
The finished transistor chips were finally assembled into low-induction ThinPAK housings by Infineon in Malaysia. "The single transistor measures only 4.5 x 2.5 mm and is optimized for breakdown voltages of 600 V. It has an on-resistance of 75 mΩ and handles a maximum of 120 A. "We are the only ones in Europe who can manufacture these kinds of normally-off transistors at present," Würfl underlined.



HiPo GaN device

The Belgian company EpiGaN together with facility manufacturer Aixtron moved the epitaxy to Si – so that the manufacturing costs for the substrates drop by more than a factor of ten. At the same time, the wafer diameter increased to 6" or even 8", a necessary step towards cost-effective industrial production. Chip-manufacturer Infineon matched up the newly developed GaN technology with a Si process line for industrial production of power semiconductors at their Austrian location in Villach. Part of the project possessed a decidedly "exploratory character", as Würfl puts it, due to the completely new techniques and processes for implementing GaN power transistors that had never before been tried. Promising ideas for producing semiconductors were successfully tested together at the University of Vienna and the Academy of Sciences in Bratislava, Slovakia.

The Austrian company Artesyn is positioned at the end of the value-added chain as a systems-level partner. They developed a 3-kW rectifier for telecommunications applications including cellular base stations. This unit converts line voltage to DC with an efficiency of 98 %. A specialized switching topology was developed and implemented that is matched to the



HiPo GaN sub-assemby in a 3-kW rectifier for telecommunications applications
Source (3): FBH Berlin

properties of the GaN switching transistors. Thanks to their broad usage, the market for energy-saving power converters is enormous. Their smaller size and weight also makes them highly attractive for aerospace applications.

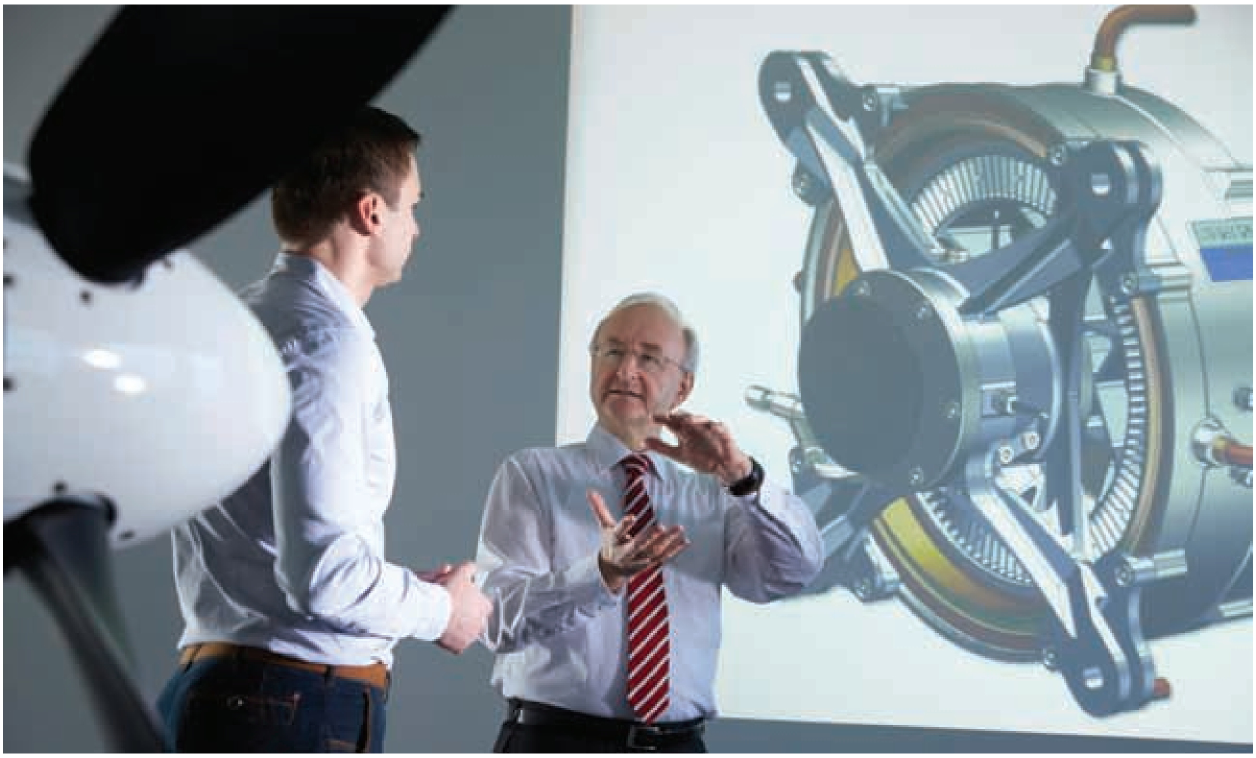
The FBH researches electronic and optical components, modules and systems based on compound semiconductors. Specifically, FBH develops light sources from the visible to the ultra-violet spectral range: high-power diode lasers with excellent beam quality, UV light sources and hybrid laser systems. Applications range from medical technology, high-precision metrology, and sensors to optical communications in space. In the field of microwaves, FBH develops high-efficiency multi-functional power amplifiers, and millimeter wave frontends targeting energy-efficient mobile communications as well as car safety systems. In addition, compact atmospheric microwave plasma sources that operate with economic low-voltage drivers are fabricated for use in a variety of applications, such as the treatment of skin diseases. The FBH has a strong international reputation and ensures rapid transfer of technology by working closely with partners in industry and research. The institute has a staff of 290 employees and a budget of 23 million Euros.

www.fbh-berlin.com, www.hiposwitch.eu

Ultra-Light Motor for the More Electric Aircraft

Siemens has developed an exceptional electric motor that combines high power with minimal weight. New simulation techniques and sophisticated lightweight construction enabled the drive system to achieve a unique weight-to-performance ratio of 5 kW per kg. The electric motors of comparable strength that are used in industrial applications deliver less than 1 kW per kg. The performance of the drive systems used in electric vehicles is about 2 kW per kg. Since the new motor delivers its record-setting performance at rotational speeds of just 2,500 revolutions per minute, it can drive propellers directly, without the use of a transmission.

Sometimes a technological revolution can be captured in a few simple figures. In this case, those numbers would be five kilowatts per kilogram. What these figures express is the power/weight ratio of a new electric motor from the Electric Aircraft Unit at Siemens Corporate Technology. "With a weight of 50 kilograms, it delivers around 260 kilowatts of continuous output," explains Frank Anton, head of the electric aircraft team. "That's a world record for this power class. Powerful electric motors used in industry have a power/weight ratio of, at most, one kilowatt per kilogram, and in the



Digital model and real high-efficiency motor for electric aircrafts

automotive industry they reach two kilowatts per kilogram at best."

For the applications that are of interest, the power/weight ratio is a crucial metric. Back in 2011, researchers working together with Airbus Group and Diamond Aircraft, notched up a world premiere with the maiden flight of the first ever aircraft powered by a electric hybrid drive. 2013, the same plane flew with an optimized drive system. The electric motor used in this setup had a power/weight ratio of around 5 kilowatts per kilogram, which at the time was unsurpassed, but it only delivered a relatively modest 60 kilowatts of continuous power – enough for a single-engine light aircraft at most.

Siemens' goal is therefore to develop an even more powerful electric motor of minimal weight, since this is precisely the precondition for being able either to replace completely the internal-combustion or jet engines currently used in aircraft and helicopters or to combine those engines with an electric drive within a hybrid system.

CAE optimized layout

In order to develop their record-beating motor, experts set about testing all the components from previous motors and optimizing them as far as was technically feasible. In this way, they were able to cut the weight of the motor's so-called end shield by more than half, reducing it from 10.5 kg to a mere 4.9 kg. Made of aluminum, this component supports the motor bearing and the propeller, which is fixed to a continuous drive shaft without a gearbox in between. "It's subject to very large forces whenever the nose of the aircraft moves up or down, so it's an absolutely vital component for the safety of the aircraft," Anton explains. "That's why, in the past, it was always pretty solid and therefore correspondingly heavy."

To slim down this end shield, experts in lightweight engineering and the developers of Nastran at Siemens Product Lifecycle jointly developed a special optimization algorithm and integrated it into the Siemens CAE program NX Nastran. This algorithm breaks down the component into more than 100,000 individual elements and simulates the forces acting on each one of these cells. In the course of optimization loops, the software is able to identify the elements that are barely subject to stress and are therefore dispensable.

The result was a filigree structure that nonetheless met all the safety requirements in regard to stiffness and stability. And that was only the start. Developers now have come up with the prototype of an end shield made of carbon fiber-reinforced polymers that weighs a mere 2.3 kilograms, less than a quarter of the conventional component.

Regarding the motor's electromagnetic design, the developers used a few tricks to reduce weight by as much as possible. Cobalt-iron alloy in the stator features high magnetizability, and the permanent magnets of the rotor are arranged in a so-called Halbach array. This means that four magnets are positioned next to one another in such a way that the orientation of each field is in a different direction. One result of this is that magnetic flux can be optimally directed with a minimal use of material. A new cooling concept has also helped reduce weight. "Because of the high current density, we needed a smart way of dealing with the waste heat," Anton explains. "We use direct-cooled conductors and directly discharge the loss of copper to an electrically non-conductive cooling liquid – which in this case can be, for example, silicone oil or Galden."

Regional airliners with hybrid drives

The new electric motor is relatively powerful, not far short of being sufficient to propel a regional airliner, since output power between 500 kW and 2 MW would be enough. Such new drives would prove a blessing for the environment and for people living near airports, since they would significantly reduce not only CO_2 emissions from air traffic but also aircraft noise. At the same time, airlines would benefit from big cost savings. "Kerosene accounts for over 50 percent of an aircraft's lifecycle costs," Anton explains. "The use of hybrid electric drives would reduce fuel consumption by around 25 percent, with the result that the total costs of an aircraft would fall by about 12 percent."

This is because an intelligent hybrid drive combining an electric motor and a combustion engine can use turbines that not only are significantly smaller than those of today but can also be continuously operated at peak efficiency during flight. Today's turbines, by contrast, are designed to deliver a maximum level of power that is only required during takeoff and ascent. Aside from that, they only require 60 percent of their maximum output. "With a kerosene-electric hybrid drive system, the turbine would run continuously at optimum power and provide energy, via a generator, for the electric motor powering the propeller," Anton explains. "During takeoff, extra energy would be provided by a battery."

Siemens is now working with Airbus to turn this vision of electrically powered flight into reality. Under the terms of a cooperation agreement dating from 2013, Siemens is involved primarily in developing new electric drive systems, while Airbus is working on new aviation concepts. If the engineers succeed in developing electrical motors that are even lighter and even more powerful, the first 60–100-seater aircraft with a hybrid electric drive could be taxiing for takeoff as early as 2035.

www.siemens.com

PCIM
EUROPE
International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management

Growth Through Innovations

Over 240 speakers from more than 25 countries present the latest technological trends in power electronics components and systems at the PCIM Europe 2015 Conference. And this conference serves also as a platform for product announcements, which will be demonstrated at the exhibition floor by around 400 companies.

Highlights of the conference include top-class keynote speeches at the beginning of each conference day. They are covering for example the development trend for power semiconductor devices or future battery management solutions. Besides 24 oral sessions and two poster sessions there are five special sessions on: “Solar Inverter Topologies“, “Passive Components”, “Digital Control Power – the Future of Power Electronics”, “Power GaN for Automotive Applications” and “E-Mobility”(see PEE 1/15, pages 18-20). Nine seminars and nine tutorials of well-known experts regarding topics such as “Practical Application of 600 V GaN HEMTs in Power Electronics“ or “Advanced Design with MOSFET and IGBT Power Modules“ round up the program.

“The situation for power electronics and thus for power semiconductors in the coming years is very promising, but we see a considerable shift to China in terms of consumption”, commented Leo Lorenz, General Chair of the PCIM Europe Conference. “Silicon devices and here particularly IGBTs will dominate the market over the coming years, though Silicon Carbide and Gallium Nitride are gaining more attention. Silicon Carbide was first seen in Solar Inverters, but due to price pressure inverter manufacturers now are stepping back to multilevel Silicon topologies”.

Since Silicon devices have been matured over the last two decades progress is incremental, whereas SiC and GaN are moving fast. Thus the focus here is on some interesting conference contributions in power modules and SiC/GaN devices after a more general introduction to the PCIM 2015 in our previous issues.

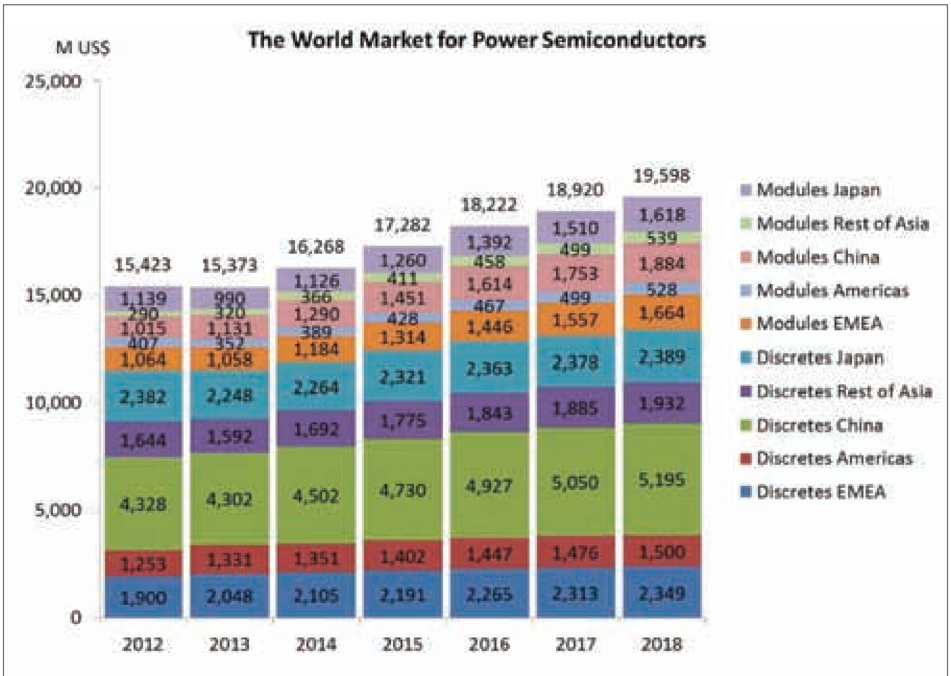
RCDC IGBT 6.5 kV Module

In Infineon’s (**www.infineon.com**) commonly known 6.5 kV IGBT-modules IGBT and freewheeling diode chips are assembled in parallel connection on six AlN substrates, which are mounted on an AlSiC base plate. Within the new 1000A / 6.5 kV module all former chips positions are replaced with the RCDC-chips (Reverse Conducting IGBT with Diode Control). The functionality of an IGBT-switch and a freewheeling diode is given by this single chip solution. Due to the integration into the existing module platform of high insulation modules the outer diameters as well as the pinning remain unchanged.

