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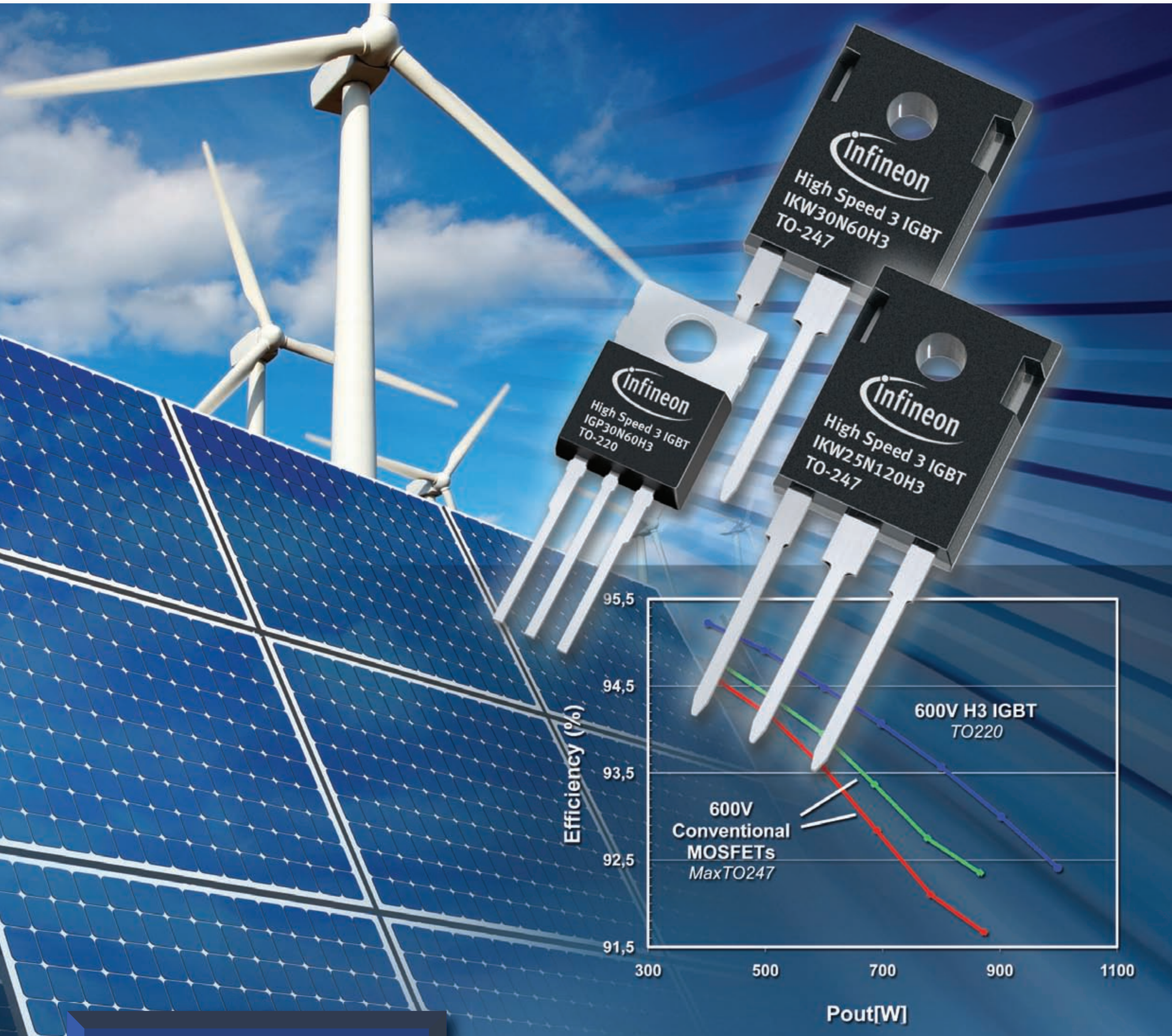
POWER SEMICONDUCTORS

600/1200V IGBTs Set Benchmark Performance in High Switching Speed Applications



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COVER STORY

600/1200V IGBTs Set Benchmark Performance in High Switching Speed Applications

High energy efficiency standards set by governmental agencies and lower system costs are the main driving forces toward development of more efficient power switches. The selection of the right switch (that provides the optimum cost / performance required by the application) depends on power level and load conditions. The third generation of high speed IGBTs from Infineon Technologies (H3) in the voltage class 600V and 1200V are optimised for high speed switching in welding, UPS, SMPS and Solar applications. The new devices show excellent dynamic behaviour, smooth switching and significant loss reduction, providing the system designers with a cost-effective solution to meet today's stringent requirements of energy efficiency regulations and simplify the system design by reduction of cooling and filtering efforts. More on page 30

Cover supplied by Infineon Technologies Germany

Renewable Energies Push Power Electronics

The total market for high power devices and modules (including IGBTs, thyristors and diodes) was $390 million in 2009 and is expected to ramp up to more than $570 million by 2015, according to market researcher Yole. Electricity T&D will benefit from the strongest Compounded Annual Growth Rate of 11% between 2010 and 2015. Wind turbine converters have not suffered so much from the 2009 crisis, and their growth is expected to be the second strongest, with 2010 - 2015 CAGR of more than 9%. At the end of 2009, worldwide nameplate capacity of wind-powered generators was roughly 160 gigawatts (GW). Energy production was 340 TWh, which is about 2% of worldwide electricity usage;and is growing rapidly, having doubled in the past three years. Several countries have achieved relatively high levels of wind power penetration (with large governmental subsidies), such as 19% of stationary electricity production in Denmark, 13% in Spain and Portugal, and 7% in Germany. Also the photovoltaic (PV) market - in terms of both new installations and shipments of PV modules and inverters grew substantially in 2009. Almost 7.5 GW of new PV capacity was added worldwide in 2009. And an incredible 1.5GW of new capacity was installed in Germany in December. Prices of centralised PV inverters have fallen around 10% over the last year, a relatively small amount compared to the severe price declines experienced by PV module suppliers. SMA Solar Technology Kassel/Germany, the largest supplier of PV inverters gained further market share to held more than 40% on the global market. Here the battle has begun and makers of microinverters are waging a war against makers of distributed DC/DC converters for control of the power conversion market for PV systems. The emergence of disruptive power architectures including microinverters and DC/DC converters will be one of the most important trends in the PV market in the near-term, market researcher Darnell believes. Here new opportunities for power semiconductors will arise, as PEE's Special Session at PCIM on May 4, 2.00 - 4.00 pm in Room Paris will illustrate.

The first paper entitled Comparison of High Power Semiconductor Technologies for Renewable Energy Sources will look at the features for the available high power semiconductors of choice and also takes a look at future devices and their expected impact on efficiency. High power semiconductors are key components for control of the generation and connection to the net work of renewable energy sources as wind turbines and photovoltaic. For highest efficiency of the energy source it is therefore essential to select the right device for the given conditions. The second paper covers High Power Renewable Energy Applications, Facts & New Design Proposals. Renewable energy applications are a great challenge today. Efficiency and reliability are the prevailing requirements. The best solution for MW converter design is paralleling of inverters / power blocks. An alternative solution is a medium voltage source and transmission connected to MV grid-side inverter based on low-voltage silicon - power blocks - connected in series. In addition, interleaved PWM reduces the size of the sinusoidal filter and the switching frequency. GaN-Based Power Device Technology and its Impact on Future Efficient Solar Grid Connected Micro and String Inverters will be introduced by the third paper within this Special Session. GaN-based power device technology is progressing rapidly and expanding its applicability in a wide range of power applications including Solar Inverters. Along with intrinsic scalability in low and high voltage power conversion topologies and coupled with dramatic FOM improvement vs. Si based devices, GaN power products are set to have a direct impact on future efficient grid connected PV micro and string inverters. Finally, the paper New Low Loss Transfer Mold IPM for Photovoltaic Generation will introduce a low loss large-scale Dual In-line Package Intelligent Power Module with rating of 50A/600V. The low loss large-scale DIPIPM was achieved by using the V4 package with novel heat dissipating insulation sheet. High efficiency is required when DC electricity generated by solar cells is converted to AC electricity. To realize high efficiency, the switching loss is reduced by using fast 5th generation full gate CSTBT and high output current driver IC which leads to a higher switching speed.

Also the Best Paper Award (participation at PCIM China 2011 including expenses) has been sponsored by PEE for the third time. This year's awardee is Christian Nöding, Center of Competence for Distributed Power Technology at University of Kassel/Germany for the paper 'Evaluation of a Three-Phase Two-HF-Switch PV Inverter with Thyristor-Interface and Active Power Factor Control'. He will present an inverter topology for PV systems connected to the medium voltage grid using inexpensive thyristors and high performance IGBTs or SiC switches. All these papers are centered around the fast growing renewable energy market.

I hope to see you at PCIM in general, at PEE's Special Session in particular, or on our booth 12-544.

Achim Scharf
PEE Editor

Good Market Outlook for High-Power Devices

The power electronics market is booming at all voltage ranges, outlines a new market report from Yole Développement. More importantly, power devices for application markets >1.7kV like wind power converters, electricity transportation and distribution (T&D), rail traction and ship & vessel propulsion correspond to high added_value businesses.

"It is sure that their total 2010 expected market size of $405 million including power devices and power modules is small compared to lower voltage markets, but they remain very dynamic and offer the potential of high margins", explains analyst Brice Le Gouic.

These market developments are primarily driven by energy saving considerations and green technology developments. They are actively supported - e.g. electricity T&D - by several governments and leading companies are working to improve their technology.

As such, Silicon IGBTs, thyristors (GTOs and IGCTs), diodes and future SiC devices will get access to more and more technological improvements like transition to 8" wafer platforms and use of silicon carbide (SiC) materials among others. However, the long time period of order contracts, the low volume production they imply and the issues to increase voltage to use SiC_based components induce quite light competition between the well established players of those markets.

The total market for high power devices and modules (including IGBTs, thyristors and diodes) was $390 million in 2009 and is expected to ramp up to more than $570 million by 2015. Rail traction will contribute more than 65% of this value because of the high level of production it represents and the number of inverter units per locomotive. Electricity T&D will benefit from the strongest CAGR of 11% between 2010 and 2015. Indeed, Yole expects plenty of work to be realised for HDVC transportation, and ABB to provide an important contribution to HVDC light architecture by making IGBTs. Wind turbine converters have not suffered so much from the 2009 crisis, and their growth is expected to be the second strongest, with 2010 - 2015 CAGR of more than 9%. Finally, ship and vessel markets have been impacted unevenly in 2009. Military vessels have kept on

growing - relatively to the long time period of ship manufacturing - whereas passenger yachts for private use have drastically decreased. As a consequence, Yole estimate the global IGBT module market for ships and vessels to resume in 2013 and reach $26 million by 2015.

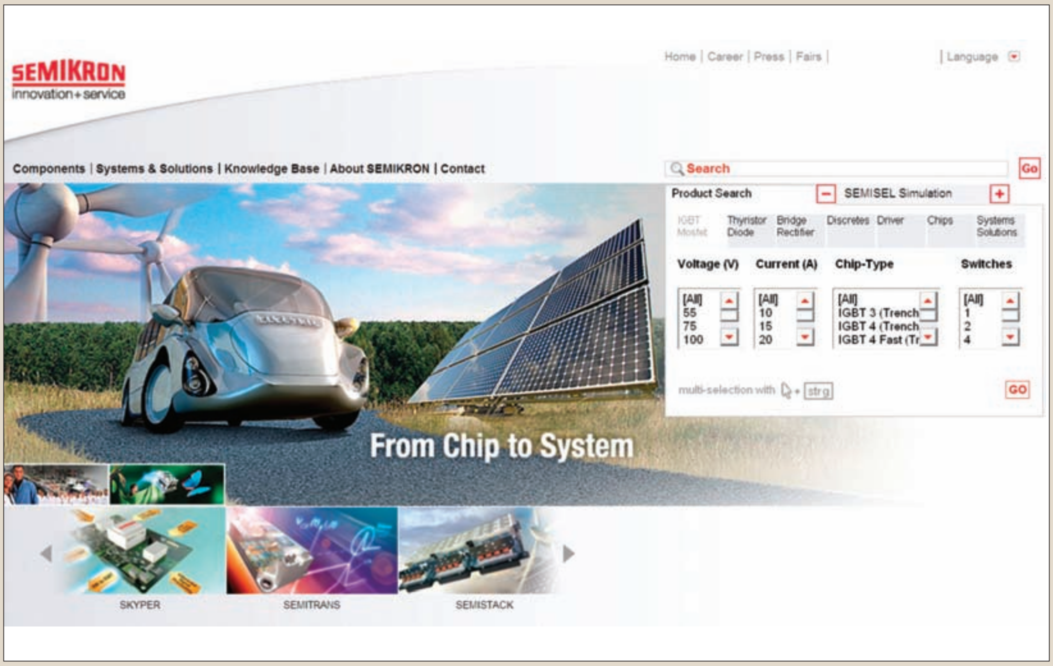
www.yole.fr

Fast Access to Power Electronics

SEMIKRON has re-launched its website. Visitors can enjoy short paths to technical information, products and contact details, not to mention state-of-the-art search and filter functions that facilitate user selections.

The general full-text search function searches for key words, product names, product families or even article numbers. In the product and parameter search mode, technical parameters such as current, voltage, circuit, case and semiconductor type can be selected, while navigation by product group gives direct access to product pages containing technical explanations and detailed product data with additional parameters. With the fourth function - the selection and simulation programme Semisel - users are given product suggestions or can perform design simulations. The hit lists for product searches contain both technical parameters and images showing circuit topologies and module cases; the hit lists also contain direct links to the simulation tool or the power electronics eCommerce portal of Sindopower, a holding company of the Semikron Group. In addition, with the help of the intelligent Download Manager selected data sheets can be downloaded for comparison. Hit lists also feature a product selector that contains search fields with multi-select boxes for individual parameters. The new site also includes an extensive knowledge data base containing technical explanations, user support, and specialist articles that can be found using dedicated search filters. For this purpose, a data-base-linked program was developed. SKiPIE, the Semikron intelligent Product Information Engine, functions in collaboration with the Product Information Management System and the Content Management System from market leader Open Text, guaranteeing fast and reliable data access.

www.semikron.com



Fast access to information is one of the key functions at the new www.semikron.com

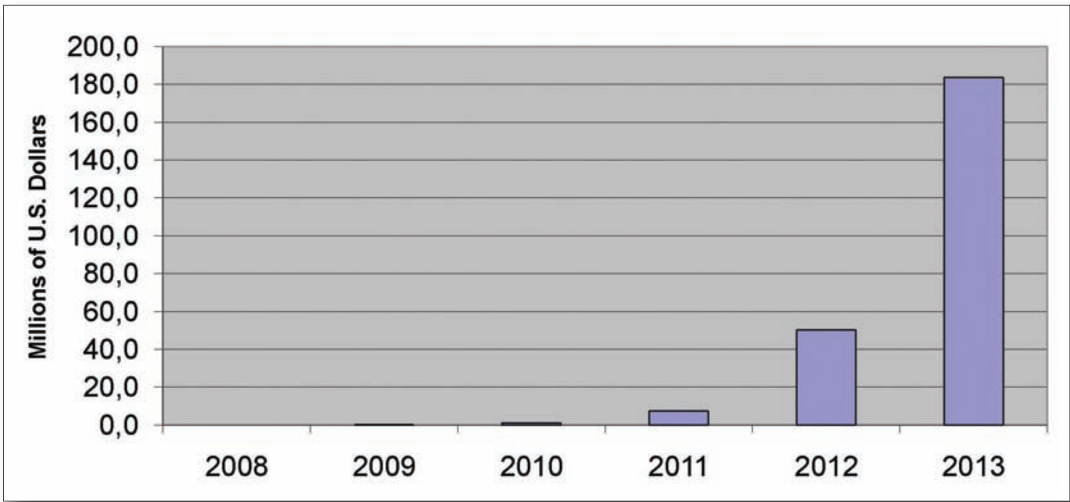
GaN Power Management Chip Market Set for Boom

Thanks to rapid growth in the high-end server, notebook, mobile handset and wired communication segments, the Gallium Nitride (GaN) power management semiconductor market is expected to reach $183.6 million in revenue in 2013, up from virtually zero in 2010, according to iSuppli Corp.

GaN is an emerging process technology for power management chips that recently moved beyond the university-based testing phase and into the commercialisation stage. The technology represents an attractive market opportunity for suppliers by providing their customers with capabilities that may be out of the reach of present semiconductor process materials. "We believe that during the past two years, several events have occurred that have made GaN an up-and-coming star in the power management semiconductor world", said analyst Marijana Vukicevic. "First, the use of Silicon has reached its practical limits in power management semiconductors. Furthermore, there have been major breakthroughs in growing GaN layers on silicon. Power designers also want to develop more efficient systems and to update their high-voltage products to waste less electricity". Component suppliers have begun offering GaN parts. International Rectifier released its first GaN technology-based Point-of-Load (POL) solutions in February, while Efficient Power Conversions Corp. (EPCC) is placing all its bets on GaN technology, releasing 10 power devices in March (see our APEC report and feature 'Can Gallium Nitride Replace Silicon?' in PEE 2/10 as well as 'The Next stage in the Commercialisation of GaN-Based Power Devices' in this issue).

The adoption of GaN devices will be driven by the improved efficiency and small form factors enabled by the material. Such benefits are in particularly high demand for portable electronic products, including mobile PCs and smart phones. They also provide advantages for power-hungry electronic equipment, such as enterprise servers and wired communications infrastructure gear. However, adoption of GaN technology for these applications in 2010 and 2011 will be slow due to the high cost of parts using the material. As the technology advances and the cost of manufacturing GaN technology drops in 2012 and 2013, the technology will begin to steal market share away from conventional MOSFETs, driver ICs and voltage regulator ICs.

www.isuppli.com



Global GaN power management semiconductor revenue forecast 2008 - 2013

High-Efficiency Solar Cell Made from Earth-Abundant Materials

IBM has built a solar cell composed entirely of earth-abundant elements, that set a new world record for efficiency and holds potential for enabling solar cell technology to produce more energy at a lower cost. Comprising copper (Cu), tin (Sn), zinc (Zn), sulfur (S), and selenium (Se), the cell's power conversion demonstrates an efficiency of 9.6%, 40% higher than the value previously attained for this set of materials.

"In a given hour, more energy from sunlight strikes the earth than the entire planet consumes in a year, but solar cells currently contribute less than 0.1% of electricity supply, primarily as a result of cost", said David Mitzi, who leads the solar cell team at IBM Research. "The quest to develop a solar technology that can compare on a cost per watt basis with the conventional electricity generation, and also offer the ability to deploy at the terawatt level, has become a major challenge that our research is moving us closer to overcoming". The solar cell development also sets itself apart from its predecessors as it was created using a combination of solution and nanoparticle-based approaches, rather than popular but expensive vacuum-based technique. The production change is expected to enable much lower fabrication cost, as it is consistent with high-throughput deposition techniques printing, dip and spray coating and slit casting.

While previous commercial efforts to employ thin film solar cell modules have produced 9% to 11% efficiency levels, they have primarily focused on only two costly compounds - copper indium gallium selenide or cadmium telluride - and as such, have been either too costly to produce or contain elements that could ultimately limit production capacity. Attempts to create affordable, earth abundant solar cells from related compounds have not exceeded 6.7%, compared to IBM's new 9.6% efficiency rating. IBM does not plan to manufacture solar technologies, but instead will license intellectual property resulting from its solar cell related research.

www.ibm.com

PV Installations and Module Shipments Up In 2009

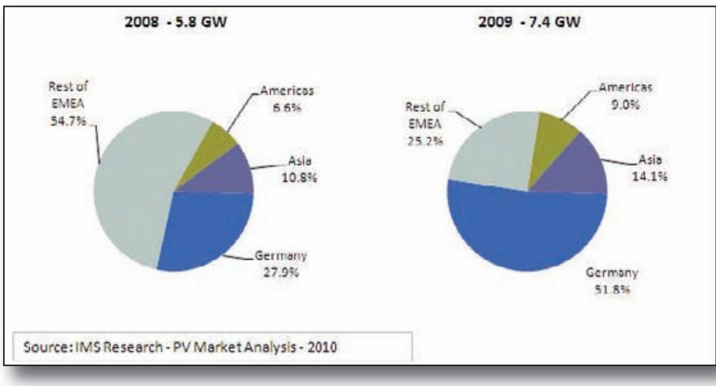
The PV market - in terms of both new installations and shipments of PV modules and inverters grew substantially in 2009 according to recently released analysis from IMS Research.

Almost 7.5 GW of new PV capacity was added worldwide in 2009. On 9th April, the German Federal Network Agency finally released its December figures for new PV installations confirming that the German market grew massively in 2009 to reach 3.8GW, and in fact the global PV market saw double-digit growth. "An incredible 1.5GW of new capacity was installed in Germany in December. This was earlier predicted by IMS Research which measured inverter shipments at 3.5GW in Q4'09, and also predicted that the global PV market grew by 25% to exceed 7GW", PV Research Director, Ash Sharma commented. Despite the upcoming cut to Germany's feed-in tariffs, IMS Research still forecasts the global PV market will grow in 2010, up to 10GW in terms of new installations with strong demand coming from many different countries. Feed-in tariffs have become preferred policy instruments because they are performance-based (pay for actual MW), do not require taxpayer subsidies (cost assigned to energy users), and do not conflict with other renewable energy policies. The ability of feed-in tariffs to attract low-cost capital from a broad range of different investor types has become even more important in the wake of the financial crisis.

Prices of PV inverters have fallen around 10% over the last year, a relatively small amount compared to the severe price declines experienced by PV module suppliers. SMA Solar Technology Kassel/Germany, the largest supplier of PV inverters gained further market share to held more than 40% on the global market.

Many PV inverter manufacturers are investigating the option of using Silicon Carbide (SiC) diodes within low power inverter designs. Incorporating a SiC Schottky diode within a PV inverter, can increase overall system efficiency by nearly 0.5%. Furthermore, the announcement by the Fraunhofer Institute for Solar Energy Systems last year that they had set a new world record of over 99% efficiency for a PV inverter using SiC JFETs has raised many eyebrows within the power electronics world. SiC power semiconductors have been on the verge of making a substantial impact on the power semiconductor market for a number of years. Compared to Silicon, these devices offer the advantages of low switching and conduction losses, and higher temperature and frequency capability. Higher cost and device limitations at higher currents, however, remain the largest barriers to mass adoption. Many supporters of SiC within the PV industry argue that cost is already comparable. Manufacturers still have to pay a premium for the SiC diodes themselves, but inverter systems using these devices can be run at higher frequencies, leading to cost savings in other areas of the inverter, such as the inductors. There are also additional advantages to running the system at higher frequencies including reduction of system noise.

www.pvmarketresearch.com



PV module and inverter market growth 2008 - 2009

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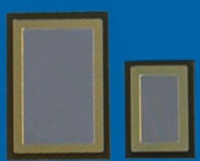

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PART NUMBER	I_f (A)	V_f (V) TYPICAL	I_R (µA) TYPICAL	Q_c (nC) TYPICAL	T_j (°C) MAX
CPW3-1700S010B	10	1.8 @ 25°C 3.2 @ 175°C	10 @ 25°C 20 @ 175°C	80	175
CPW3-1700S025B	25	1.8 @ 25°C 3.2 @ 175°C	25 @ 25°C 50 @ 175°C	210	175

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Micro Inverters Battle DC-DC Converters for Supremacy in PV Systems

The battle has begun and makers of microinverters are waging a war against makers of distributed DC/DC converters for control of the power conversion market for photovoltaic (PV) systems. The emergence of disruptive power architectures including microinverters and DC/DC converters will be one of the most important trends in the PV market in the near-term, market researcher Darnell believes.