One of the major advantages of the RCDC technology is the significant improvement of the thermal resistances within the module (R_{th_JC}) and towards the cooler (R_{th_CH}), which allows for an increased ampacity while the junction temperature remains at 125°C. This is in contrast to previously announced 1000A / 6.5 kV modules, which rely on an increase of the junction temperature to 150°C. The reason for the improved thermal resistances is the increase of the effective Silicon area available during operation in IGBT- as well as diode-mode. While in previous 6.5 kV modules with footprint 140 mm x 190 mm 24 parallelized silicon dies are contributing to IGBT mode, now 36 RCDC chips serve for heat spreading. In the case of diode-mode the improvement is even higher due to three times more active dies in parallel compared with the common IGBT module. Since the same silicon volume is used during IGBT and free-wheeling mode the thermal coupling during IGBT- and diode-mode has to be taken more seriously into account than for standard IGBT, where the thermal coupling between the spatially separated IGBT and diode dies occurs mainly via the substrate and base plate. However, a beneficial reduction of the thermal ripple is observed, which can lead to an additional improvement of the power cycling reliability. By the means of FEM-simulation the Zth-curves of IGBT-mode, diode-mode and the thermal coupling have been investigated with the result that the R_{th_JA} of the IGBT-mode is reduced by roughly 20 % and of the diode-mode even by roughly 50 % compared to the FZ750R65KE3 module.

Low inductive phase-leg IGBT module for easy paralleling

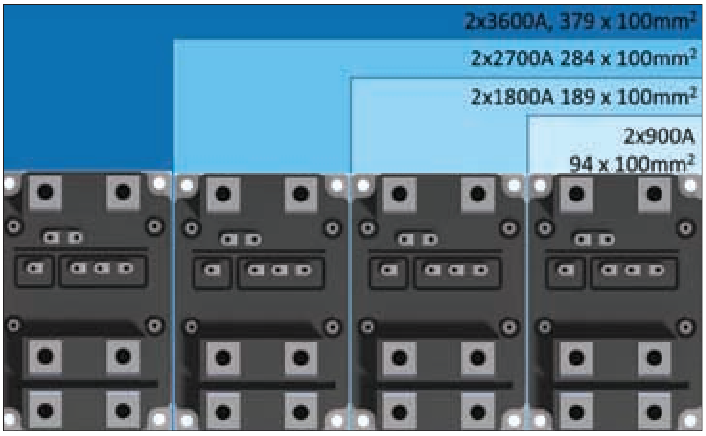
Present IGBT module solutions are at its limit when it comes to advanced and faster IGBT/diode chip-sets since the overall stray inductance per switched ampere is too large and high over-voltage will occur. Also the available electrical contact area of today’s modules is limited and dates back to times when the packages were rated with 40% less current than now. In addition modules lack of scalability and thus



LEFT: The world market for power semiconductors (discretes/modules) 2012-2018

Source: PCIM/Fuji Electric

a large variation of outlines exist to match various inverter ratings. The presented new LinPak module concept from ABB (**www.abb.com/semiconductors**) addresses all these issues and is published as an open standard, meaning module manufacturers can freely adopt the outline and customers benefit from a standard solution provided by more than one supplier making inverter designs easier. The LinPak offers as well exceptional low stray inductance of 10 nH and an easy customer interface enabling the construction of a very low inductive DC-connection with sufficient contact area for the high current densities. This is the ideal fit for the full utilization of the advanced fast IGBT/diode chip sets such as the 1700V SPT++. It also makes the package fit for future hybrid and full SiC solutions that come with even faster switching speeds. With the LinPak just one module type per voltage rating is needed. Thanks to a homogenous current path



LinPak enables parallel connection of more than four modules without any significant de-rating

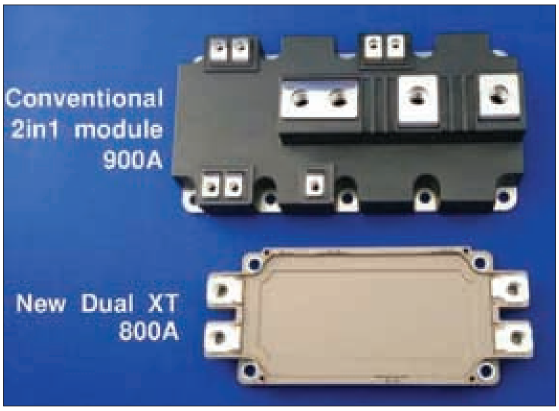
concept, the module enables parallel connection of more than four modules without any significant derating.

Due to the inherent advantages of wide-badgap (WBG) materials such as SiC and GaN, today such devices provide low switching losses making them suitable for higher frequency applications and low leakage currents for higher temperature operational requirements. Also, unipolar (WBG) devices provides very low losses at low currents compared to Bipolar switches such as the Si IGBT due to the inherent built in voltage of around 0.7V-0.8V for Silicon. However, Silicon Carbide based devices in particular suffer from significantly higher costs due to starting material manufacturing costs, expensive epitaxial growth especially for higher voltage devices with thick base regions. Hence to reduce cost, the utilization of less SiC device area is one approach but at the cost of higher losses and higher thermal resistances especially for unipolar SiC MOSFETs and Diodes. Furthermore, unipolar WBG devices will suffer from oscillatory behavior during switching transients and high on-state losses at higher temperatures and currents which again are more challenging for higher voltage devices. Finally, unipolar devices provide less fault current handling capability compared to state-of-the-art bipolar silicon devices. Therefore, it becomes clear that the above aspects of WBG technologies have hindered the introduction of such devices into mainstream power electronics applications. Thus ABB proposes a hybrid approach to resolve some of the above issues with potential advantages for future power electronics applications.

To investigate the new hybrid Cross Switch XS concept, test samples were made consisting of a 1200 V/25 A SPT IGBT device in parallel to a 1st Generation Cree 1200V/30A / 80 mΩ SiC MOSFET. The area ratio of the IGBT to MOSFET was 3:1. The total current rating of the combined XS hybrid was hence at 50 A. For comparison, reference samples were also made with one consisting of two paralleled SPT IGBTs and the other having two paralleled SiC MOSFETs with the same 50 A rating for each. No separate gate units were utilized and the same gate signal was applied for all chips in parallel. The XS hybrid offers 40 % lower losses compared to the Silicon IGBT reference sample and softer performance than the SiC MOSFET.

7th generation IGBT modules for compact power conversion systems

Recently the main requirements found in the market are further downsizing and higher efficiency of power conversion systems. Enhanced power density of the power modules will be the key to succeed. The increasing package reliability in higher junction temperature operation will be the major challenge. By further improvement of the chip characteristics and the development of new high reliability package materials and technologies, the performance of the modules were significantly improved. Additionally, the maximum operating temperature was even increased to up to 175°C. The new 7th generation IGBT module to be introduced by Fuji Electric (**www.fujielectric.co.jp**) realized further downsizing and higher efficiency of power conversion systems.



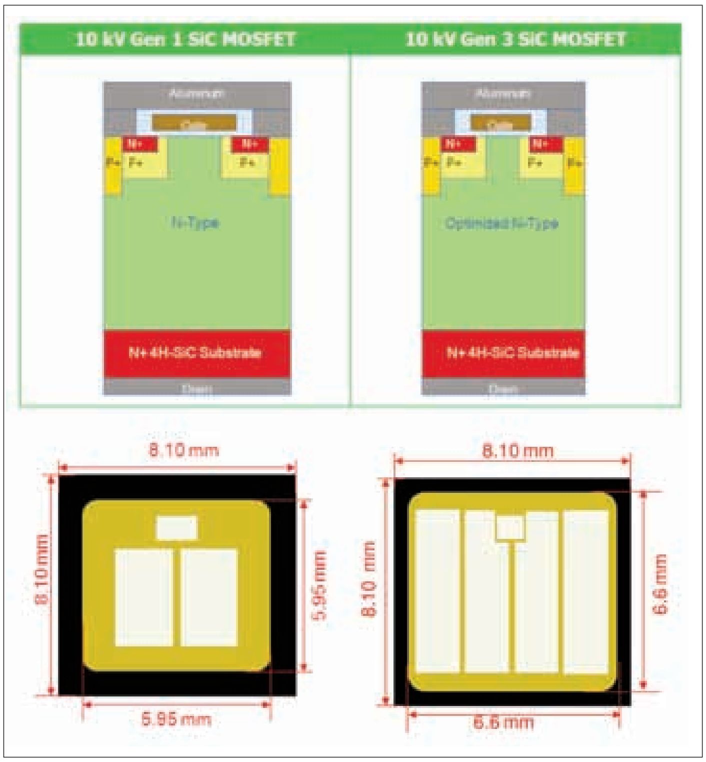
New 800 A rated module in 1200 V class Dual XT from Fuji Electric featuring 32 % smaller foot print

The 7th generation IGBT realized the shrinking of the die and the higher power density of chips, by the development of a new fine pattern gate trench structure, new field stop layer and thinner drift layer. The on-state voltage was reduced by 0.3 V compared to the 6th generation while the current density remains the same. For the turn off waveform, the tail current was reduced and the voltage rises faster due to reduction of the miller capacitance. By the above described improvements 10% reduction of turn-off losses will be demonstrated. By improved package thermal characteristics, the temperature increase of chipset is relaxed and it has been possible to enhance the power density of the module. As a result, a new 800 A rated module in 1200 V class Dual XT is developed (highest conventional rating was 600A). The foot print per unit current is 32 % smaller than the conventional 900A 2in1 module. The inverter losses at the same time are reduced by 12 %.

New generation 10 kV SiC power MOSFET and diodes

The development of solid-state power distribution technology has been hindered in the past by the lack of availability of efficient medium-voltage power semiconductor devices. 4H-SiC, due to its 10x higher breakdown strength when compared to Silicon has long been thought to be a solution, however, manufacturing maturity wasn't available until recently. Now, with 600-1700 V SiC diodes on the market for over a decade, and 1200-1700 V SiC MOSFETs available for over four years, medium voltage SiC MOSFETs are also maturing. 3300 V SiC MOSFETs and diodes have been announced publicly as being used in rail systems, devices with blocking voltages above 3300 V are also advancing in maturity. In particular, the 10 kV SiC MOSFET and diode chip set is of particular interest in a number of applications such as simpler, two-level or three-level medium voltage drives using 4.16 kV or 7.2 kV line-voltages. Cree (**www.cree.com/power**) will present a much improved 10 kV SiC MOSFET and diode chip set relative to initial research samples made in the past. The specific on-resistance, total current per die, and switching losses per chip are now much improved.

Work on the 10 kV SiC MOSFET has been ongoing for over five years. The device structure being developed is a planar DMOSFET structure, with backside drain contacts, and top-side gate and source contacts. The first generation, developed in 2007-08 timeframe, with 8.1 mm x 8.1 mm die size, has been upgraded to a newer "generation 3" technology. The n-type doping has been optimized, and a more compact guard ring edge termination has been employed, to reduce the cell pitch and provide lower specific R_{DSON},



A comparison of the first generation 10 kV SiC MOSFET cross-section and top-view (left) with the improved third generation 10 kV SiC MOSFET shown on right. Optimized n-type doping and a more compact edge termination allows the specific RDSON to drop from ~160 mΩ·cm² to ~100 mΩ·cm²

dropping from 160 mΩ-cm² in the first generation to ~ 100 mΩ-cm² in the newer generation at 25°C. For the 10 kV, 20 A SiC diode die, the die size and design has been made compatible with the 10 kV SiC MOSFET. The forward voltage drop is less than 5 V at room temperature.

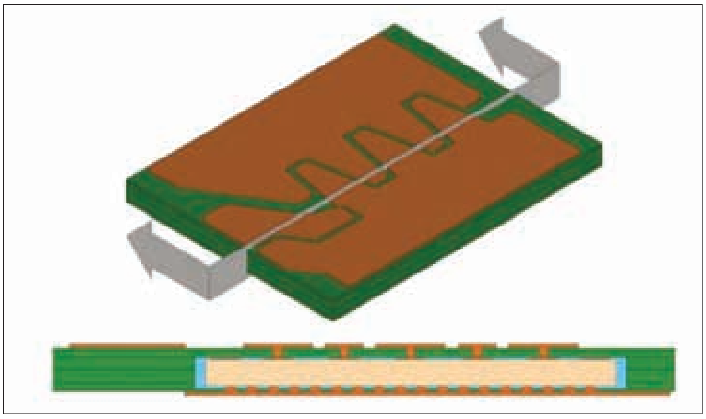
Silicon Carbide Schottky-Barrier diode rectifiers with high avalanche robustness

Silicon Carbide Schottky diodes are gradually replacing Silicon rectifiers in the high voltage power conversion systems with requirements for high efficiency and compact size. SiC Schottky rectifiers utilize a Junction-Blocked Schottky (JBS) design, in which the Schottky metal is shielded by a mesh of closely spaced shielding p-bodies. Available literature data for avalanche robustness of SiC Schottky diodes are scarce and fragmentary, and no avalanche currents above 12 A have been reported for Schottky-barrier diodes yet. On the other hand, practical applications often require much higher avalanche current. Clear understanding of the effect of inductive load on avalanche robustness is yet another requirement. Fairchild Semiconductors (**www.fairchildsemi.com**) will introduce a new 1200 V / 15 A SiC Schottky-barrier rectifier with a JBS design. The junction termination of the new rectifier has been optimized to prevent early breakdown around device periphery. Avalanche energy in the range of loads between 0.02 and 20 mH increases from 0.38 J for a load of 0.02 mH to 0.62 J for a load of 20 mH. Avalanche robustness of the new SBD rectifiers is close to that of the p-n diodes that were formed on the same wafer together with the SBDs. High avalanche robustness of the new SBDs is also verified for repetitive avalanche conditions.

Large area embedded GaN power transistors

Large area 650 V lateral normally-off GaN power transistors that can provide more than 35 A are being introduced into the open marketplace this year. Very low inductance packages are needed because the devices can switch on and off in less than 20 ns therefore every nH of inductance can result in serious gate voltage over-shoot. In addition, lateral GaN devices can provide very high current operation only if the device electrodes are augmented by thick printed circuit board equivalent plating. This process augments the conventional, limited thickness metallization of the die and thereby removes the electromigration concerns. However, it is the thermal issues that largely dictate the form of the packaging of power transistors. GaN Systems (**www.gansystems.com**) will present a new embedded PCB plating solution.

The GaNPX package is the first implementation of a discrete GaN power device to be embedded within a laminate construction. Conventional



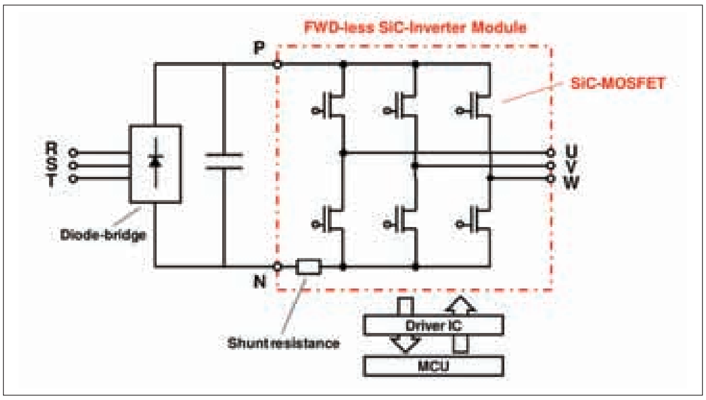
Embedded GaN transistor showing multiple drains and source busbars

packaging techniques such as clip or wire bonding, and molding compounds, are replaced using a series of galvanic processes. The GaN die is protected within the laminate construction. The die is thinned to 250 microns; this allows the total package thickness to be kept to less than 450 microns. This greatly reduces the critical loop inductance and hence the difficulties of driving the high speed, high current switch. When carefully implemented, the new embedded power GaN devices provide a small volume, low resistance and low inductance package. Three large area, low on-resistance, 650V devices are currently being produced. As will be shown, they are thermally and electrically superior to the SJ MOSFETS.

Freewheeling diode-less SiC-inverter

Hitachi (**www.hitachi.com**) will demonstrate a FWD-less SiC-inverter with fast short-circuit protection. 600-V rating SiC-MOSFET was developed and integrated into an inverter module without FWDs. The power loss of the inverter was reduced by 60 % as compared with conventional Si-inverter. In addition, fast short-circuit protection of the inverter by using shunt resistances is possible. These results indicate super-small size, very-low cost and safety operation of the SiC-inverter.

A conventional Si-Inverter uses both Si-IGBT and Si-FWD with inverse-parallel connection. On the other hand, since SiC-MOSFETs have reverse conduction characteristic, FWDs can be eliminated. Though the body diode (BD) of the SiC-MOSFET has high on-voltage, the low on-voltage channel conduction by synchronous rectification can minimize the BD conduction only during dead time.



Configuration of a fabricated 3-phase 200-V-class inverter, which includes a diode-bridge, an electrolytic capacitor, and a FWD-less SiC-inverter module

GaN FET Module Performance Advantage over Silicon

Gallium Nitride (GaN) FETs are increasingly finding use as next-generation, high-power devices for power electronics systems. GaN FETs can realize ultra-high power-density operation with low power loss due to high carrier mobility in the two-dimensional electron gas (2DEG) channel, and high breakdown voltage due to large critical electric field. GaN FETs are a majority carrier device, therefore, the absence of reverse recovery charge creates a value proposition for high-voltage operation. **Narendra Mehta, Senior Systems Engineer GaN products, Texas Instruments, Dallas, USA**

With GaN devices now being grown on affordable Silicon substrates, compared to GaN on Sapphire or bulk GaN, power GaN FETs will find an increasing rate of adoption for highly efficient and form factor constrained applications in the 30 V and higher DC/DC voltage conversion space. In this article the loss mechanisms in a hard-switched DC/DC converter and how a GaN FET power stage can outperform Si MOSFETs will be investigated and a 80V GaN FET power stage to 80V Si devices compared.

80-V GaN halfbridge

A GaN FET power stage device such as the LMG5200 is an 80 V GaN half-bridge power module. This device integrates the driver and two 80V GaN FETs in a 6 mm x 8 mm QFN package, optimized for extremely low-gate loop and power loop impedance. The inputs are 3 V CMOS and 5V TTL logic compatible. Due to GaN's intolerance for excessive gate voltage, a proprietary clamping technique ensures that the gate voltage of the GaN FETs is always below the allowed limit. This device extends the advantage of discrete GaN FETs by offering a user-friendly package, which is easy to layout and assemble into the final product.

The LMG5200 meets the IPC-2221B and the IEC 60950 pollution degree 1 clearance and creepage requirements without any need for underfill. This is because the minimum spacing between high-and low-voltage pins is greater than 0.5 mm. This eliminates the need for boards to be manufactured with underfill and simplifies board design. The pin-out also eliminates the need for a via-in-pad design as there is adequate spacing between the power pins for via placement. Additionally, this helps in to reduce board complexity and cost (Figure 1).

DC/DC converter losses

In this section mechanisms that cause losses in hard switched converters will be briefly discussed.

A synchronous buck converter (Figure 2) is used as a DC/DC converter to compare the losses in a hard-switched converter. The approach for comparing the loss mechanism can be applied to other hard-switched converters as well. Losses in a switched-mode converter can be broadly divided into conduction losses and switching losses. The high-side MOSFET dissipates most of the switching losses. Conduction losses are

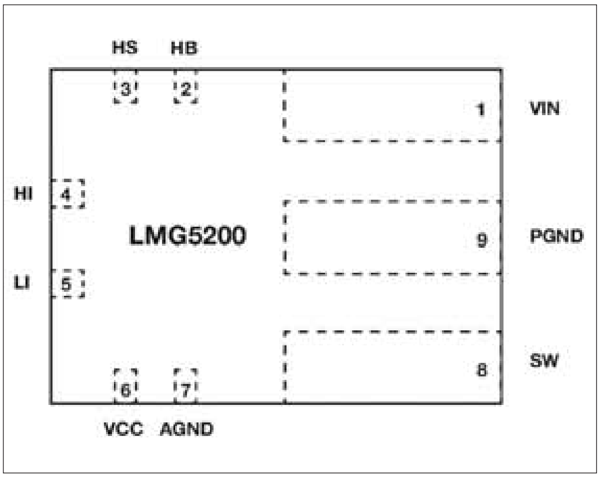


Figure 1: Top-down view of a GaN FET power stage device, showing pin-out

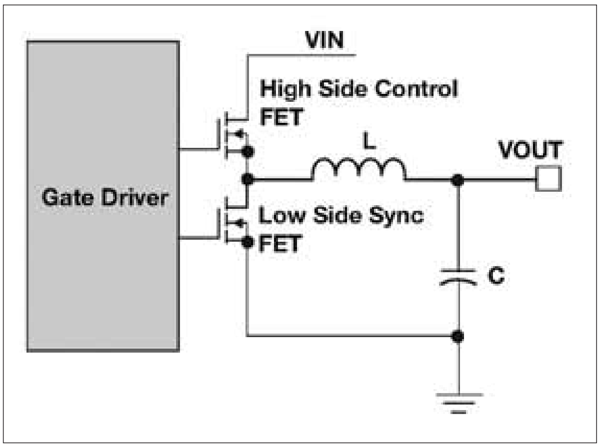


Figure 2: Simplified view of the buck power stage

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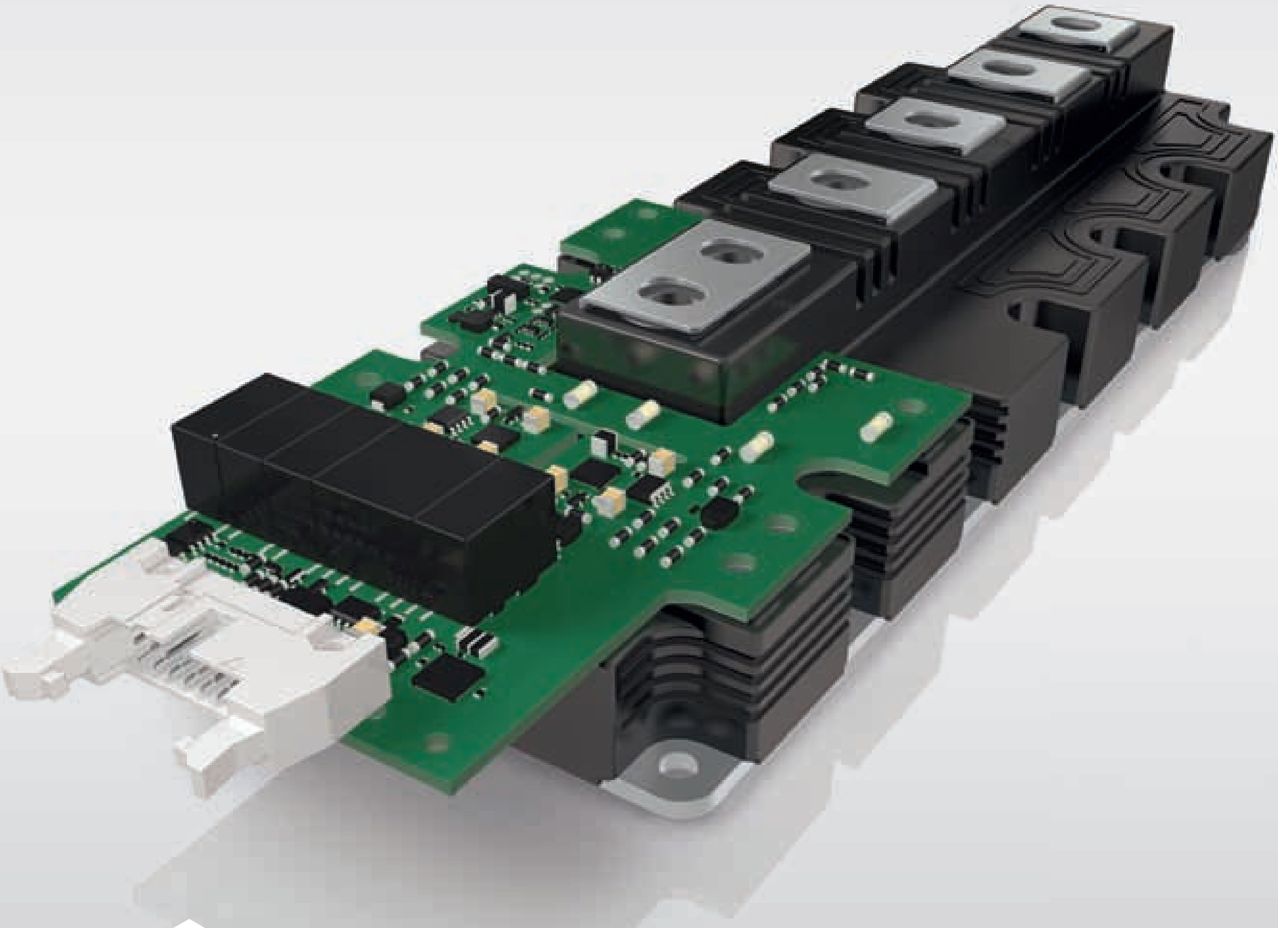

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a function of the duty cycle and are shared between the high- and low-side devices.

For low-duty cycle DC/DC converters, the low-side FET has a higher amount of conduction loss, which can be calculated as:

$$P_{COND(HS)} = R_{DS(ONHS)} \times I^2_{RMS(HS)} \quad (1)$$

$$P_{COND(LS)} = R_{DS(ONLS)} \times I^2_{RMS(LS)} \quad (2)$$

where $R_{DS(ONLS)}$, $R_{DS(ONHS)}$ is the low-side and high-side FET resistance, and $I_{RMS(LS)}$, $I_{RMS(HS)}$ are the low- and high-side RMS currents, respectively.

The switching loss (Figure 3) due to the I_{DS} current and V_{DS} overlap is in the high-side of a buck converter and can be estimated as:

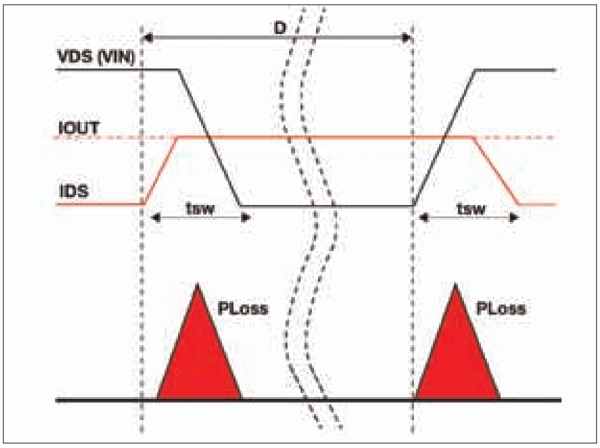

Figure 3: Turn-on and turn-off losses during inductive switching

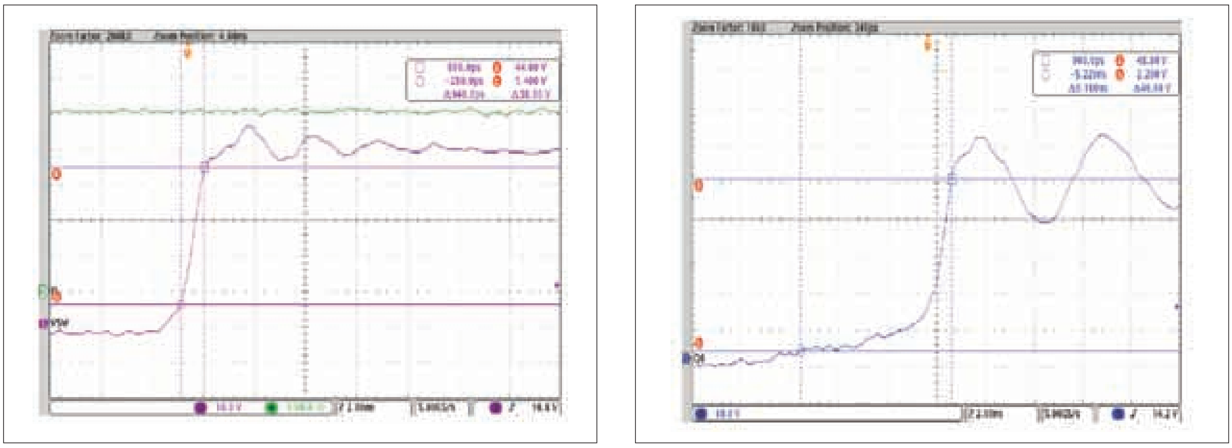

Figure 4: Comparison of a GaN FET power stage (LMG5200) switch-node (left) to Silicon (Si7852DP) switch-node voltage waveform

$$P_{SWHS} = V_{IN} \times I_{OUT} \times f_{SW} \times t_{SW} \quad (3)$$

where t_{SW} is the switching time. This includes the current commutation time through the FET and the time for the FETs drain-to-source voltage to rise / fall by V_{IN} during turn-off and turn-on, respectively.