The shortcomings inherent in the central inverter architecture are expected to provide a host of opportunities for several new technologies. There are a growing number of companies developing products and technology specifically designed to generate more power from the PV panels already on the market. A distributed converter architecture using either of two specific disruptive technologies, microinverters or DC/DC solutions, is expected to present a significant challenge to the conventional central inverter architecture over the coming years.

A significant advantage both of these disruptive technologies have over traditional central inverter technology is the ability to perform maximum power point tracking (MPPT) at the panel level. Due to variations in shading, dirt, and ageing of solar panels, individual panel voltages will differ, causing the output voltages of strings of panels to vary. In addition to improvements in efficiency, the ability to reconfigure PV arrays without additional complex string calculations and improved operational flexibility, another opportunity for both microinverter and DC/DC solutions is the further development and availability of communications systems for both commercial and residential PV systems.

The demand for technology to address the problem of PV shading is another area of opportunity. Due to the nature of solar array configuration, small amounts of shade (for example, shading of less than 10% of the surface area of a PV system) can lead to disproportionate power losses. Common causes of shade include structural objects such as trees, chimneys and dormers, and intermittent debris including falling leaves, bird droppings, dust and clouds passing overhead. These are unavoidable challenges that cannot be engineered out of an installation. In an effort to promote the use of disruptive technologies such as microinverters and DC/DC solutions, and avoid an outright battle in front of potential customers, a number of solution manufacturers have adopted a strategy of partnerships and alliances within the semiconductor industry (see also our PCIM preview in this issue).

"Microinverter architectures increase energy harvesting from solar PV systems, reduce installation and maintenance costs and eliminate the risk related to high voltage DC, enabling mass market deployment of solar PV", said Paul Engle, CEO of UK-based Enecsys

Enecsys Limited, a UK-based manufacturer of PV microinverters, has attracted further investment of $4.2 million from Good Energies, a global investor in renewable energy and energy efficiency industries. This new investment adds to the $10 million received from Wellington Partners and BankInvest in June 2009 for a total investment of $14.3 million in Enecsys. "Good Energies invests in companies that significantly accelerate the clean-energy transition and that possess technology differentiation. We prepare for our first product launch in the early part of this year and we believe this partnership brings expertise into the industry and positions Enecsys to become a leader in solar inverters", said CEO Paul Engle.

www.darnell.com
www.enecsys.com

ABB to Acquire the Power Semiconductor Business of Polovodiče

ABB has announced to acquire the semiconductor business of Polovodiče a.s. in the Czech Republic. The additional production capacity for high-power semiconductors will help ABB to cope with the expected rising demand fueled by growth in renewable energy and efforts to improve energy efficiency.

Polovodiče a.s. has been making power semiconductors since the mid-1950s and had revenues in the low double-digit millions of US-Dollar, mostly from its power semiconductor activities. Together with the semiconductor assets about 200 employees will join ABB. The parties agreed not to disclose the value of the transaction, which is subject to customary regulatory approvals.

PEE took the chance to interview Bernhard Eschermann, manager for the power semiconductor business within ABB, about this acquisition and ABB's position in the power semiconductor market in general.

PEE: According to IMS the world market for power modules was around $3 billion (+16%) in 2008, for 2009 and 2010 similar growth rates can be expected. Particularly the renewable energies contributed (>80%) to the growth of (IGBT) power modules in 2008. What is ABB's position in this business so far? In 2008 ABB was not listed in the IMS market study!

ABB will continue to focus on the high-voltage and high-power market. Our

Bernhard Eschermann, manager for the power semiconductor business within ABB, strengthens with the acquisition of Czech-based Polovodiče the company's IGCT position

acquisition in the Czech Republic is rather aimed at the industrial market for starters, LCIs and rectifiers. The expansion of our Lenzburg facility, however, will help us to improve our position for the high-power segment of the renewable energies market.

PEE: Polovodiče offers only 2 types of IGBT power modules rated 1200V 120/70A. In this case is this acquisition an extension of ABB's offering for the lower power range?

The main focus of the acquisition is to strengthen ABB's offering of bipolar devices. We will continue to operate the existing power module assembly of applications compared to IGBTs?

In medium voltage drives the IGCT has a strong market position, particularly for higher power ratings. In wind power mainly IGBTs are used, but with the growth of wind turbine power ratings, stringent grid codes and the ensuing trend towards full converters, also IGCTs will find more use. ABB continuously invests in product improvements for both technologies to give the best possible choice to customers per power rating and application.

PEE: Besides offering power modules, ABB also supplies power semi chips to other power module vendors. Is this an interesting and growing business opportunity?

Our module portfolio is centered on high-power, where we want to be in the lead. We do not intend to dilute this focus by supplying a broad range of 1200V and 1700V module types outside our portfolio. Thus, our supply of IGBT chips provides opportunities both for ABB and its chip customers and remains an integral part of our business model.

PEE: Due to the accelerated power semi demand most of the production lines are fully loaded. So far the Lenzburg facility runs on 6-inch wafers. Is the $150 million investment announced intended to switch over to 8-inch wafers or just to add 6-inch production capacity? What is the average lead time in general of the Lenzburg facility today?

Our current investment is mainly for capacity expansion. For high-voltage IGBTs up to 6.5kV, an investment in 8-inch production will make sense, when the quality of 8-inch Silicon wafers is further improved. The average delivery time is very dependent on the particular product. With the new production capacity fully scaled up, we will be able to meet the expectations of our customers again for our full range of products.

PEE: ABB is one of the companies to offer 6.5kV IGBTs and modules. Within this year high-voltage SiC switches (10kV MOSFETs) will be introduced which might be able to replace such IGBTs. Some years ago ABB has sold all its SiC assets to Cree. Do you regret this decision from today's perspective?

There is no regret. We are closely monitoring the development for wide band gap materials as SiC and GaN and will take the necessary steps when required. With the improvements in Silicon-based products that ten years ago were not thought as possible, we see that this technology still has a lot of potential regarding electrical performance, reliability and cost.

PEE: Finally, what are your expectations on the upcoming PCIM conference/exhibition?

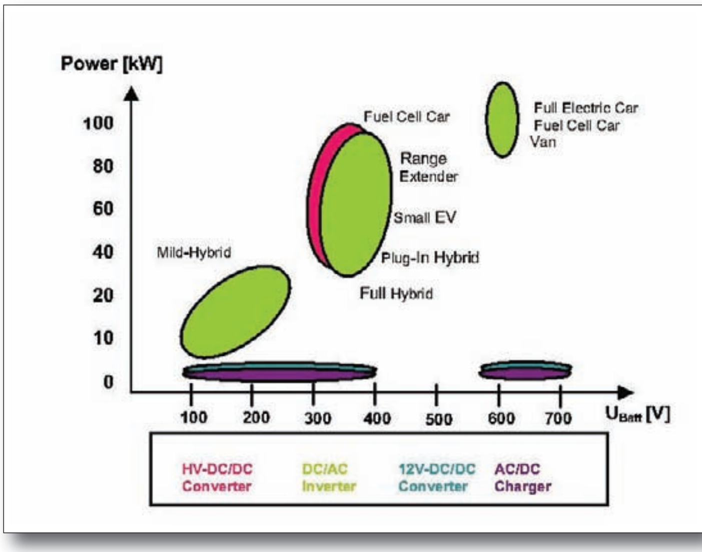
The PCIM conference is a unique opportunity to sense the upcoming trends in power semiconductors and to discuss business opportunities with existing and future customers in a relaxed atmosphere. We look forward to it. **AS**

www.abb.com/semiconductors

Power Electronics in Electric Cars

At CIPS 2010 (March 16 - 18) in Nuremberg Daimler outlined the requirements on power electronics in the upcoming electric vehicles. Firstly, these cars should come to the same cost structure than conventional automobiles in order to ramp up by the year 2015, secondly power electronics should be standardised, and thirdly power modules should overcome aluminium bonding wires.

Electric vehicles will definitely contribute to realisation of the worldwide ambitious CO_2 goals. In order to improve the competitive situation, to speed up time to market and to reduce the overall cost for the users, a standardised set of power components, modules and sub-systems for electric traction should be developed by OEMs and automotive suppliers. This will improve reliability and maturity of the systems and enable a desigin-to-cost strategy", stated Wolfgang Wondrak, head of advanced engineering power electronics at Daimler AG in Boeblingen/Germany. "The upcoming advent of the electrical vehicle calls for low-cost power electronics solutions that are standardised throughout the various automotive market segments. Electric drive range will be one of the most important factors for the end-user. This raises the need for electrical components with highest efficiency. Key challenges for these components are efficiency, operation conditions, reliability, volume and weight. Currently, the costs of electric vehicles are dominated by battery prices, but also power electronics have to contribute to economic improvement".



General components and power classes to be supplied by power electronics in (H)EVs

A standardised set of power components, modules and sub-systems for electric traction should be developed by OEMs and automotive suppliers. This will improve reliability and maturity of the systems and enable a desigin-to-cost strategy", stated Daimler's Wolfgang Wondrak

General requirements

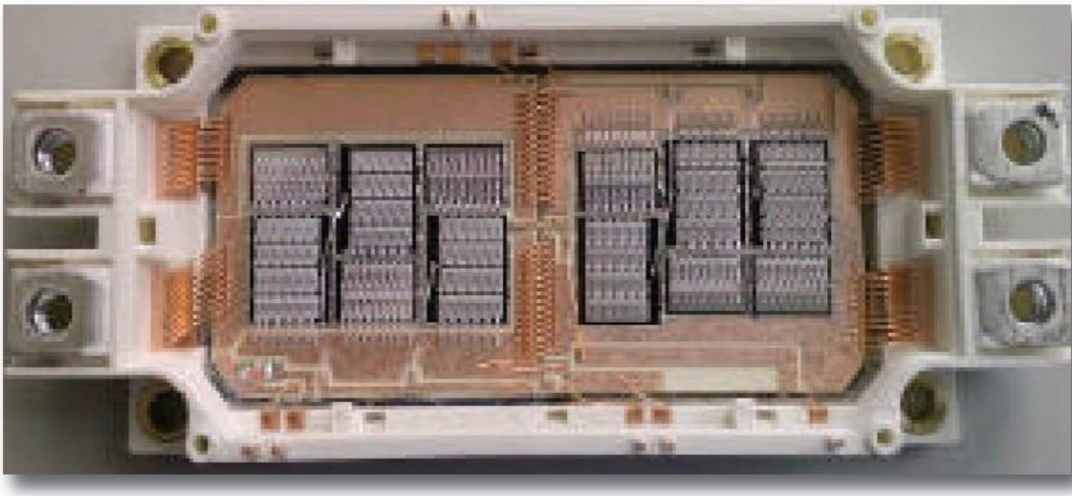
General requirements on power electronic components in cars arise from the automotive-specific environmental conditions, i.e. high temperatures near the motor or the transmission, low temperature operation down to -40°C, challenging vibration levels, restricted space, EMI requirements. Also cooling must be carefully designed. Since the combustion engine cooling system may reach temperatures in excess of 120°C, separate low-temperature coolers are implemented in hybrid vehicles, specified to stay below 85°C or below 65°C in the case of battery cars.

According to Wondrak scaling of power electronic components can be realised on different system levels: Using suited devices in automotive quality to fit the voltage requirements and allowing minimisation of power losses (voltage scaling); adopting power modules to fit the current requirements by paralleling multiple chips through scaling DCB ceramics to a pre-defined cooling geometry.

Also standardisation will have a big impact on die further development of electric vehicles. Common agreement on high-voltage connectors, charging cables, and high-voltage safety requirements will pave the way to OEM independent parts. Therefore, these measures will increase the volume for dedicated automotive power electronic components and thus enabling cost-effective production. Whereas a set of common standards will help market penetration of electric cars, technological challenges for the future will be increased efficiency, air cooling capability, and further miniaturisation.

Copper bonding as first attempt

"Higher junction temperature in power modules is a demand from hybrid cars, and a potential for the



Copper wire bonds connecting power terminals power terminals and DCB substrates in EconoDUAL power modules

next step increase in power density for industrial drives. Our next generation of IGBT and diodes will therefore have a junction temperature of 175°C. Today's assembly and interconnect technologies have to change for module setup that consistently meets reliability requirements at higher temperature and swing in temperature. Cu wire bonding as interconnect for the top side of power semiconductors can overcome the limits of Al wire bonding. Wire bonds no longer limit lifetime in power cycling. Current capability increases by 70% at constant boundary conditions. Cu wire bonding can also apply to terminal interconnects bringing up its current capabilities", stated Dirk Siepe from Infineon Technologies in the paper 'The Future of Wire Bonding'.

It is the intermittent operation of power electronics, which links the maximum operation temperature to power cycling capability. Power cycling degrade the joint of wire bonds resulting in lift-off from the chip surface. The analysis of end of life failures reveals cracks running through the wire but not along the interface to the chips. Improvement of Al wire bonds dealt with perfection of the bonding interface, i.e. ensuring high bonding strength throughout the whole bonding area. This improved the lifetime but still the wire material limits the end of life and crack formation happens. Al ribbon bonding has the same limits of Al material and does not differ in power cycling capability.

Clips or metal plates soldered to the top side of power semiconductors have been thought to solve the problem. After several steps of improving Al wire bonding, solder fatigue takes place in parallel to wire bond degradation. That is the reason why Al wire bonded and silver sintered (NTV) devices exceeded the lifetime of soldered devices in power cycling. If the joint from chip to the substrate is not degrading, junction temperature is not rising during the test. Consequently, the wire bond fatigue is not accelerated. As the extension of lifetime is only marginal, Al wire bonds stay as barrier for the intended increase of junction temperature.

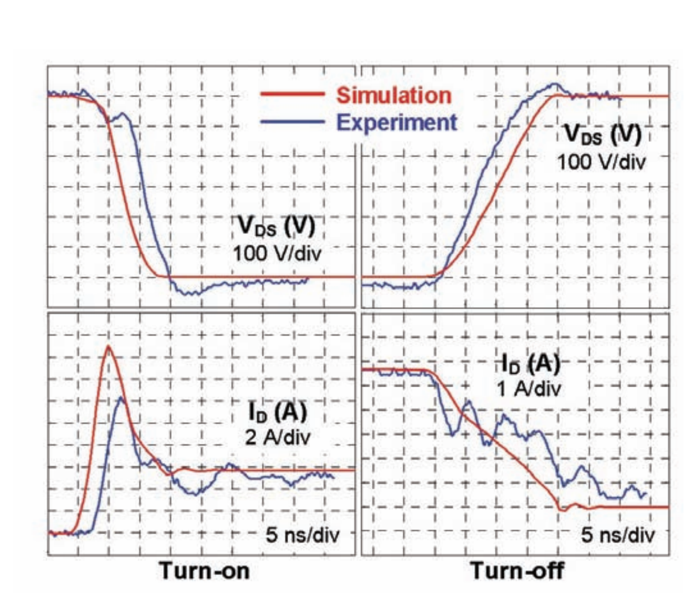
Looking for bonding materials to eliminate the weakness of pure Al not many choices exist. Efforts to adjust the CTE of wires by using metal matrix composites did not pay off. Besides bonding process issues power cycling would not improve because of Al still making the bond. Al alloys show potential for improvement in reliability but have the disadvantage of less thermal and electrical conductivity. Electrical and thermal conductivities have to improve as well, as higher current densities are the consequence of higher junction temperatures. All these considerations point to copper as wire or ribbon bonding material.

A short comparison of copper and aluminium shows the massive advantages of the copper wire including the essential need of copper if the power density is increasing. Copper has higher yield strength and less thermal expansion. The higher mechanical strength at less mismatch in thermal expansion gives reason for a breakthrough in reliability, and a factor of 2 in electrical and thermal conductivity supports copper in higher power applications. "Copper wire bonding is an attractive technology for front side interconnects of power semiconductors. It can combine mass production and superiour reliability. Together with new die-attach methods it prepares the ground for future generations of power semiconductors including those based an wide band gap materials", Siepe concluded. More on that technology will be presented at PCIM 2010.

Silicon Carbide and packaging

The fast development of Silicon Carbide (SiC) technology in recent years is bringing solutions to the many barriers that Silicon (Si) devices have encountered. SiC offers a critical electric field an order of magnitude higher than Si, which makes it possible to replace the slow Si bipolar devices (IGBTs) with much faster SiC unipolar devices (JFET or MOSFET) in medium to high voltage applications (>600 V), achieving similar or even reduced conduction loss. Moreover, the higher thermal conductivity of SiC together with the wide bandgap energy also allows high temperature operation of SiC devices above 300°C, further increasing the possible power density and enabling applications in harsh environments. "All these advantages make SiC power devices a promising choice for future power electronics converters to meet the requirements of high voltage, high frequency, high temperature and high power density", stated Dushan Boroyevich,

"10kV SiC MOSFETs are really breakthrough devices", VT's Dushan Boroyevich said



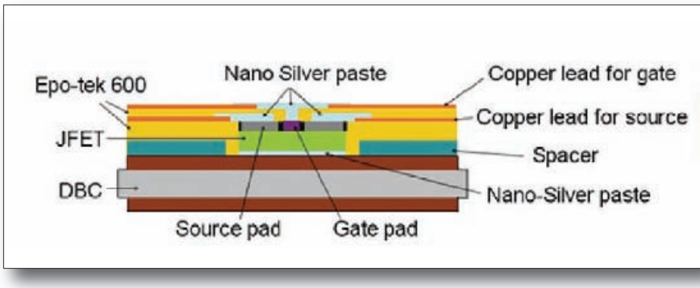
SiC JFET switching waveforms under 600V, 6A clamped inductive load with zero gate resistance

Professor at Virginia Tech's Center for Power Electronics Systems (VT CPES) in his paper on 'High-Density System Integration for Medium Power Applications'.

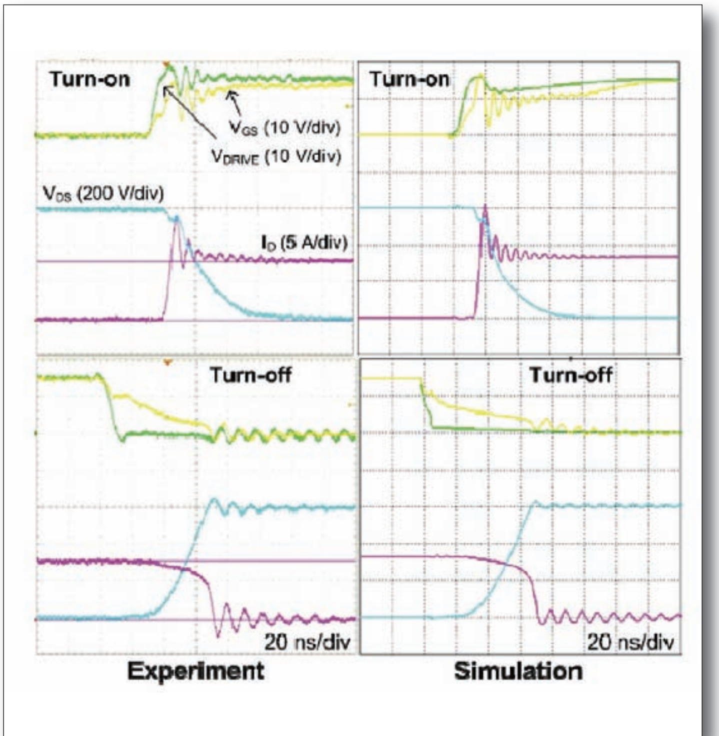
The superiourities of SiC have propelled the commercialisation of SiC Schottky diode since 2001, which features ultra-fast turn-on and almost zero reverse recovery. The main research focus on the active switches, on the other hand, is now directed at the unipolar devices of JFET and MOSFET with a clear target of 1.2kV blocking voltage. So far, SiCED has developed 1.2kV, normally-on SiC JFETs with an on-state resistance as low as 100nΩ, while Cree has claimed that 1.2kV, 20A normally-off SiC MOSFETs are already nearing commercial viability (see our feature 'Application Considerations for Silicon Carbide MOSFETs'). Providing much lower on-state resistance than high-voltage Si MOSFET and much faster switching speed than Si IGBT, these devices are promising to resolve the trade-off between high frequency and high efficiency for 600V - 800V energy conversion systems. In spite of the substantial work, characterisations of SiC active switches is still an ongoing effort as new prototypes are emerging constantly. Additionally Cree has announced 10kV SiC MOSFETs which can replace 6.5kV IGBTs in certain applications. “Such 10kV SiC MOSFETs are really breakthrough devices”, Boroyevich said.

Extensive measurements were recently conducted at Virginia Tech on 1.2kV, 5A SiC JFET prototypes provided by SiCED. Static characteristics, including the output and transfer characteristics, on-state resistances, gate and body diodes, as well as junction capacitances, were obtained using a curve tracer and impedance analyser. The previously overlooked fact that the gate-source and gate-drain capacitances cannot be measured separately due to the normally-on channel has been investigated and explained. The switching performance has been measured on a carefully designed double-pulse tester with minimised stray inductances in order to reduce the parasitic impact on the device's switching characteristics. With the tester, the SiC JFET was switched using zero gate resistance, with only minor ringing during the ultrafast switching transients of up to 60kV/µs and 3kA/µs under 600V, 6A, clamped inductive load operation. A SPICE-based SiC JFET model was built so that the model parameters can be directly extracted from the characterisation data. The simulations with this model show reasonable agreement with the experimental waveforms obtained in the switching tests.

A fall characterization procedure has also been carried out on Cree's 1.2 kV, 20A prototype SiC MOSFETs. The static characterisations have been repeated from 25°C to 200°C to evaluate the influence of the temperature. Previous observations of $R_{DS(ON)}$ that is 5 - 8 times smaller than comparable 600V Si CoolMOS and has unusual temperature-dependence have been confirmed. Possessing bigger junction capacitances due to the larger die size, the switching speed of the SiC MOSFET was a little slower than SiC JFET, with a dv/dt of 20kV/µs and di/dt of 2kA/µs under similar operating conditions. Based on the characterisation data, a level-one model for the SiC MOSFET was built by using a mature Si power MOSFET modelling tool.



Planar-interconnected power module suitable for high-frequency switching and high-temperature SiC devices



SiC MOSFET switching waveforms under 600V/8A clamped inductive load with 5Ω gate resistor

In order to take full advantage of SiC high switching speed and temperature capabilities, a high temperature planar package was designed, developed, fabricated and tested to achieve a power module with smaller parasitic parameters and footprint. The SiC device is sandwiched between DBC and the copper leads attached to the device with nano-silver paste. Copper leads are used for both the external and the internal interconnects. Nanosilver paste is used as the electrically conductive connecting material. Epo-tek 600 and spacer act as insulation layer. Test results prove that the designed planar package can support the SiC multi-chip power module operation at high temperatures (250°C). **AS**

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Good Outlook for Exhibition and Conference

At PCIM Europe 2010 in Nuremberg from 4 - 6 May 2010, more than 260 exhibitors on 10.900 square meters exhibition space are expected. Up to 6.200 exhibition visitors and over 500 conference delegates are anticipated. Thus PCIM Europe is the leading international power electronics event showing increasing interest even in tough times.

PCIM Europe 2010
International Exhibition & Conference for
POWER ELECTRONICS
INTELLIGENT MOTION
POWER QUALITY
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'Energy Savings and Sustainability' is in the focus of the conference. The program (see 'The World of Power Electronics Technology' in Power Electronics Europe 2/2010) with its emphasis on power electronics, intelligent motion and power quality/energy management includes tutorials, more than 170 first-time presentations, three keynote papers, special sessions to 'Digital Power and Energy Efficiency' and 'Power Electronics for Efficient Inverters in Renewable Energy Applications'. The latter is organised by Power Electronics Europe to be held on May 4, 2.00 - 4.00 pm in Room Paris.