The low-side FET does not have any switching loss due to zero voltage switching (ZVS) turn-on and turn-off. The actual waveforms for inductive switching are more complicated than those shown in Figure 3, however, the error in the calculated loss is acceptable as long as the correct switching time is used for the turn-on and turn-off.

The device construction of GaN allows very short switching times due to small gate and output capacitance for the same RDSON. As noted in Figure 4, switching time for the GaN FET power stage is less than 1 ns compared to 6 ns for a Si FET with a comparable breakdown voltage (Si7852DP).

Faster switching edges means the switching losses are significantly lowered in the GaN module compared to the Si MOSFET-based buck converter. Also there is minimal overshoot in the GaN FET power stage switch-node waveforms due to an extremely small (<300 pH) power loop inductance. The gate loop and common source inductance are also minimized in the GaN FET power stage package to be below 200 pH. High parasitic inductance in these loops can cause a significant power loss.

Besides the high-side turn-on and turn-off losses, forced commutation of the low-side MOSFETs body diode is a significant source of switching loss in high-voltage DC/DC converters. This loss is primarily due to the reverse recovery charge (Q_{RR}) in the freewheeling low-side FET. The power loss due to reverse recovery is given by:

$$P_{RR} = f_{SW} \times Q_{RR} \times V_{RR} \quad (4)$$

Because GaN is a majority carrier device, it does not have reverse recovery-based losses. The body diode of the low-side MOSFET conducts during dead time. This causes a power loss in the diode associated with the forward voltage of the diode. GaN has a higher third quadrant conduction voltage (V_{SD} of 2 V at 10 A for LMG5200) compared to ~1 V for Si FETs. Hence, the GaN device exhibits a higher power loss during dead time. It is critical to ensure that the dead time is small in order to minimize this loss. The power loss associated with the body diode can be calculated as:

$$P_{BD} = f_{SW} \times V_{SD} \times I_{OUT} \times (T_{DEADON} + T_{DEADOFF}) \quad (5)$$

The energy stored in the output capacitance of the MOSFETs is dissipated during turn-on. Since the output capacitance is a strong function of the drain-to-source voltage, the proper way to calculate this power loss P_{CAP} is:

$$P_{CAP} = f_{SW} \times Q_{OSS(VIN)} \times V_{IN} \quad (6)$$

where $Q_{OSS(VIN)}$ is the output charge of the MOSFET, evaluated at the input voltage. GaN devices, due to their small output capacitance for the same R_{DSON} compared to Si, exhibit a much smaller P_{CAP} loss as well. Gate driver losses are another contributor to switching loss.

Besides the active device-related losses in a hard-switched buck converter discussed, there are losses associated with the inductor. These losses include core loss and AC- and DC-winding loss, Fuji Electric

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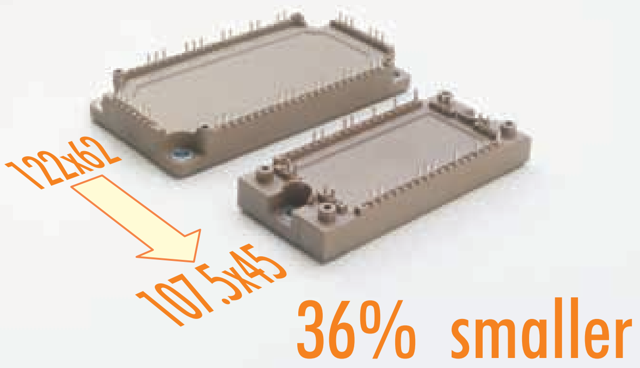
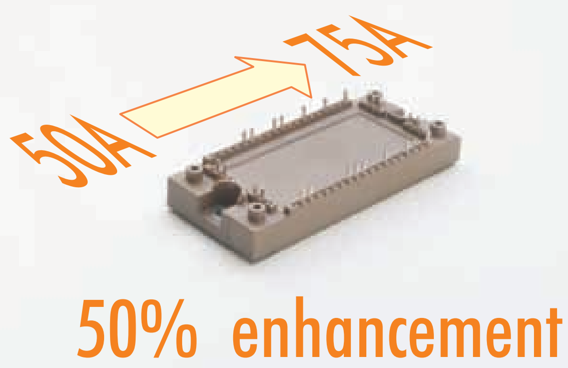
Downsizing package Example 75A PIM-IGBT



Upgrading current rating Example 50A PIM-IGBT



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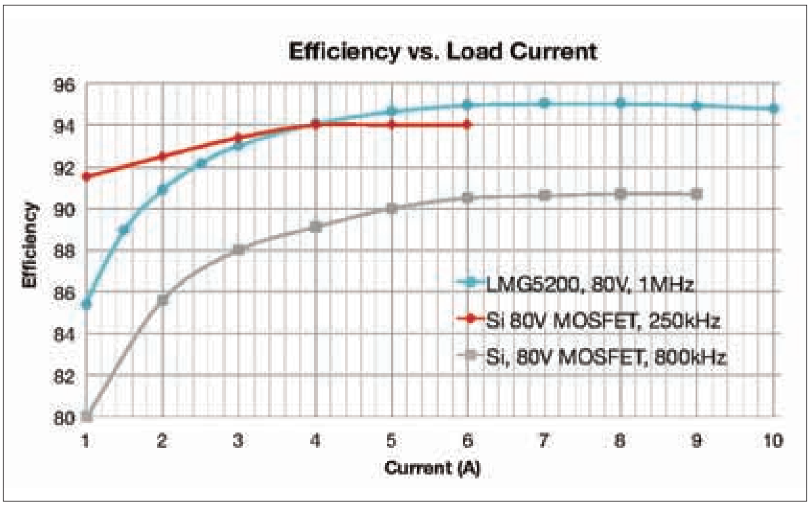
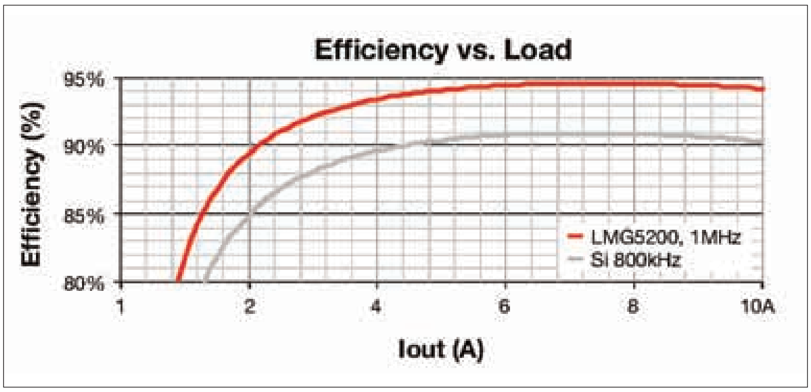
RIGHT Figure 5: LMG5200 vs Si at different frequencies





LEFT Figure 6: Calculated efficiency comparison between the GaN FET power stage design at 1 MHz and Si FET design at 800 kHz

which also should be taken into account when calculating system efficiency.

Efficiency improvements compared to Silicon

Figure 5 shows the efficiency delta between a 48 V:12 V LMG5200 buck and 80 V Si MOSFET- based buck. The LMG5200 is switching at 1 MHz while the Si-based implementation is switching at 250 kHz and 800 kHz, respectively. As shown, the LMG5200 has higher efficiency versus load than the Si solution switching at a lower frequency (1 MHz vs 800 kHz). This is indicative of the fact that switching and conduction losses in the GaN FET power stage are much lower compared to the similarly rated Si MOSFET. When the Si MOSFET-based converter is redesigned for a 250 kHz switching frequency, higher efficiency for Si designs at light loads as expected can be seen. However, as the load increases to 4 A, the GaN FET power stage switching at 1 MHz shows a much higher efficiency.

A comparison with Si at 800 kHz shows that the efficiency of the GaN FET power stage is much higher across a wide load range, even while switching at 1 MHz. A comparison of the efficiencies observed in the hard-switched buck with the calculated results indicates that the calculations are within the margin of error for the simplified model (Figure 6).

Conclusions

Power GaN FETs, due to their extremely low gate charge and output capacitance, can be switched at extremely high speeds with significantly reduced switching losses and improved efficiency compared to Silicon FETs. The LMG5200, an 80 V GaN FET power stage, has been optimized for applications requiring high efficiency and/or small form factor. Its advanced package greatly simplifies manufacturability and board design while reducing costs. The LMG5200 can improve the performance across a wide variety of applications while reducing adoption risk. These applications include multi-MHz synchronous buck converters, Class D amplifiers for audio, and 48 V to POL converters for data communications and telecommunications servers. GaN FET power stage devices provide significant efficiency benefits across a wide load range while improving switching frequency and power density.

Literature

Texas Instruments Enters GaN Power Market with 80-V Halfbridge (www.power-mag.com/news.detail.php?STARTR=10&NID=224)

TI White Paper: GaN FET module performance advantage over silicon

Texas Instruments Enters GaN Power Market with 80-V Halfbridge

Texas Instruments (TI) introduced on March 13 a 80-V / 10-A integrated GaN FET power-stage prototype, which consists of a high-frequency driver and two GaN FETs in a half-bridge configuration – all in a quad flat no-leads (QFN) package. TI does not introduce a GaN switch – instead the company relies on Enhancement-Mode GaN switches from Efficient Power Conversion (www.epc-co.com) and its already supplied GaN drivers.

According to TI Enhancement-Mode GaN power FETs can provide significant power density benefits over Silicon MOSFETs in power converters but pose new challenges for designers. TI solves the challenges of driving GaN power FETs with a family of drivers – UCC27611, a 4 A/6 A high-speed, optimized single gate driver, LM5114, a 7.6 A single low-side driver with independent source and sink outputs – and the LM5113, a 100 V integrated half-bridge driver for GaN power FETs. Compared to discrete implementations, these drivers provide significant PCB area savings to achieve high power density and efficiency while simplifying the task of driving GaN FETs reliably.

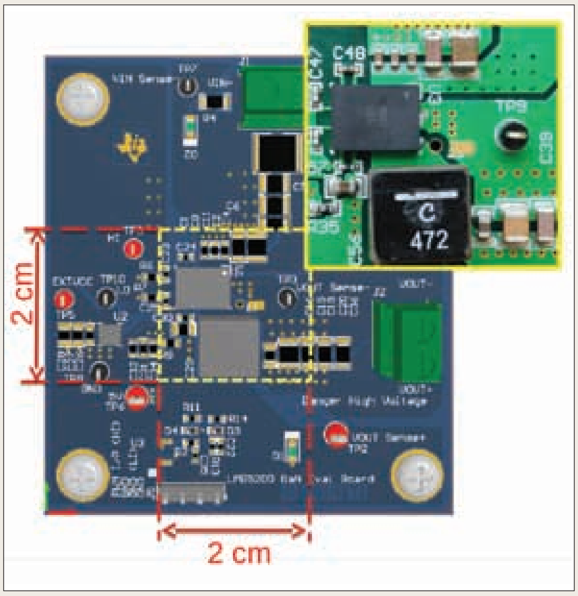
The new LMG5200 GaN FET power stage will help accelerate market adoption of GaN power-conversion solutions that provide increased power density and efficiency in space-constrained, high-frequency industrial and telecom applications.

Typically, designers who use GaN FETs that switch at high frequencies must be careful with board layout to avoid ringing and electromagnetic interference (EMI). The dual 80-V power stage prototype eases this issue while increasing power-stage efficiency by reducing packaging parasitic inductance in the critical gate-drive loop. The LMG5200 features multichip packaging and is optimized to support power-conversion topologies with switching frequencies up to 5 MHz.

Also the 6-mm x 8-mm QFN package requires no underfill, which significantly simplifies manufacturing. The reduced footprint solidifies the value of GaN technology and will help increase adoption of GaN power designs in many new applications, ranging from high-frequency wireless charging applications to 48-V telecom and industrial designs.

For quick evaluation the LMG5200 EVM board is a small easy to use power stage with an external PWM signal. The EVM is suitable for evaluating the performance of LMG5200 power stage in many different DC/DC converter topologies. It can be used to estimate the performance of LMG5200 to measure efficiency. The module is capable of delivering a maximum of 10 A of current however adequate thermal management (forced air, running at low frequency etc) should be followed to ensure that the temperature is not exceeded. The EVM is not suitable for transient measurements as it is an open loop board. In addition to ordering the EVM, designers can get started faster using PSpice and TINA-TI models for the LMG5200 to simulate the performance and switching frequency advantages of this technology. Prototype samples of the GaN power stage are available to purchase in the TI Store. The LMG5200 is priced at $50 each with a maximum purchase of 10 units. The LMG5200 EVM is available for $299.