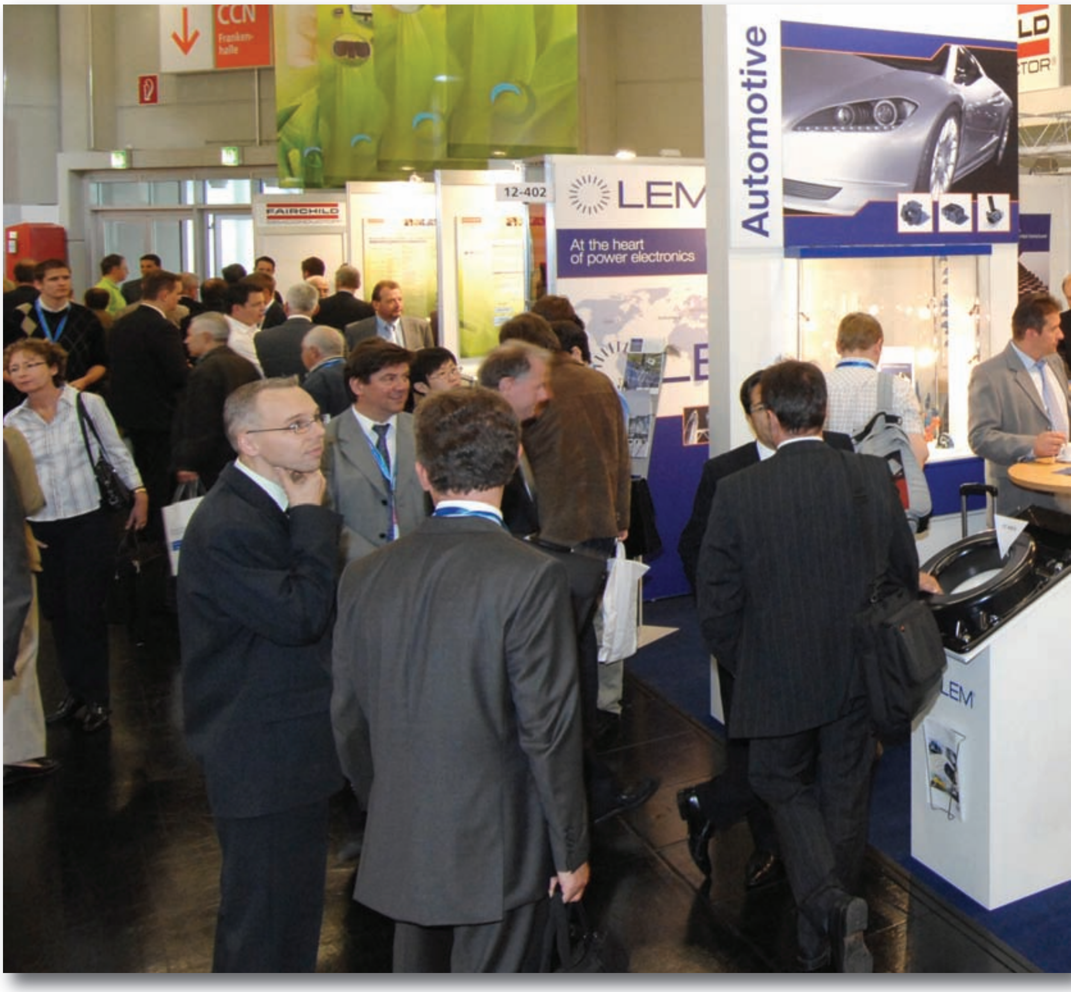
Focus on renewable energy applications

For the third time time Power Electronics Europe has organised a Special Session with this year's focus on Renewable Energy Applications featuring papers from Björn Backlund, ABB Switzerland Ltd; Dejan Schreiber, SEMIKRON Elektronik (Germany); Alberto Guerra, International Rectifier (USA) and Shang Ming, Mitsubishi Electric Corporation (Japan).

The first paper entitled '**Comparison of High Power Semiconductor Technologies for Renewable Energy Sources'** will look at the features for the available high power semiconductors of choice and also takes a look at future devices and their expected impact on efficiency.

High power semiconductors are key components for controlling the generation and connection to the network of renewable energy sources such as wind turbines and photovoltaic cells. For highest efficiency of the energy source, it is therefore essential to select the right device for the given conditions. The ABB paper looks at the performance features for the available high power semiconductors of choice and also takes a look at future device technologies and their expected impact on efficiency. For inverter applications, the IGBTs and IGCTs represent the two main candidates. Both devices have a distinct set of features making the question which

From May 4 - 6 it's again time to visit PCIM conference and exhibition in Nuremberg



More than 260 exhibitors, up to 6.200 exhibition visitors and over 500 conference delegates are expected at this year's PCIM

one is the best technology obsolete. What it comes down to is to select the device based on application requirements and own capability to utilise the device to its best. Certain comparisons are though helpful to see what is possible to achieve with the two technologies. One example is the possible output power for a 2-level inverter as function of the switching frequency at a given set of conditions.

Another interesting item is the development of new wide band-gap semiconductor materials in addition to the dominating silicon starting material. The salient features of Silicon compared with the most developed candidates for new semiconductor materials are covered in this paper. One important aspect of the high power semiconductor development is its impact on efficiency and energy saving, or in other words how "green" it is. Renewable energy sources are today almost exclusively equipped with power electronics and therefore it makes a difference what power semiconductor are used also due to the large impact of secondary effects such as cooling capacity.

Renewable energy sources are quite often remotely located without a sufficient infrastructure to feed the electrical energy into the grid. For a complete study of power electronics for renewable energy sources we must therefore also look at the possibilities to transmit the energy in an efficient way.

The second paper covers **'High Power Renewable Energy Applications, Facts & New Design Proposals'.**

Wind turbine designs with full size converters based on separate generator windings have many advantages, but also one large drawback, as outlined in SEMIKRON's paper. Many cables are required between the generator and the converter – 3 x three-phase winding set. Therefore, all of these converters are situated near the generator, in the nacelle. For high powers at low voltages, the generator currents are >> 1500A. An attractive solution is the MV synchronous generator and only a diode rectifier. However, in this case, the DC voltage variations are large (1:2) and require MV silicon devices. As wind turbines should produce power even at minimal rotation speed and a minimal DC voltage, for instance for 1000VDC, the output voltage at the MV transformer is relatively low, 660V. At the same time, DC voltage may reach more than 2kV. A logical solution for MV grid side inverter is a string of serially connected inverters, which can divide the variable rectified generator voltage. These grid-side inverter cells, are connected to the primary windings of the MV line transformer, and are independently maintaining their DC link voltages. For lower generator voltages, some of the cells must be bypassed, so that the equivalent total voltage of the cells is lower and corresponds to the generator voltage.

For PV applications, the SEMIKRON's proposal aims for higher system efficiency, consisting of a voltage duplicator and two cells in series, with 4 times higher transmission voltage and inverter operation with modulation factor 1, using interleaving in PWM control, to significantly reduce the output filter.

'GaN-Based Power Device Technology and its Impact on Future Efficient Solar Grid Connected Micro and String Inverters' will be introduced by the third paper within this Special Session.

In the last couple of years, the PV industry has shown various trends for increasing overall conversion efficiency as well as maximizing the harvesting of solar energy. The specific trend toward an intelligent PV panel requires high efficiency, high reliability and low cost. "In-situ" conversion and "in-situ" pre-regulation with microinverters/converters require highly efficient DC/DC stage. Topologies based on Silicon MOSFETs have intrinsically limited improvement capabilities. Based on state-of-the-art active components and passive components, constrained integration opportunities pose a limit to the technology evolution. GaN based switches, have a better figure of merit (FOM) than other power components based on Si or SiC material. The potential improvement exploitable from the GaN technology is large, based on the material limits.

In this paper the practical impact of IR GaN technology is anylised, when applied to the primary stage of a 200W micro-Inverter module and when used in the buck-boost circuit of a power optimiser DC/DC module, replacing traditional power MOSFET switches. The 200W micro-inverter (DC/AC) used for the comparison and GaN switch evaluation is manufactured by Enphase Energy, while the DC/DC Power Optimizer utilised for the buck-boost topology evaluation, is manufactured by Solar-Edge. Both systems, intended for "in-situ" single PV panel connection, have the MPPT function performed for each panel. Module-level MPPT is generally considered to be faster and more optimal than tracking done at the level of a centralised inverter allowing it to better follow changes in sun irradiance due to environmental factors or weather factors. Further examples are presented to illustrate the future improvement achievable by applying the GaN technology, in this case high-voltage applications in centralised inverters with transformerless advanced topologies.

Finally, the paper **New Low Loss Transfer Mold IPM for**

Photovoltaic Generation will introduce a low loss large-scale Dual In-line Package Intelligent Power Module with rating of 50A/600V.

A new low loss Photovoltaic DIPIPM in a large package has been developed by applying

fast full gate CSTBT and its optimised drive IC, together with the high-efficient heat dissipating insulation sheet. By adopting the high-speed full gate CSTBT, 10% of IGBT power loss was reduced. By change the drive circuit of N-side IGBT, 20% of module total loss reduction was realized. In addition, compared with the conventional package, the new package reduces thermal resistance by 30%. Because the converter used for photovoltaic generation system applies fast switching, reducing the switching power loss could be a very effective way to enhance the whole system efficiency. In order to achieve an optimised trade-off between on-state voltage and turn-off loss, the PV DIPIPM adopted the fast full gate CSTBT chip combined with the advanced driver IC that is capable to handle higher short circuit current.

And the winner is...

Also the Best Paper Award (participation at PCIM China 2011 including expenses) has been sponsored by PEE for the third time. It will be handed over by PCIM organiser Udo Weller and PEE Editor Achim Scharf at the PCIM opening ceremony on May 4, 9.00 am, in Room Paris.

This year's awardee is Christian Nöding, Center of Competence for Distributed Power Technology at University of Kassel/Germany for the paper **'Evaluation of a Three-Phase Two-HF-Switch PV Inverter with Thyristor-Interface and Active Power Factor Control'.**

He will present an inverter topology for photovoltaic systems connected to the medium voltage grid using inexpensive thyristors and high performance IGBTs or SiC switches.

Photovoltaic inverter technology rapidly improved during last decades, achieving more than 98% conversion efficiency. In terms of efficiency this leaves little space for major improvements. However, inverter cost are still relatively high, corresponding to approximately 250€/kW. In order to compete with conventional energy sources cost must be drastically cut down without significant prejudice on the efficiency, functionality and power quality. An approach to this is to minimise the amount of HF-switches and to combine high performance IGBTs or SiC switches with rugged low-cost switches like thyristors.

A three phase sinusoidal current can be generated by this proposed circuit while complying with the reactive power specifications of the new medium voltage grid code. Reactive power is an important part of modern inverters for grid stability and compensation features. The major advantages of the circuit are the high performance/cost ratio and the robustness of the semiconductors. Using factors for comparing different types of topologies a comparison between common inverters are made to show the benefits of the presented system.

The feasibility of this topology is proved by experimental results presented in this paper,

showing its correct operation even with firing angles above 180°. With only two IGBT switches a peak efficiency of 98.4% could be reached with this laboratory setup. Further research of this concept will be focused on behaviour of the circuit on single- and multi-phase errors defined in the new grid code. **AS**

High-Voltage Phase-Leg Modules for Medium Voltage Drives and Inverters

Medium voltage inverters (line voltages of 1000 .. 3300 V) or auxiliary inverters for rail applications rated at rather low power levels of 100 .. 1000 kW suffered by the lack of availability of suitable high voltage IGBT modules rated at lower current. Thus inverter manufacturers had to use modules with too high current ratings which yielded in bulky inverter designs. With the introduction of the new HiPak0 series there is for the first time a high-voltage phase-leg module configuration available. The modules are rated at 2 x 150A, 4500V and 2 x 250A, 3300V. **Raffael Schnell, Manager Application, ABB Switzerland Ltd, Semiconductors**

With the introduction of the HiPak0 series it is now possible to design very compact and efficient inverters for 1000 to 3300V line voltage and an output power rating of 100 to 1000kW. Higher power ratings are possible with parallel connection of the modules.

Such inverters can be particularly used in industrial applications such as medium voltage drives for fans, pumps, extruders, paper mills, harbour cranes and conveyor belts, just to name a few. Other applications are auxiliary inverters for rail application or even converters for renewable applications such as converters for wind-power.

The HiPak0 module design compromises a simple phase-leg configuration and a stream-lined electro mechanical interface: All screw type connections (power terminals / base-plate) are realised with M6 screws allowing an easy assembly procedure. The gate/auxiliary connections are done with fast-on plugs. With a foot-print of 70mm x 140mm the HiPak0 module is compatible with heatsinks of similar sized standard IGBT modules.

Figure 1 shows the module and the available ratings. The electrical configuration of the HiPak0 module enables a simple mechanical inverter layout for both 2- and 3-level topologies.

Module properties

The principal mechanical design follows the proven traction module concept and compromises Aluminum Nitride (AlN) ceramics for highest possible insulation rating of 7400Vrms (on request up to 10.2kV) and low thermal resistance. In

Type	Nominal Current	Voltage Rating
5SNG 0150P450300	2 x 150 A	4500 V
5SNG 0250P330300	2 x 250 A	3300 V

Figure 1: The HiPak0 Module line-up

	5SNG 0150P450300	5SNG 0250P330300
V_{CEs}	4500 V	3300 V
I_{nom}	150 A	250 A
V_{CEsat} @ I_{nom} , 125 °C	3.50 V	3.0 V
V_F @ I_{nom} , 125 °C	3.45 V	2.1 V
E_{on} @ I_{nom}, 125 °C	580 mJ*	425 mJ**
E_{off} @ I_{nom}, 125 °C	615 mJ*	450 mJ**
E_{rec} @ I_{nom}, 125 °C	385 mJ*	280 mJ**
$R_{th(j-c), IGBT}$	69 K/kW	52 K/kW
$R_{th(j-c), Diode}$	138 K/kW	100 K/kW
	*2800 V_{DC}	** 1800 V_{DC}

Table 1: Key Data of the HiPak0

order to enable sufficiently high thermal cycling performance the base plate is made of Aluminium Silicon Carbide (AlSiC) that offers a matched coefficient of thermal expansion (CTE) to the AlN ceramic.

Both the 3300 V and 4500 V versions offer the latest SPT+ chip-set technologies [3]. The SPT+ technology offers highest SOA margins and exceptional low conduction and switching losses. Table 1 summarises the key performance figures of both module types.

Thanks to the very narrow parameter spread easy paralleling of the phase-leg modules is possible with minimal de-rating. This allows scaling of the achievable output power nearly linearly with the number of modules in parallel.

Inverter design

With a single module footprint a large range of inverter output power can be realised. In a 2-level topology the standard line voltage range from (690), 1000 and 1700Vrms can be served with two module types (5SNG 0250P330300, 5SNG 0150P450300). For DC-fed traction auxiliaries DC voltages up to 2800V are possible, which is an often used standard DC-voltage for AC-fed trains.

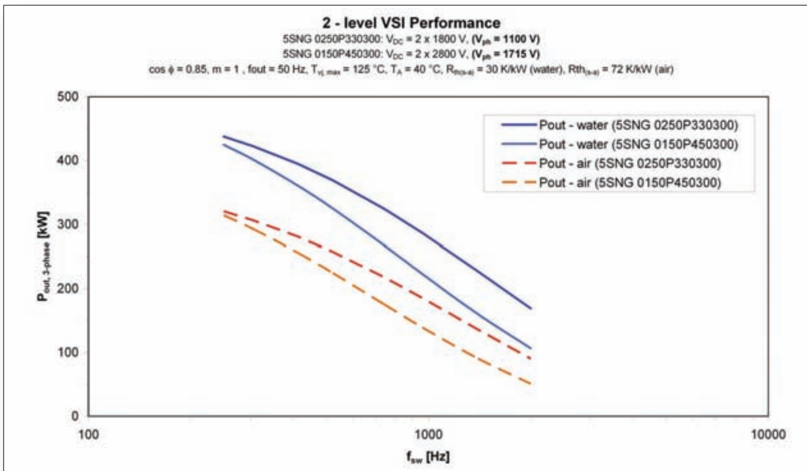


Figure 2: Output power versus switching frequency for a 2-level inverter

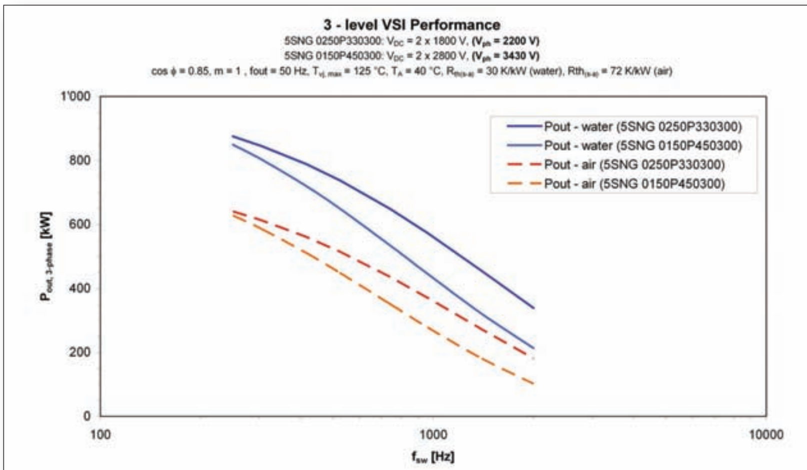


Figure 3: Output power versus switching frequency for a 3-level inverter

Figure 2 shows the achievable 3-phase output power for 2-level voltage source inverters. With forced air-cooling (dashed lines) 300kW can be reached. Water cooling allows more than 400kW output power.

In case of a 3-level inverter the nominal line voltages of 2300Vrms and 3300Vrms can be served. DC-fed traction auxiliaries up to 5600V are theoretically possible. The 5SNG 0250P330300 in 3-level topology is suited for the nominal 3000VDC traction supply voltage.

Figure 3 shows the output power range for a three phase inverter in 3-level topology. Forced air-cooling allows up to 600kW output power (dashed lines) whereas with water cooling more than 800kW can be reached.

The HiPak0 Module is designed with special focus on simple inverter designs. Figure 4 shows simplified drawing of a possible concept for a 2-level inverter phase leg. Only one type of screw is required for the mechanical connection (M6) and the gate-drive unit can be quickly connected with fast-on plugs. It allows for a simple phase-leg construction for both 2-level and 3-level topologies while maintaining the required clearance and creepage distance values for a proper insulation coordination. Thus a maximum possible clearance distance is designed in for the given package size. The housing material has a CTI > 600.

The clearance and creepage distances are shown in Table 2.

Even in harsh environmental condition such as pollution degree PD3 the HiPak0 needs to fulfil the standards for insulation coordination. Thanks to the high package CTI value the creepage distance allows for 4290Vrms working voltage between

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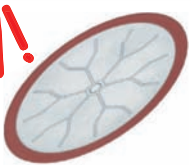

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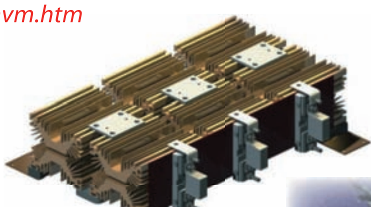

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56mm ⌀ Si Part No.	V_{RRM} V	I_{FAV} T_K=55°C A	I_{FSM} 10ms ½ sine V_R ≤60% V_{RRM} A
W2115MC520-600	5200 - 6000	2115	19000
W2899MC320-480	3200 - 4800	2899	25400
W3082MC420-450	4200 - 4500	3082	26000
W3477MC360-400	3600 - 4000	3477	28500
W3708MC320-350	3200 - 3500	3708	31000
W3842MC160-280	1600 - 2800	3842	35100
W4767MC180-220	1800 - 2200	4767	39000
W5636MC120-150	1200 - 1500	5636	46000
W7045MC030-060	300 - 600	7045	54000

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N1263JK160-180	1600 - 1800	1263	15000
N1366JK080-140	800 - 1400	1366	15900
N1651QK200-220	2000 - 2200	1651	17300
N1806QK160-180	1600 - 1800	1806	19100
N2083QK080-140	800 - 1400	2083	22000
N2154JK020-060	200 - 600	2154	22700
N2367MK200-220	2000 - 2200	2367	32400

Part No.	V_{DRM} V_{RRM} V	I_{TAV} T_K=55°C A	I_{TSM} 10ms ½ sine V_R ≤60% V_{RRM} A
N2593MK160-180	1600 - 1800	2593	34500
N3022MK080-140	800 - 1400	3022	38200
N3229QK020-060	200 - 600	3229	28000
N3904HK200-220	2000 - 2200	3904	50900
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N4472HK160-180	1600 - 1800	4472	59000
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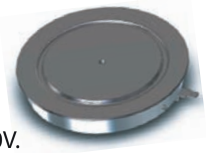

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T1200EB45E	4500	1200	4.6
T1800GB45A	4500	1800	4.7
T2400GB45E	4500	2400	3.6
T2250AB25E	2500	2250	3.0

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Clearance distance in air	d_a	Terminal to base	35 mm
		Terminal to Terminal	19 mm
Surface creepage distance	d_s	Terminal to base	64 mm
		Collector 1 to Emitter 1	54 mm
		Collector 1 to Emitter 2 (+DC to –DC)	78 mm

Table 2: Clearance and creepage distance for the HiPak0

collector and emitter, without degradation of the housing due to tracking effects. From +DC to -DC the corresponding working voltage can be up to 6200Vrms. The internal module insulation to the base-plate can be optional up to 10.2kVrms which would correspond to a long term partial discharge free working voltage of max. 5100Vrms.

Thanks to the large creepage distance between terminals and base-plate 5100Vrms is as well the maximum working voltage without tracking in PD3. Regarding the clearance distance in PD3 up to 16kV impulse voltage are allowed between the collector-emitter terminals and 27kV impulse voltage between the terminals and the base-plate according to IEC 60664-1. This is also far beyond the capability of the used silicon chips and the insulating material (AlN cermic). Thus the package insulation coordination is sufficient.

Usually very challenging is the design of 3-level inverters with standard IGBT modules. With the HiPak0 and its phase-leg configuration probably the most compact 3-level phase leg can be realised for its power and voltage class (Figure 5). For the neutral point diode function the integrated free-wheeling diode of the HiPak0 Module with shorted gate-emitter can be utilised. This way there is only one kind of module necessary for the 3-level phase leg.