GaN FET power-stage consisting of a driver and two GaN FETs in a half-bridge configuration – all in a quad flat no-leads (QFN) package



The LMG5200 EVM board is a small easy to use power stage (buck converter) with an external PWM signal

Gallium Nitride Transistors Drive Automotive Applications

Enhancement-mode gallium nitride transistors have been in production for over five years. As the technology has matured it has been adopted into a number of automotive applications such as cockpit wireless charging, LiDAR sensing, and EV charging with many more to follow. **Alex Lidow, CEO Efficient Power Conversion Corporation, USA**

Mobility has become a major theme for the consumer during this century. Smart phones allow us to take our music, games, movies, television shows, contacts, and our internet with us at all times. Applications such as Google Maps give us directions, tell us about traffic, and provide us with street and satellite images of our destination. Recently the automobile industry has caught on to this trend and has begun to show its vision of the future for the fully-mobile lifestyle. The dashboard is being taken over by the smartphone, the car is being taken over by sensors and computers to become semi, and eventually, fully autonomous. And, our cars are going semi, and eventually fully electric.

Power devices made with Gallium Nitride are an integral part of every aspect of this mobility trend. These new generation power devices have already carved out a significant position in the next generation automobile.

Electric drive

The automotive industry is evolving from vehicle propulsion that relies only on an internal combustion engine, to hybrid vehicles, plug-in hybrids, and, finally, fully electric cars. The demand for electricity grows in proportion to the amount of propulsion handled by the electric motor. For example, the Tesla S delivers 416 hp, or 310 kW of electrical power to the rear wheels. Delivering that much power requires higher voltages in order to keep the current levels flowing through the motor windings at a manageable level, with minimum conduction losses. Today the dominant transistor in electric or hybrid vehicle propulsion systems is the insulated gate bipolar transistor (IGBT) in voltages ranging from 500 V to 1200 V.

Wide bandgap (WBG) transistors made in either SiC or GaN technology hold great promise for this high power application because of their ability to block higher voltages with lower conduction losses compared with Silicon transistors and, potentially, their ability to operate at much higher temperatures. Motor drives operate at frequencies between 17 kHz and 100 kHz. The IGBT has a high saturation forward drop and stored charge, and the reverse conduction diode has a high stored charge. While the IGBT/ultrafast diode combination outperforms the silicon MOSFET, both GaN and SiC transistors have the capability to significantly increase the efficiency of these motor drives.

Figure 1 gives a conceptual graph showing the power levels and voltage levels that are best served by different types of transistors including IGBTs, GaN transistors, and SiC transistors. The requirements for electric drives sit right at the interface between GaN, SiC and IGBT technologies. Ultimately, the cost and reliability of the system will determine the winner of this application.

Wireless power transfer

Wireless power transfer was first demonstrated over 100 years ago. However, only in this century have we demonstrated safe, economic, convenient, and efficient wireless power transfer techniques. The latest techniques enable wireless charging of multiple objects within a distance of several centimeters from the power transmission unit (PTU) with efficiencies above 80 % (Figure 2). Wireless phone charging in a car is becoming more critical as the smartphone itself is becoming the information receiver and router for the dashboard infotainment center. Several automotive manufacturers are adopting operating system standards that enable seamless Android or iOS interfaces to dashboards that become slaves to the information and entertainment available in the smartphone. As a consequence, usage of wireless network data as well as the battery power will go up significantly.

Several automotive manufacturers are also planning to embed wireless charging stations in the center console of the vehicle so smartphone, as well as other mobile devices, can remain charged despite intense and continuous usage while the automobile is in operation. Given that the reference (Rezence) standard uses a 6.78 MHz standard frequency for power transmission, GaN is the heavy favorite for adoption over the slower and less efficient silicon power

Figure 1: Current and voltage ranges where various power semiconductor technologies are the most likely to be applied

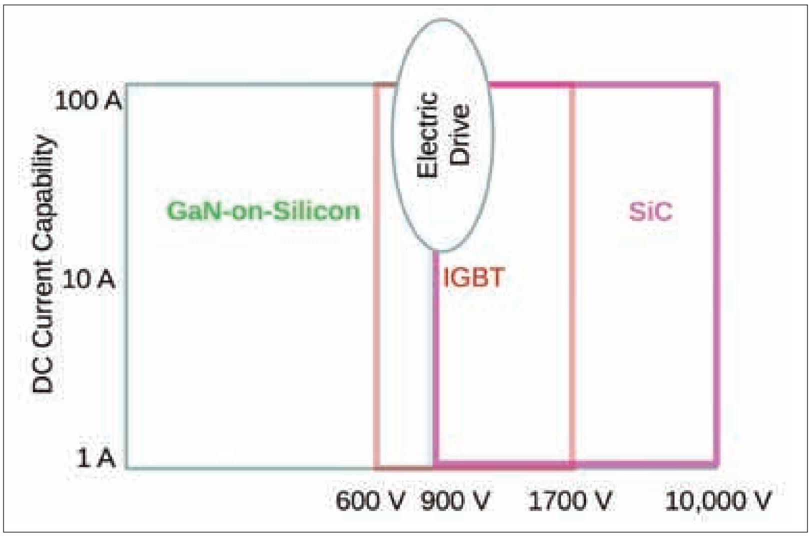


Figure 2: Wireless power transfer will be used in automobiles to keep smartphones charged despite continuous usage as part of the infotainment system

MOSFET in these applications.

Wireless charging for electric vehicles is also becoming more available as fully-electric cars become more prolific. Whereas there is no universal standard yet, loosely coupled magnetic energy transfer, similar to the method used in the Rezence standard is common to all implementations due to its ability to transfer power without precise alignment of transmitter and receiver units. GaN is certainly a good candidate technology for this application as well.

Autonomous control

It is critical that a car know what is around it at all times in order to prevent collisions. The higher the speed of the vehicle, the faster the system needs to sense, and the more precisely it needs to interpret the distance to the potential collision. Today automotive manufacturers use a variety of sensors in these functions, including ultrasonic sensing, microwave radar, short range radar, and video pattern recognition. Light Distancing and Ranging (LiDAR) sensors have only recently begun to emerge in automotive sensing applications. Initially LiDAR sensors were used to generate digital maps used for mapping and navigation software. Because LiDAR chases the speed of light for resolution, eGaN FETs, with about a 10 times advantage in switching speed over Silicon, have been used almost exclusively in these mobile applications.

The imaging speed and depth resolution has become so good with eGaN FETs that manufacturers experimenting with autonomous vehicles are using these same types of LiDAR sensors used for mapping for their driverless navigation systems. In addition, several automakers are incorporating eGaN FET-based LiDAR sensors in their vehicles for general collision avoidance and blind spot detection.

Conclusions

The around 70 million annually manufactured cars presents a huge potential market for any technology that can improve the customers' automotive experience. Infotainment mobility through wireless charging and autonomous vehicles enabled by LiDAR sensors are two areas that will infiltrate the automotive world over the next few years. Both of these applications rely on the higher speed and low cost of GaN transistors. In the future, as electric vehicles become more ubiquitous, motor controls might also become an enormous market for GaN transistors, depending upon the cost structure of higher voltage GaN transistors compared with today's IGBTs or tomorrow's SiC transistors.

Literature

Lidow, A: "Enhancement-Mode Gallium Nitride Transistors in Automotive Applications", PCIM Europe 2015, Special Session "Power GaN in Automotive Applications"

Monolithic Gallium Nitride Half Bridge

EPC has designed the EPC2105, a 80-V enhancement-mode monolithic GaN transistor half bridge. By integrating two eGaN power FETs into a single device, interconnect inductances and the interstitial space needed on the PCB are eliminated. This increases both efficiency (especially at higher frequencies) and power density, while reducing assembly costs to the end user's power conversion system. The EPC2105 is intended for high frequency DC/DC conversion and enables efficient single stage conversion from 48 V directly to 1 V system loads.

Each device within the EPC2105 half-bridge component has a voltage rating of 80 V. The upper FET has a typical $R_{DS(on)}$ of 10 mΩ, and the lower FET has a typical $R_{DS(on)}$ of 2.3 mΩ. The high-side FET is approximately one-fourth the size of the low-side device to optimize efficient DC/DC conversion in buck converters with a high V_{IN}/V_{OUT} ratio. The EPC2105 comes in a chip-scale package for improved switching speed and thermal performance, and is only 6.05 mm x 2.3 mm for increased power density.

The EPC9041 development board (2" x 1.5") contains one integrated half-bridge component using the TI LM5113 gate driver, supply and bypass capacitors. The board has been laid out for optimal switching performance and there are various probe points to facilitate simple waveform measurement and efficiency calculation.

First EPC 80-V enhancement-mode monolithic GaN transistor half bridge

Progress of GaN Transistors

Over the last several years, GaN semiconductors have emerged as a leading technology enabler for the next wave of compact, energy-efficient power conversion systems – ranging from ultra-small adapters, high-power-density PCs, server and telecom power supplies, to highly efficient PV inverters and motion control systems. Continuous progress has been made since the JEDEC qualification of Transphorm's 600 V-rated GaN-on-Si devices in 2013. Systematic voltage-accelerated off-state stress tests and temperature-accelerated on-state stress tests reveal an intrinsic Mean Time to Failure (MTTF) of 8x107 and 3x107 hours at the rated voltage and rated temperature respectively. **Yifeng Wu, Sr. VP Engineering, Transphorm Inc., Goleta, USA**

The TPH3205WS is a first 600V GaN (Gallium Nitride) transistor in a TO-247 package. Offering 63 mΩ on-resistance and 34 A current rating, the device utilizes the source-tab connection design, which reduces EMI at high dv/dt to enable low switching loss and high-speed operation in power supply and inverter applications. An already demonstrated 2.4kW, bridgeless totem-pole PFC design exhibits near 99 % PFC efficiency at 100 kHz operation. The totem-pole PFC, when combined with a GaN-based DC/DC conversion stage, enables a simplified 80 PLUS titanium power supply design providing power densities unachievable with Si-based devices. A static demo of the TPH3205WS used in a 3 kW inverter shows a peak efficiency of 98.8 % at 100 kHz and over 99 % at 50 kHz switching frequency.

Automotive applications with GaN

There has been also strong interest in developing GaN power devices for automotive applications due to the physical arguments of their potential benefits for next generation vehicles. However, most previous reports have been consumed with discussion of device structures, characteristics and challenges in achieving reliability. In passing JEDEC qualification of 600-V rated GaN transistors, reliability can now be assessed to justify GaN's suitability for the stringent automotive applications. Although it will take more time to develop mature manufacturing of high current GaN devices for the main motor drive in an Electric Vehicle (EV), it is now attractive to employ present GaN switch products for auxiliary power blocks up to 6 kW.

Present 600V GaN switch products are well suited to auxiliary power converters due to the improved figure of merit over Si devices and the special ability to perform all the functions of a MOSFET or an IGBT plus a freewheel diode. This is especially attractive for on-board chargers in an EV to deliver bi-directional power flow, which not only serve as a charger but can provide electricity from the EV battery to a camping ground or to one's home in a power outage. A unique topology as shown in Figure 1 can be controlled to be a bridge-less PFC with very high efficiency. The same circuit can also be controlled to reverse the power flow to function as a DC/AC inverter. A performance evaluation was carried out using a half bridge by two 600-V-rated GaN HEMT switches in TO247 with on-resistance of 50 mΩ. These devices are capable of >3.3 kW output power and two interleaved phases can provide >6.6 kW.

The half bridge circuit was first configured as a boost converter driven in synchronous rectification with result shown in Figure 2. The boost ratio is 240 V:400 V and the PWM varies from 100 to 300 kHz. The inductor was made of a Koolmu core with L=268 μH and wire DC resistance of 20 mΩ, sized for continuous current mode in most of the operation range. The input and output storage capacitors are 15 μF and 5 μF respectively. The heat sink and thermal insulator assembly were tested to have an ambient-

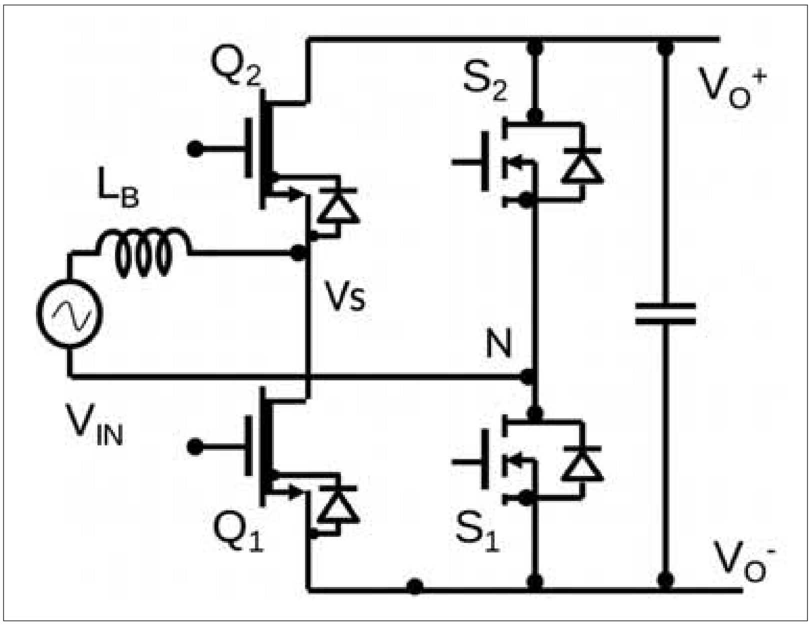


Figure 1: A Totem-pole circuit which can be controlled as either an AC/DC PFC or a DC/AC inverter for reverse current flow. Q1 & Q2 are fast GaN devices (operating at 100-300 kHz) and S1 and S2 are Si MOSFETs (operating at 50-120 Hz). This design can be an efficient front end of a bi-directional on-board EV battery charger