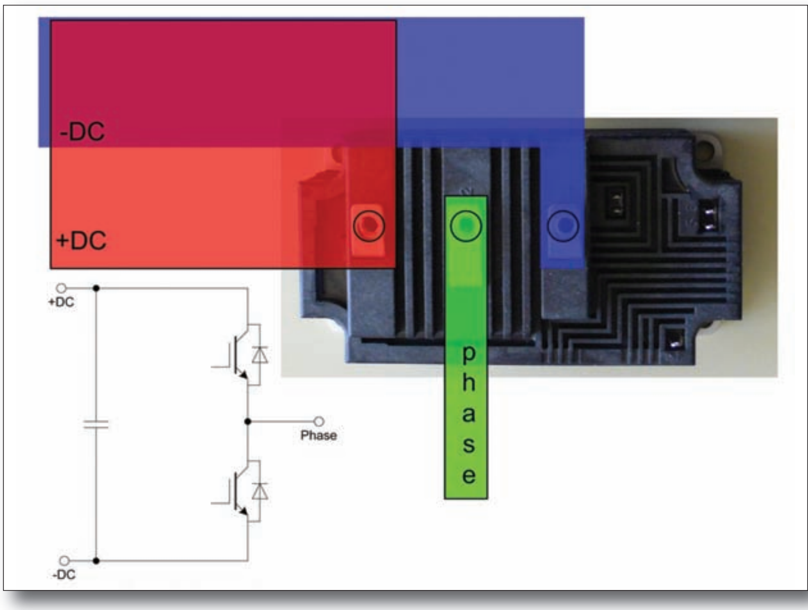

Figure 4: A 2-level phase-leg

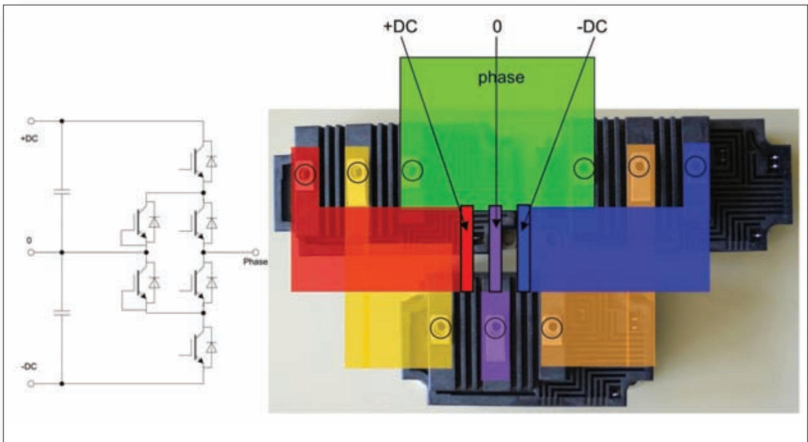

Figure 5: A 3-level phase-leg

Conclusion

A new high-voltage module line-up in phase-leg configuration has been presented. These modules rated at rather moderate current ratings are the perfect match for medium voltage inverters in the lower MW or sub MW class. The modules feature the latest chip technologies that offer lowest losses and highest ruggedness. The module design allows a simple effective design of 2-level and 3-level inverters and despite the small dimensions the requirements for insulation coordination according to IEC 60664-1 can be fulfilled even for demanding applications.

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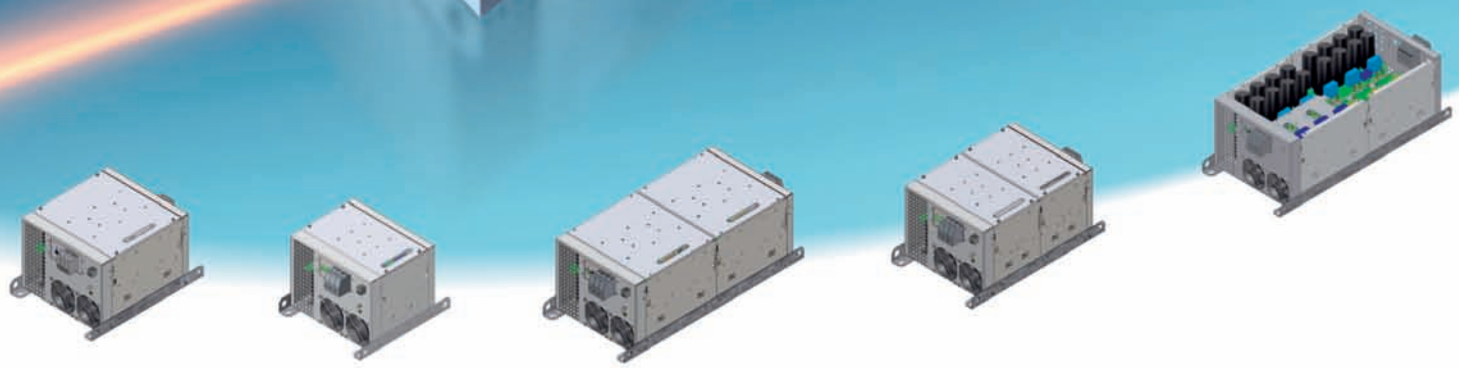

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600/1200V IGBTs Set Benchmark Performance in High Switching Speed Applications

The third generation of high speed IGBTs from Infineon Technologies (H3) in the voltage class 600V and 1200V are optimised for high speed switching in welding, UPS, SMPS and Solar applications. The new devices show excellent dynamic behaviour, smooth switching and significant loss reduction, providing the system designers with a cost-effective solution to meet today's stringent requirements of energy efficiency regulations and simplify the system design by reduction of cooling and filtering efforts. **Davide Chiola and Holger Hüsken, IGBT Application Engineering and IGBT Technology Development, Infineon Technologies, Austria/Germany**

High energy efficiency standards set by governmental agencies and lower system costs are the main driving forces toward development of more efficient power switches [1]. The selection of the right switch (that provides the optimum cost / performance required by the application) depends on power level and load conditions. Due to the higher current density and slower switching compared to MOSFETs, IGBTs are typically adopted at high power level (>1kW), low switching frequency (< 40kHz), and were narrow line or load variation have to be covered. Typical applications are "hard" switching motor drives, uninterruptable power supply (UPS) and Welding.

Thanks to recent technological advancements and the requirements of emerging markets, a wide variety of application-specific IGBTs have been introduced in recent years to extend their utilisation to new application fields; low power drives, inductive heating and SMPS in the consumer market, solar and wind power in the renewable energy market.

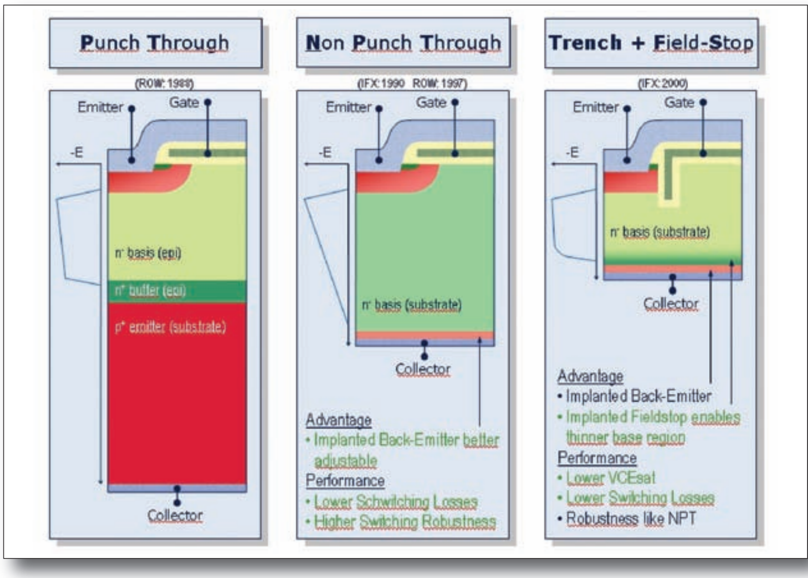

Figure 1: Comparison of different IGBT technologies

Technology and product family

The new HighSpeed 3rd generation IGBT product families in 600V and 1200V blocking voltage are extensions of the established TrenchStopTM product families building on the same technology base [2,3] (see Figure1).

It is well known that for a given IGBT technology base (characterised by cell layout and vertical design) different device properties can be achieved by plasma engineering in the drift zone of the device. By adjusting the gain of the inherent pnp transistor of the IGBT, the conductivity modulation in the drift zone and hence both V_{CEsat} and E_{off} can be varied. Thus, different 'trade-off points' or relations between conduction and switching losses can be achieved. As members of the

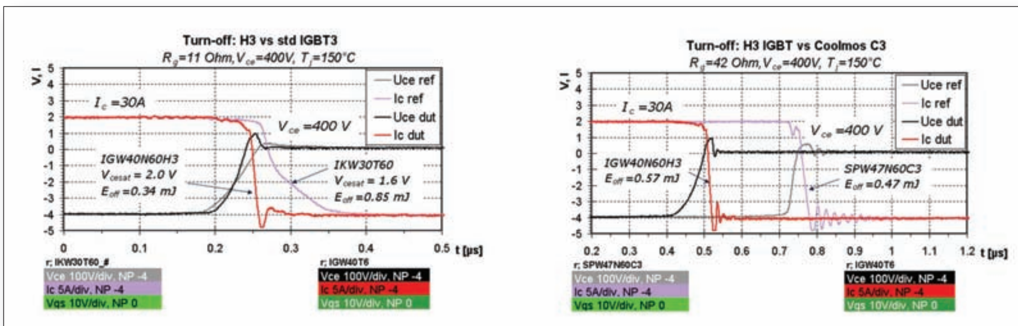

Figure 2: Switching behaviour of the 600V H3 IGBT against standard TrenchStop (left) and Coolmos C3 (right)

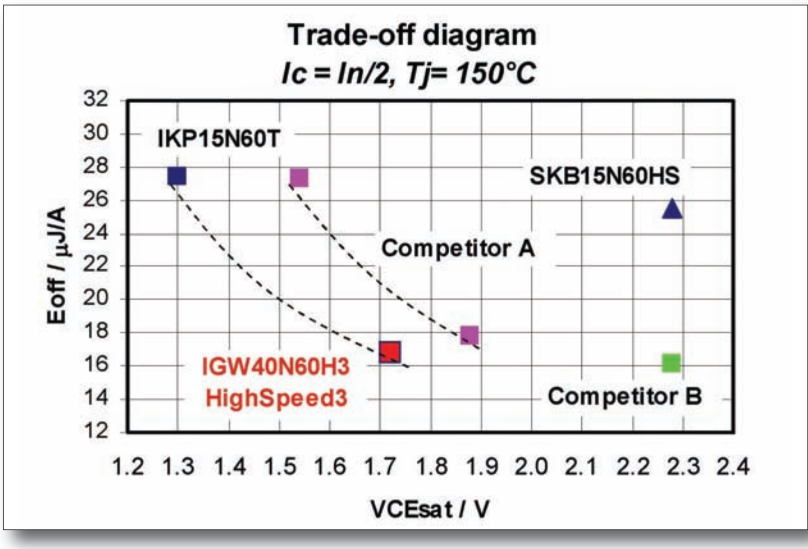

Figure 3: **600V IGBT evaluation with normalised turn-off losses vs V_{CEsat} at 50% nominal current**

TrenchStop technology family, the HighSpeed 3rd generation also features short-circuit ruggedness, pulse current capability and smooth switching behaviour for low EMI.

For applications where a reverse conducting capability is required, the 3rd generation IGBT is co-packed with the latest generation of EmitterControlled (EmCon) diodes. Analysis of target applications shows a unidirectional energy transfer or, in other words, the power factor of the target applications is always positive and furthermore close to 1. This allows an optimisation of diode size with the benefit of further improving system efficiency by reducing both diode and IGBT losses.

Dynamic characterisation

The switching behaviour of the 600V and 1200V devices is measured in a wide range of temperatures, switching currents and gate resistors. As an illustrative example for the 600V voltage class, the new H3 IGBT is compared against a TrenchStop and a Coolmos™ C3 with similar current rating in half-bridge switching test circuit with inductive load, the diode is a 8A rated SiC Schottky diode from Infineon for all devices.

The current waveforms of the H3 IGBT are clearly showing the total absence of current tail at high temperature (Figure 2, left), and turn-off switching behaviour that resembles the one of a unipolar fast switching device like the Coolmos C3 (Figure 2, right). The turn-off energy is reduced by 60% compared to the standard TrenchStop IGBT3 for a corresponding increase in V_{cesat} of 25%. In these test conditions, the 40A rated H3 IGBT is actually showing faster di/dt at turn-off than the 30A Coolmos C3 (2080 vs 1000A/µs in Figure 2), still showing smooth switching behaviour and a moderate voltage overshoot of 100V. The Coolmos C3 still results in 17% lower E_{off} due to the steeper voltage rise.