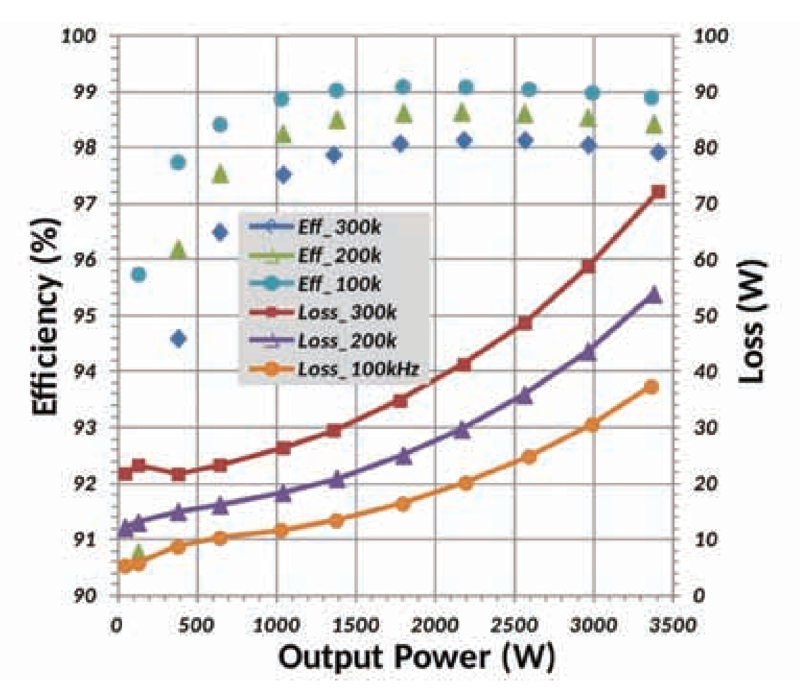


Figure 2: **Experimental test result of a half bridge operating as a boost converter using two 50 m?, 600-V rated GaN HEMTs in TO247 packages. The devices are driven in sync-rec mode at boost ratio 240 V:400 V achieving peak efficiency >99 % at 100 kHz and >98 % at 300 kHz, respectively**

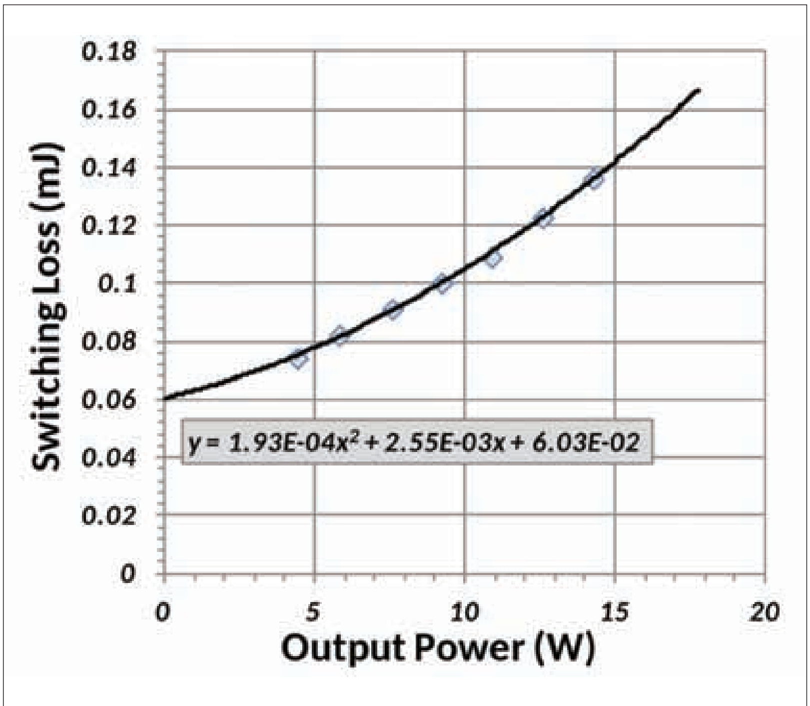


Figure 3: **Switching loss (including turn-on and turn-off) as a function of current at 400 V for the 600-V, 50 m? GaN half bridge converter**

to-case thermal resistance of 2.7 K/W for each device, while the junction-to-case thermal resistance of each packaged device is 1 K/W. All circuit losses are included in the performance plot and each data point was captured after thermal equilibrium in an air ambient of 25°C. As already mentioned above the converter delivers >3.3 kW output power with a peak efficiency >99 % at 100 kHz and >98 % at 300 kHz respectively. This high level of performance is not possible with Si devices at such high PWM frequencies, which is key to a compact circuit and system design.

With the data available at various inductor current levels and frequencies, as well as the magnetic losses of the inductor at corresponding frequencies and voltage excitations tested in a separate fixture, the switching losses as a function of current is then extracted as seen in Figure 3. This together with the thermal characteristics of the device and the heat-sink assembly allows the construction of a simulation model to predict performance including loss breakdown and junction temperature as a function of power and frequency. The modeling result is verified in Figure 4 with almost identical overlaps of experimental data.

At 100 kHz, the high device efficiency well above 99 % up to full load translates to a total device dissipation of only 28 W at the output power of 3.4 kW, resulting in a junction temperature of 76°C. It is device physics that switching losses increase at higher frequencies for any semiconductor. The merit of GaN is to extend that to a much higher frequency while maintaining a reasonably low loss to prevent overheating. The GaN half bridge has no issue operating at 3.4 kW and 300 kHz with a junction temperature 140°C, well below the 175°C specification limit. Compared to traditional Si devices at 12-50 kHz, the GaN transistors open up a large design space

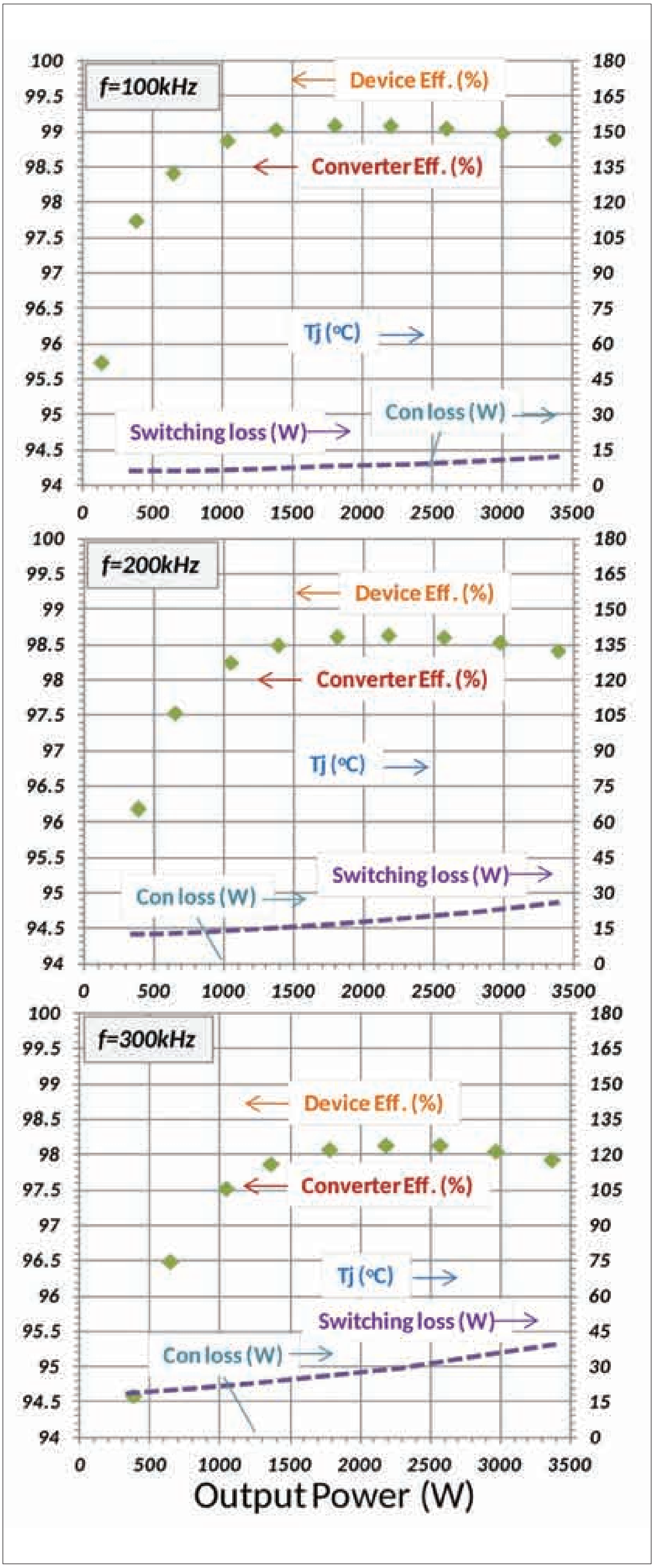


Figure 4: Modeled result of the GaN half bridge converter with experimental data in green diamonds to confirm validity. PWM frequencies were 100, 200 and 300 kHz, respectively. The heat-sink thermal resistance from package to ambient is 2.7 K/W for each device and ambient temperature 24°C

for designers striving for compact power circuits.

GaN and cooling

There is a strong interest with EV makers to consolidate all cooling systems in a vehicle into an integrated one, where the fluid temperature could be as high as 105°C. The same sim7ulation model is applied to such a case assuming a conservative case-to-fluid thermal resistance of 1.5 K/W for each device package (a total of 2.5 K/W from junction to fluid). The inductor was assumed to have a magnetic loss of 3 W and a DC resistance of 20 mΩ which can be made small at high frequencies. Input and output passives were assumed to have 10 mΩ series resistances respectively. The test results using PWM frequencies 50, 100 and 200 kHz show that even in such a stringent situation the GaN half bridge is comfortable operating at 50 kHz and 100 kHz, with a maximum junction temperature of 140°C and 150°C respectively, well under the 175°C limit. At 200 kHz, full load junction rises to 165°C with a headroom of 10 K. This results show great promise for such applications although actual tests need to perform for in-system validation.

Conclusions

GaN high voltage devices turned a new leaf after the first product qualification in 2013 and have now shown systematic intrinsic reliability data that aligns to automotive applications. An analysis based on experimentally validated model indicated outstanding performance for the GaN bridge topology in compact on-board bi-directional EV chargers operating at much higher PWM frequencies than that of typical Si-based circuits, even at elevated coolant temperatures up to 105°C. Although to achieve and to maintain mature manufacturing similar to today's Si still require investment and time, there is little doubt that these new power devices will help open up a new design space for attractive future products in this industry.

Literature

Wu, Y: "Progress of GaN Transistors for Automotive Applications", PCIM Europe 2015, Special Session "Power GaN in Automotive Applications"

DC/DC Converter Modules Replace Discrete Designs

The decision to 'make or buy' a DC-DC converter has never been straightforward with many factors to consider. More low power applications can now be satisfied with new generations of low cost modules.

Paul Lee, Director of Business Development, Murata Power Solutions, UK

Your new product design requires a processor, so do you design one and then find board space for two billion transistors? Would you buy a 100 mW resistor in an SOIC-8 package? Frivolous examples but they illustrate the extremes where the decision to buy a module or achieve a function with discrete components is easy. For DC/DC converters, the decision is often quite difficult with their particular combination of size, dissipation, isolation, EMC and electrical performance specifications.

The argument for buying is easier at higher power levels: 'state of the art' bus converters for distributed power applications can achieve 600 W output in a quarter brick format utilizing a 14 layer board in heavy copper. This would be hugely difficult to implement discretely in a motherboard for the same performance. At lower powers such as 1 W there is a very large market for simple isolated converters which typically power isolated data interfaces or generate low power 'spot' voltages for analogue circuitry such as -5 V for an op-amp rail (Figure 1). Today, these converters can be bought as surface-mount or through-hole modules from reputable sources for about $2 in volume. However, many users feel that in volume they can design and implement the converter themselves from basic theory and device application notes at lower total cost.

Of course the cost comparison is not simply between the bought-in module and the BOM cost of the discrete design. Taking an example of a 1 W isolated converter which could be implemented with ten discrete components, other direct cost factors include the placement/inspection cost of ten components versus one, purchasing overhead for ten components from perhaps five manufacturers, including specialist magnetics, versus one module supplier and the stores handling/inspection/stocking/picking overhead for perhaps eight different component types including specialist magnetics versus one module.

The costs of testing functionality and isolation would also need to be included. Then you would need to consider the indirect extra costs. These would include the cost to board area – a discrete design is unlikely to be smaller, cost to skyline - a surface mount module with embedded magnetics can be very low profile and the specialist power circuit design, product qualification and overhead. There are a number of other indirect costs such as PCB design and overhead, design support cost, ongoing certification and inspection costs if agency approved and the costs associated with multiple supplier monitoring, QA and control.

If the transformer and other magnetic components are also designed and manufactured 'in-house' then all the above considerations apply again for these parts with would include multiple wire types and gauges, insulation, hardware and cores. The transformer in the above example would typically have a minimum of six windings with wire down to 0.07 mm gauge on a core of 4 mm diameter

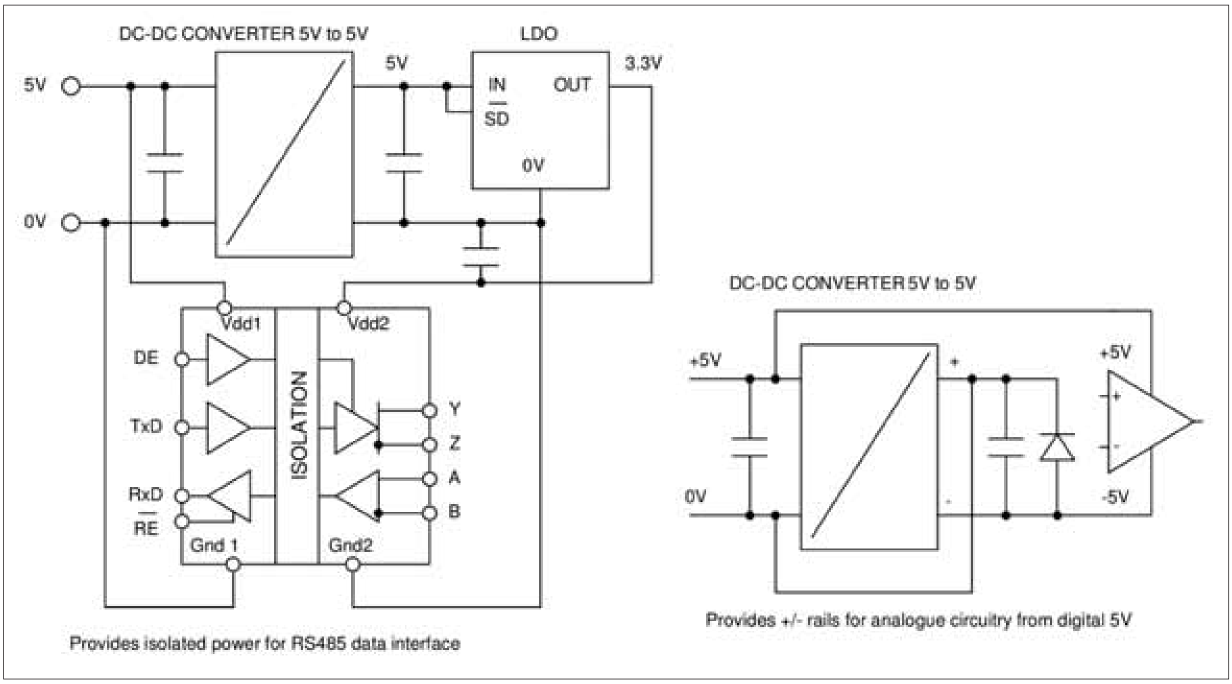


Figure 1: Typical applications for isolated DC/DC converters

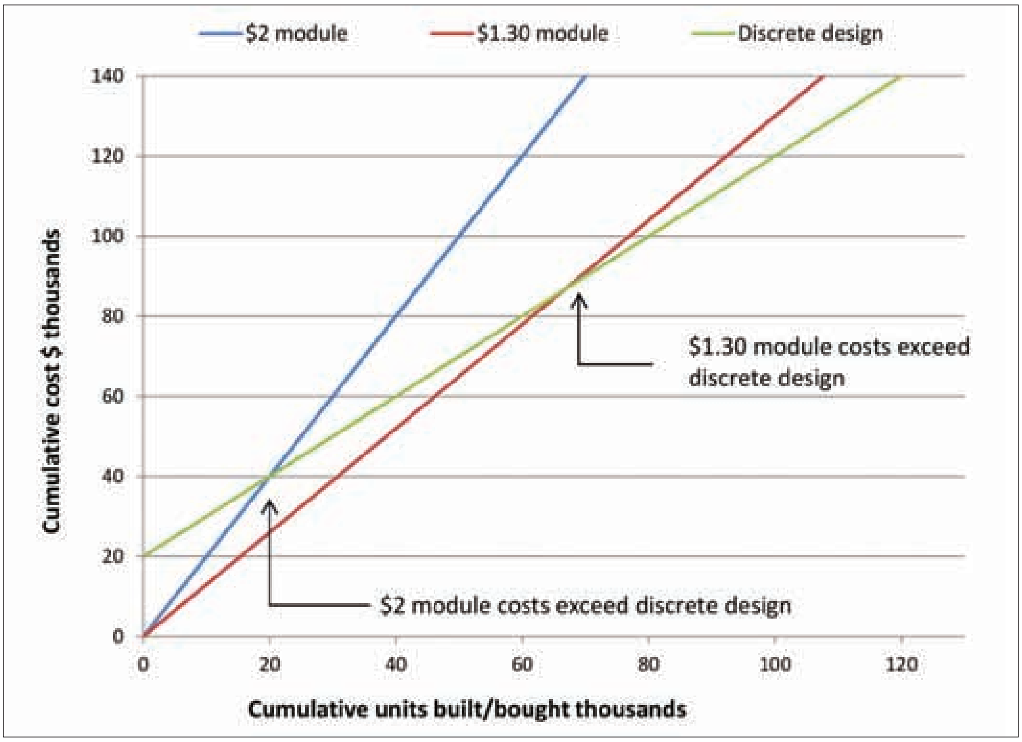


Figure 2: Example of crossover points make or buy for DC/DC converters

requiring specialist techniques and equipment to wind. Of course, if available, the magnetic part could be bought in, but could be as expensive as a complete DC/DC module.

Circuit and magnetics design are not trivial despite, and perhaps because of, the minimal component count. The example given of a 1 W converter is a self-oscillating push-pull circuit which relies on careful selection of transistor gains and biasing along with deliberate cyclic saturation of the transformer ferrite core operating outside of its normal data sheet parameters. To be viable, the completed design must have high efficiency with low noise on inputs and outputs while maintaining reliable isolation, accurate output across its load range and even with a degree of overload protection. A lot to get right with just 10 discrete components!

Speed to achieve a solution is a factor with even a simple converter requiring many weeks of design, documentation and qualification over all prospective operating and environmental conditions. If the converter forms any sort of safety barrier, the costs and time to achieve agency rating are measured in thousands of dollars and months with ongoing costs for inspections and re-certifications.

All of these costs and associated overheads and delays need to be compared with the simplicity of purchasing a proven, reliable module and also saving the 'opportunity cost', the value of the time that could be used elsewhere in core business and the value of a quicker time to market and earlier sales.

There may be some volume at which your company can afford to become a DC/DC converter manufacturer, keep the design in-house and write off the design costs. However, new 1 W converter module designs are pushing out the make/buy volume crossover point. At much lower costs than equivalent older products and with performance advantages, the differential between make and buy may now be down to a few cents, if anything, perhaps moving the crossover point out by fivefold or more.

To put some figures into an example, let's say that the total time taken to implement a discrete design is eight man-weeks. This would include time for a design engineer, support technicians, drawing office, production engineer, component engineer, qualification engineer, EMC engineer, management and probably more functions. If the average burdened employment cost of these staff is $50/hour then the one-off cost is about $15,500. Add prototyping materials, tooling, external agency costs and disposables, this figure could easily approach $20,000. If the direct cost of a discrete design is $1, comprising BOM, placement, component sourcing, handling, test and ongoing design support, then the gain over buying a $2 bought-in DC-DC converter pays off the design costs after building about 20,000 units. If the bought part is now closer to $1.30, the pay-off quantity is close to 70,000 units. An unexpected further cost

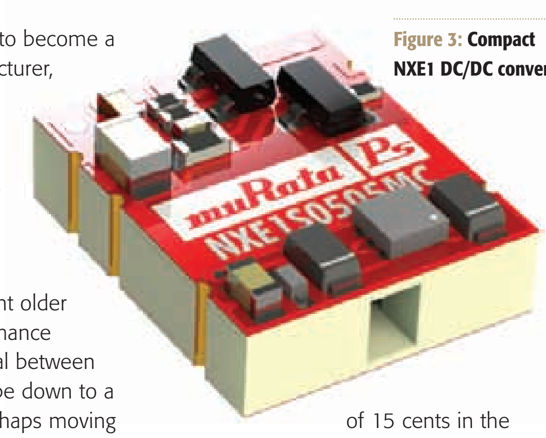


Figure 3: Compact NXE1 DC/DC converter

of 15 cents in the discrete design doubles the payback quantity again. This is all without factoring in the value of opportunity cost, quicker time to market and convenience of a warranted 'fit and forget' module (Figure 2)

.Latest low cost products on the market also offer significant performance improvements over previous generations. An example is the NXE series having the additional advantage of patent-pending embedded magnetics giving completely repeatable performance and lower profile than typical discrete parts. The NXE with proprietary 'inspectable land grid array' (iLGA) package is also pin-compatible with the 1 W industry standard footprint enabling existing users of DC/DC converter modules to upgrade and realize the benefits as well.

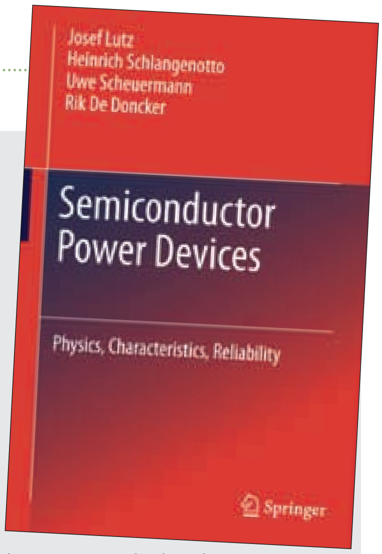
Perhaps the 'make or buy' decision is now a little easier at lower powers and the day is closer when product designers would no more design DC/DC converters discretely than they would a logic gate or op-amp.

Ring-Shaped Power Capacitors for E-Mobility

TDK Corporation presents the EPCOS RingCap – a power capacitor with an innovative design that is especially suitable for xEV applications. Thanks to its ring configuration, the new RingCap can be integrated into a clutch bell housing or wheel hub motors. The dimensions of the capacitor can be adapted according to the specific requirements of the customer: The outer diameter may be up to 315 mm, while its width is no more than 50 mm. The EPCOS RingCap is designed for rated voltages of between 100 V DC and 900 V DC and offers capacitance values of between 100 µF and 2000 µF. Apart from the main winding, Y-capacitors with separate terminals can additionally be integrated in the winding. A special heat-treatment under vacuum increases long-term stability of the capacitor. In the standard version with dielectric made of polypropylene (PP) or polyethylene terephthalate (PET), the capacitor is suitable for a temperature range between -40 °C and +105 °C. With a dielectric made of polyethylene naphthalate (PEN), it can even handle temperatures of up to +150 °C. Due to the low equivalent series inductance (ESL) values ranging from less than 10 nH up to 30 nH, no unwanted over-voltages occur in the DC link circuit during high-speed switching operations. For better protection against environmental effects, the capacitor is also available with a resin-filled housing.

http://en.tdk.eu

New Book Semiconductor Power Devices



Semiconductor power devices are the heart of power electronics. They determine the performance of power converters and allow topologies with high efficiency. Semiconductor properties, pn-junctions and the physical phenomena for understanding power devices are discussed in depth. Working principles of state-of-the-art power diodes, thyristors, MOSFETs and IGBTs are explained in detail, as well as key aspects of semiconductor device production technology. In practice, not only the semiconductor, but also the thermal and mechanical properties of packaging and interconnection technologies are essential to predict device behavior in circuits. Wear and aging mechanisms are identified and reliability analyzes principles are developed. Unique information on destructive mechanisms, including typical failure pictures, allows assessment of the ruggedness of power devices. Also parasitic effects, such as device induced electromagnetic interference problems, are diccussed.

The book addresses also power device function, thermal behavior of devices and packages, reliability. The treatment of semiconductor physics differs from other textbooks. "What might be called the German method of taking into account emitter recombination and behavior of the middle region is employed in the analysis of diode forward I-V characteristics" (review Phil Hower, TI) however, is essential for the function of modern power devices (emitter engineering).

www.springer.com/gp/book/9783642111242

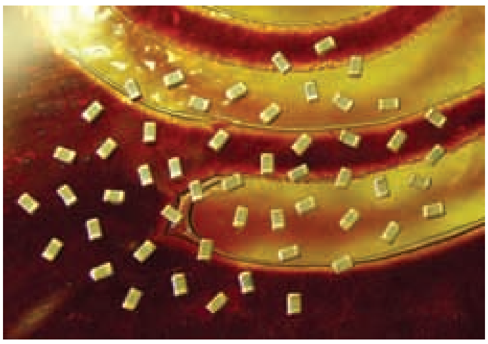
Highly Efficient 228 W DC/DC Modules

GE's Critical Power business has expanded its Hammerhead series of DC/DC modules with 228 W quarter-brick QHHD019A0B isolated converters. The low-height modules provide a single, regulated output voltage over a wide input voltage range of 18-75 V DC. In terms of output voltage, Hammerhead converters provide a nominal 12 V output voltage that is rated for 19 A output current. The new modules achieve typical full-load efficiencies of greater than 93 % at input voltages of 24 and 48 V. Standard features include remote on/off, remote sense, output-voltage adjustment and over-voltage, over-current and over-temperature protection. In addition, an optional heat plate is available, which allows for an external, standard, quarter-brick heat sink attachmentóenabling designers to achieve higher output currents in high-temperature applications. With the addition of the new 228-W QHHD DC-DC converters to its family of Hammerhead products - which include EHHD, KHHD and SHHD modules, GE can provide board designers with converters from 15 W in a 1-by-1-inch module to 228 W in a DOSA-standard quarter brick unit.

www.gecriticalpower.com

Gold Plated Terminations for MLCs

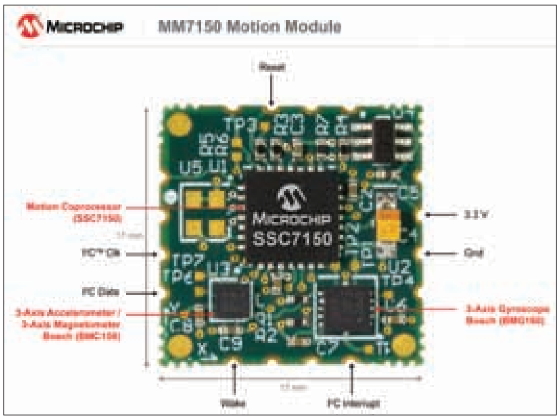
UK-based Knowles/Novacap offers now gold plated terminations. Conventional termination is normally tin/lead, but lead has been banned by the RoHS directive. However, pure tin-plated terminations allow tin whiskers to grow from surfaces and can cause electrical short-circuits and failures. To help eliminate this problem of tin 'whiskering' Novacap has developed a gold flash termination for conductive epoxy or gold/indium solder attachment. Tin whiskers are microscopic single-crystal metal fibers, thinner than a human hair, capable of bridging great distances between leads on electronic components, and creating short-circuits and failures. They are caused by deposit stress, such as heat, to pure tin plated components and are almost invisible to the eye, needing magnification and special lighting to be seen. However, failures that they can cause represent a clear and present danger especially to Hi-Rel applications such as medical implantable devices and military equipment. Novacap's gold termination consists of a 5 micro-inch minimum gold flash over a nickel barrier and is defined by the use of a "NG" in the part number ordering code. It can be specified for both their PME and High Capacitance BME product lines. But other "hard to find" terminations, such as tin/lead (desired for many military applications) can still be specified.



www.knowlescapacitors.com

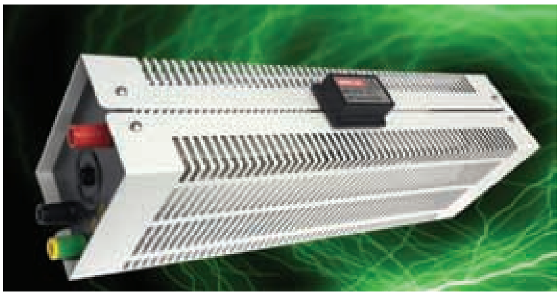
Motion Module Combines Co-Processor with Motion Sensors

Microchip announced the MM7150 Motion Module which combines SSC7150 motion co-processor with 9-axis sensors, including accelerometer, magnetometer and gyroscope in a small form factor. With a simple I?C™ connection to most MCUs/MPUs, embedded/IoT applications can easily tap into the module's advanced motion and position data. The SSC7150 motion co-processor is pre-programmed with sophisticated sensor fusion algorithms which intelligently filter, compensate and combine the raw sensor data to provide accurate position and orientation information. The small form factor module is self-calibrating during operation utilizing data from the pre-populated sensors: the Bosch BMC150 6-axis digital compass; and the BMG160 3-axis gyroscope. The MM7150 motion module is single-sided to be easily soldered down during the manufacturing process. Developing motion applications for a variety of products made easy using the MM7150 PICtail™ Plus Daughter Board. The MM7150 Motion Module is well suited for a wide range of embedded applications such as portable devices and robotics; industrial applications such as commercial trucks, industrial automation, patient tracking, smart farming, and consumer electronics.



www.microchip.com/MM7150-Page-022415a

Variable Wire Wound Resistor



The VRH320 Variable Wire Wound Resistor available from UK-based ARCOL Resistors has a wide range of applications for voltage and current adjustment including industrial machinery RPM adjustment, instruments, automated control installations, load simulation and educational modelling. The VRH320 has been ergonomically designed to enable simple and accurate adjustments by use of its top mounted slider. It is encapsulated in an IP20 rated lacquered metal casing which has dimensions of 446 mm x 93 mm x 160 mm. There are six resistance values available in this range encompassing 10 Ω to 10 kΩ. Key specifications of the VRH320 include a 320 VA continual loading with a 640 VA overload capability for a period of 15 min. As with all ARCOL products the VRH320 is RoHS compliant.

www.arcolresistors.com

Integrated High-Speed Gate Driver/MOSFET RF Modules

IXYS introduced its IXZ631 Series CMOS high-speed, high-current integrated gate driver and MOSFET modules by its Colorado division. The modules are specifically designed for Class D, E, HF and RF applications at up to 27 MHz, as well as other applications requiring high-speed, high-power switching. The IXZ631 modules feature the IXRFD630 high speed gate driver paired with an RF power MOSFET, packaged in low-inductance surface mount RF package incorporating layout techniques to minimize stray lead inductance. Designed with small internal delays, the modules are suitable for high power operation where combiners are used. Two devices are available, the IXZ631DF12N100 1,000 V/12 A device and the 500 V/18 A IXZ631DF18N50. Both modules feature voltage rise and fall times of less than 5 ns, and minimum pulse widths of 8 nanoseconds. In pulsed mode the 500 V module provides up to 95 A of peak current; the 1,000 V module 72 A.

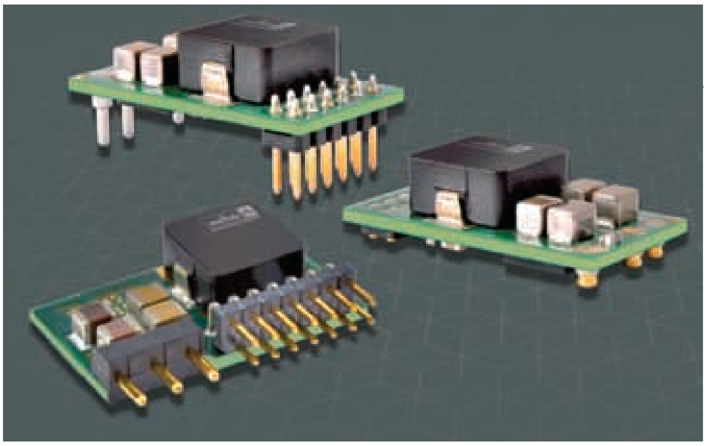
www.ixyscolorado.com

650V IGBTs for (H)EV Applications

Infineon ihas announced a family of robust 650V IGBTs that can deliver highest efficiency in fast switching automotive applications. The AEC-Q-qualified IGBTs can reduce power losses and improve reliability EV and HEV applications such as on-board charging, power factor correction (PFC), DC/DC and DC/AC conversion. The new IGBTs have a blocking voltage 50 V higher than previous automotive IGBTs and achieve their 'best-in-class' efficiency ratings due to TRENCHSTOP 5 thin wafer technology. Compared with existing 'state-of-the-art' technologies, this technology reduces saturation voltage by 200 mV, halves switching losses, and lowers gate charge by a factor of 2.5. Improved switching and conduction losses also support lower junction and case temperatures than alternative technologies, leading to enhanced device reliability and minimizing the need for cooling. The performance of the new devices allows also entering MOSFET dominated applications and offering designers a wider spectrum of suitable semiconductor base technologies. Featuring current ratings of 40 A or 50 A, TRENCHSTOP 5 AUTO IGBTs are available as single discrete IGBT device or co-packaged with a fast "Rapid" Silicon diode. In each case the two variants H5 HighSpeed and F5 HighSpeed FAST can be supplied depending on whether optimized switching speed or highest possible efficiency is the overriding design criteria.

For a typical PFC used in on-board chargers the replacement of current 'state-of-the-art' technologies by TRENCHSTOP 5 AUTO IGBTs can lead to an efficiency increase from 97.5 % to 97.9 %. In the case of a 3.3 kW charger this equates to a power loss reduction of 13 W. Assuming a charging time of five hours, this would be equivalent to reducing CO_2 emissions by 30 g in a single charging cycle.

www.infineon.com/discrete-automotive-igbt



Digital 20/25 A POL DC/DC converters

Murata Power Solutions' new OKDx-T/20-W12 and OKDx-T/25-W12 series PoL DC/DC converters offer high power density, PMBus compatible digital power solution for space constrained embedded applications such as powering CPUs, datacom/telecom systems, distributed bus architectures (DBA), programmable logic, and mixed voltage systems in the networking, computing/servers, telecom, and industrial market sectors. The devices deliver 20 A/66 W and 25 A/82.5 W output respectively, and measure 25.65 mm x 13.8 mm x 8.2 mm. Offered in three different packages - through-hole, single-in-line and surface-mount - the converters can easily be configured and monitored via the standard PMBus communication protocol. They accept input voltages from 4.5 V to 14 V and have an output voltage range of 0.6 V to 3.3 V with a typical efficiency of 97.1% at 5 V input, 3.3 V output and 50 % load. The products are delivered with a default firmware configuration suitable for a wide range of operation in terms of input voltage, output voltage, and load. Both series' includes advanced features like non-linear transient response, phase spreading, synchronization, digital current sharing, and optimized dead time control. Both series are compatible to the AMP standard (Architects of Modern Power, www.ampgroup.com).

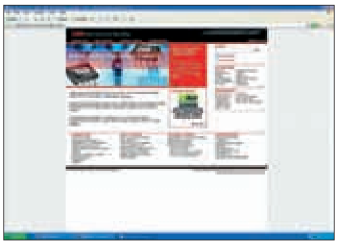
www.murata.com

1.2 kV All-Silicon Carbide Half-Bridge Module

Richardson RFPD now offers the 1.2 kV, 13 mΩ all-SiC half-bridge module from Cree. The CAS120M12BM2 includes C2M MOSFETs and Z-Rec diodes and features ultra-low loss, high-frequency operation, zero reverse recovery current from the diodes, zero turn-off tail current from the MOSFETs, fail-safe operation, ease of paralleling, and a copper baseplate and aluminum nitride insulator. It is available in an industry-standard 62 mm x 106 mm x 30 mm housing. The new module enables compact and lightweight systems, offers high efficiency operation, mitigates over-voltage protection, and facilitates reduced thermal requirements and system cost.The CAS120M12BM2 is suited for a range of applications, including induction heating, solar and wind inverters, DC/DC converters, line regeneration drives, and battery chargers. According to Cree, additional key features include total switching energy (ESW) at 120 A/150°C of 2.1 mJ and on state resistance at 120 A is 13mΩ.

www.richardsonrfpd.com

AC/DC Converters



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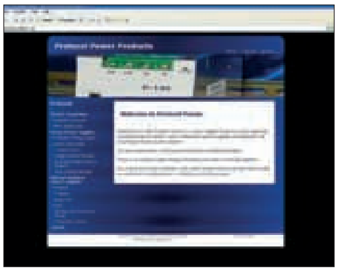

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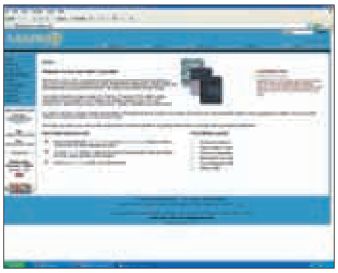
Diodes



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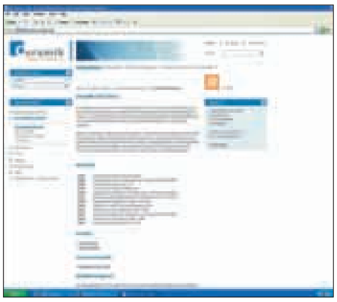

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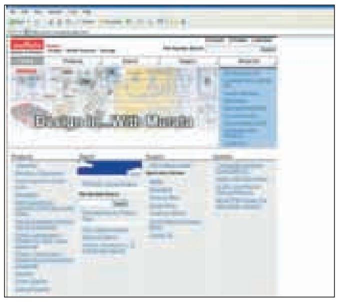

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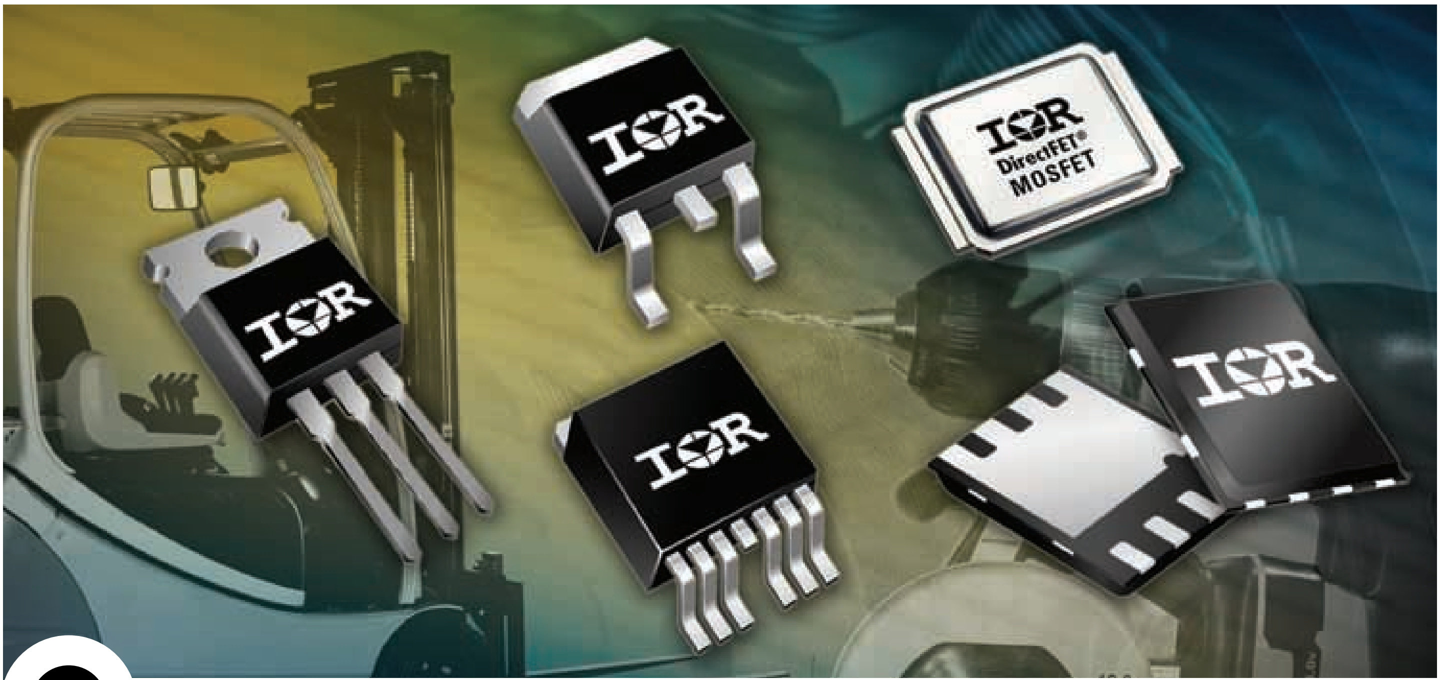

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Specifications

Package	B_{VDSS} (V)	ID @25°C (A)	$R_{DS(on)}$ max @Vgs = 10V (mΩ)	Qg@ Vgs = 10V (nC)	Part Number
PQFN 5x6	25	100	0.95	56	IRFH8201TRPbF
	25	100	1.05	52	IRFH8202TRPbF
	30	100	1.1	58	IRFH8303TRPbF
	30	100	1.3	50	IRFH8307TRPbF
	40	100	1.4	134	IRFH7004TRPbF
	40	85	2.4	92	IRFH7440TRPbF
	40	85	3.3	65	IRFH7446TRPbF
DirectFET Med.Can	30	192	1.3	51	IRF8301MTRPbF
	40	90	1.4	141	IRF7946TRPbF
	60	114	3.6	120	IRF7580MTRPBF
D^2-Pak	40	195	1.8	150	IRFS7437TRLPbF
	40	120	2.8	90	IRFS7440TRLPbF
	60	120	5.34	86	IRFS7540TRLPbF
D^2-Pak 7pin	40	195	1.5	150	IRFS7437TRL7PP
	60	240	1.4	236	IRFS7530-7PP
D-Pak	40	90	2.5	89	IRFR7440TRPbF
	60	90	4	86	IRFR7540TRPbF
TO-220AB	40	195	1.3	300	IRFB7430PbF
	40	195	1.6	216	IRFB7434PbF
	40	195	2	150	IRFB7437PbF
	40	120	2.5	90	IRFB7440PbF
	40	118	3.3	62	IRFB7446PbF
	60	195	2.0	274	IRFB7530PbF
TO-247	40	195	1.3	300	IRFP7430PbF

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