A competitor benchmarking is shown in the V_{cesat}/E_{off} trade-off diagram of Figure 3. The turn-of losses are measured at half the rated current, to represent a typical application condition, and scaled by current

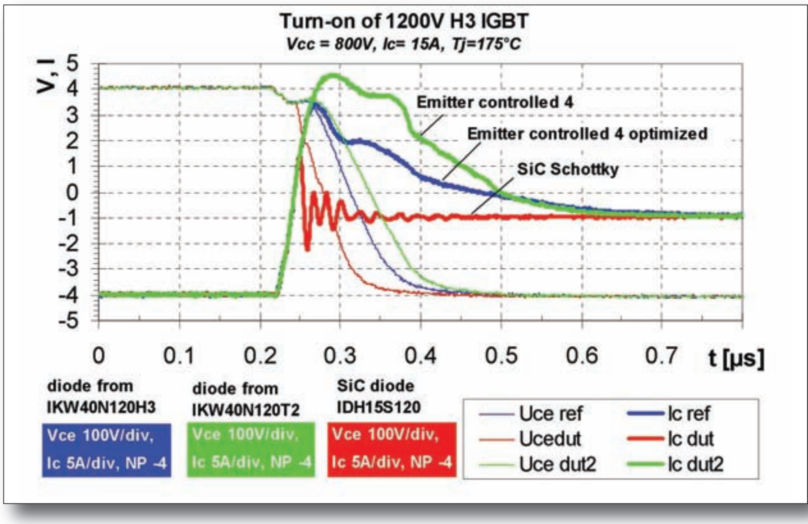

Figure 4: Effect of different diodes on turning on the 1200V H3 IGBT

rating, due to the different die size of devices under test.

The H3 set benchmark performance, with a significant improvement to the previous high speed generation from Infineon ("HS" family). The chart shows also the superiour trade-off provided by the combination of Trench + Field Stop structure in comparison to alternative technologies.

For the 1200V a similar improvement to the previous generation is achieved: 40% reduction in turn-off losses and 400mV increase in V_{cesat} compared to the 1200V TrenchStop2. To illustrate the effect of the anti-parallel diode on the turn-on switching behaviour of the IGBT, the 40A H3 IGBT is turned on at T_j = 175°C, V_{cc} = 800V, Ic = 15A with respectively a 15A, 40A 4th generation EmCon and 15A SiC Schottky diode (Figure 4).

The diode has a significant effect on the IGBT turn-on losses: the SiC Schottky would be the best choice in hard-switched topologies aiming to achieve the best efficiency like solar inverters. However an optimised emitter controlled 4th generation diode provides the best cost / performance in most of the target application and was therefore selected as co-pak with the H3 IGBT.

Application studies

In order to assess the performance of the 600V High Speed3 IGBT in a fast switching application, 20A and 30A devices were tested in a PFC test board (1kW, 400V output, 110V to 230V input voltage in CCM mode). The H3 IGBT is compared to a Coolmos C3 and other conventional (non Superjunction) MOSFETs. Figure 5 shows the PFC test board for the in-circuit test.

The 70 mΩ Coolmos C3, best in class in TO247 package, shows the best efficiency at high load current above 600W. The H3 IGBT in TO220 clearly outperforms conventional MOSFETs in much bigger packages, utilising 1/7 to 1/10 of the chip area. Despite having less than half of the chip area, the H3 IGBT outperforms also the 160 mΩ Coolmos C3 above 850W, clearly showing the power density advantage of this high speed IGBT technology, and indicating a cost-effective solution for high power PFC application above 1kW (telecom SMPS, for example).

To illustrate the benefit of the new H3 generation 1200V product family in application conditions, we discuss the case of a hard-switching bridge type inverter. This topology is commonly used e.g. as the output stage of a UPS or solar inverter, with the number of legs adapted to the required 1- or 3-phase output. In any case, the purpose is to generate a sinusoidal current signal from a DC bus voltage. If the PWM technique is chosen as control method, the losses in each switch can be straightforwardly calculated using IPOSIM [4]. Figure 6 shows the loss breakdown in case of an inverter generating a 50Hz 40Arms output signal from 600V bus voltage.

The power factor cosφ (where φ is the phase angle between current and voltage) is varied between 0.85 and 1.0. Junction

Figure 5: PFC test board for the in-circuit test

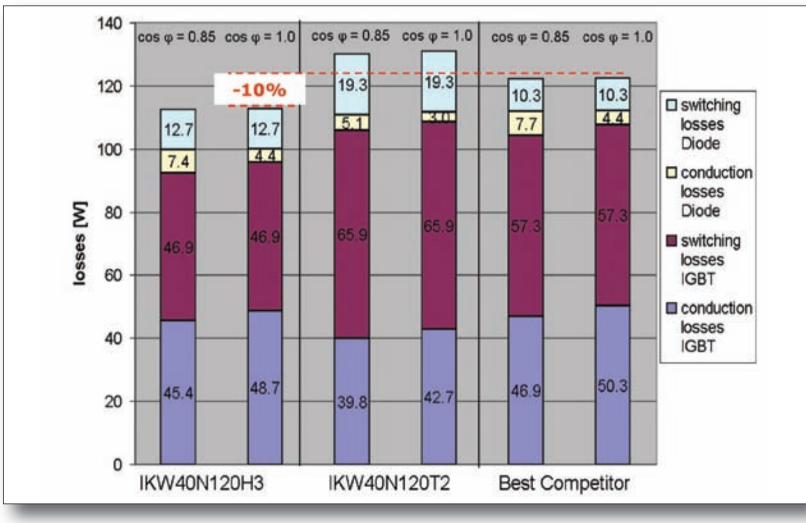

Figure 6: Loss comparison in inverter operation at 20kHz

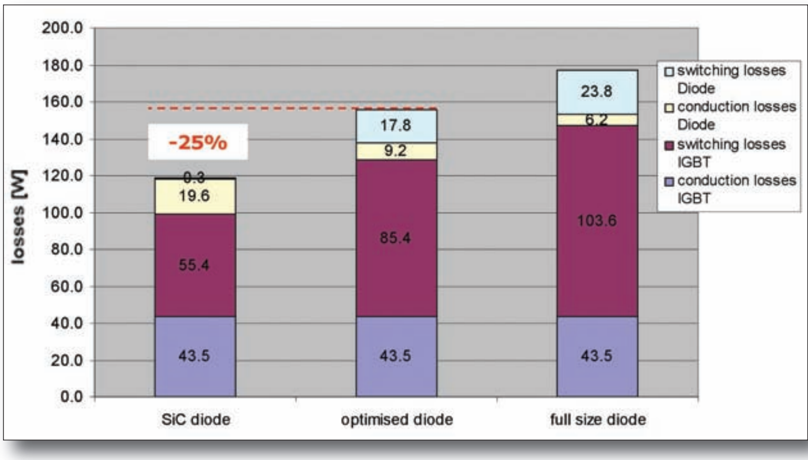

Figure 7: Comparison of Silicon vs SiC diode in inverter for power factor 0.85 for IGBT and diode

temperature of all devices was assumed to be 125°C for all devices (note that for Infineon products this gives 50°C margin to maximum junction temperature as compared to only 25°C for most competitor products). The IKW40N120H3 show 10% loss reduction compared to the best competitor of same current rating, increase in efficiency is remarkable already for a moderate switching frequency of 20 kHz with both IGBT and diode contributing.

The impact of diode choice is further illustrated in Figure 7. Here, the losses are considered for a combination of the 40A H3 IGBT with the full size diode used in IKW40N120T2, the optimised diode of IKW40N120H3 and the SiC diode IDH15S120 (T_j=175°C, V_{cc} = 800V, 20kHz, 40A rms, cosφ = 0.85, m = 0.9). Using a SiC diode, the switching losses of the IGBT are reduced by 20%, those of the diode are virtually eliminated, providing an overall loss reduction of 25%.

Conclusion

In this article the third generation of High Speed IGBTs from Infineon Technologies (H3), in the voltage class 600 and 1200V, optimized for high speed switching in welding, UPS, SMPS and Solar applications, have been presented. Their electrical and thermal behaviour was verified by characterisation measurements and in-circuit application tests.

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The Next stage in the Commercialisation of GaN-Based Power Devices

With the first commercially viable GaN based power device released into production, a new stage of implementation of this transformational technology is taking place. Distinguishing features of the new technology platforms are discussed in this article as well as the related performance of the resulting power devices. The prospective availability of 600V GaN based power devices in a variety of applications including power factor correction for AC/DC converters and motor drive circuits is discussed. **Michael A. Briere, ACOO Enterprises LLC/International Rectifier, USA**

There are an increasing group of academics and industrial suppliers of power semiconductor devices joining the theme that power electronics can play a significant role in the realisation of opportunities to significantly impact global energy consumption, by more than 25% by 2025 [1]. This can be achieved through the use of more efficient working load architectures, enabled by new power electronics, provided that significant and rapid adoption of these architectures occurs. The rate of adoption is determined to a large extent by the economic barriers or incentives involved. The availability of new power electronics based on commercially viable wide band gap semiconductors such as GaN on Silicon power devices fabricated in Silicon foundries, provides the required performance to cost value proposition to enable lower economic barrier to adoption for these energy efficient architectures.

As Silicon based power device technology approaches maturity, it becomes increasingly expensive to achieve even modest improvements in the device figures of merit (FOM) [2]. Necessary further advances in power device performance must be achieved through the use of alternative materials. One of the most promising alternatives to Silicon is Gallium Nitride (GaN).

Even though the basic GaN HEMT (high electron mobility technology) transistor was first invented over 15 years ago by M. Asif Khan [3], significant development efforts on practical power devices using GaN-on-Si technology have been fairly recent, predominantly in the past 5 to 7 years. GaN based power devices are expected to improve rapidly over the next 10 to 20 years. In fact, it is expected that an order of magnitude in improvement in the key device performance FOMs will be achieved over the next 5 years.

Salient features of a power switch

In order to provide a compelling alternative to Silicon based devices, the new GaN based devices must achieve certain performance characteristics. The first amongst these is cost. Cost effective GaN based power devices require the use of large diameter (at least 150mm) Silicon substrates for hetero-epitaxy, as well as device fabrication compatible with high volume silicon CMOS factories. These requirements have been achieved in a platform known as GaNpowIR [2].

It is often promoted that another salient feature necessary for commercially viable GaN based power devices is that their gates be enhancement mode, that is that the device not conduct without an applied bias. The author strongly disagrees with this common proposition. Whereas, it is true that an enhancement mode gate is useful in several applications, and IR has developed several novel approaches to realise this feature, it is not often actually required. In fact, it is relatively straightforward to provide gate drive circuitry to operate depletion mode devices and companies such as IR provide such devices as part of a complete solution.

Potential issues with start-up shoot through are likewise resolved. Amongst the several well established methods of achieving enhancement mode GaN based

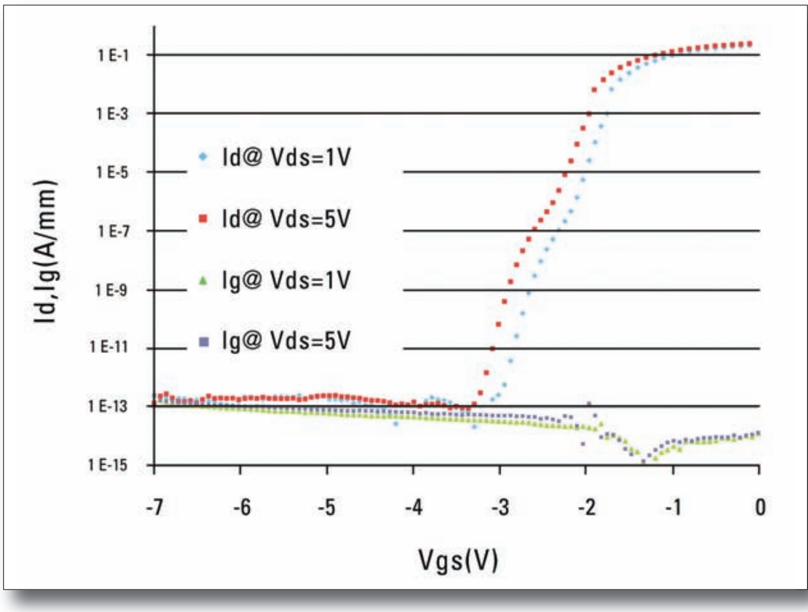


Figure 1: Measured I_d normalised to gate width (850mm) as a function of V_{gs} for V_d = 1V and 5V, L_g = 0.3μm for LV GaNpowIR device

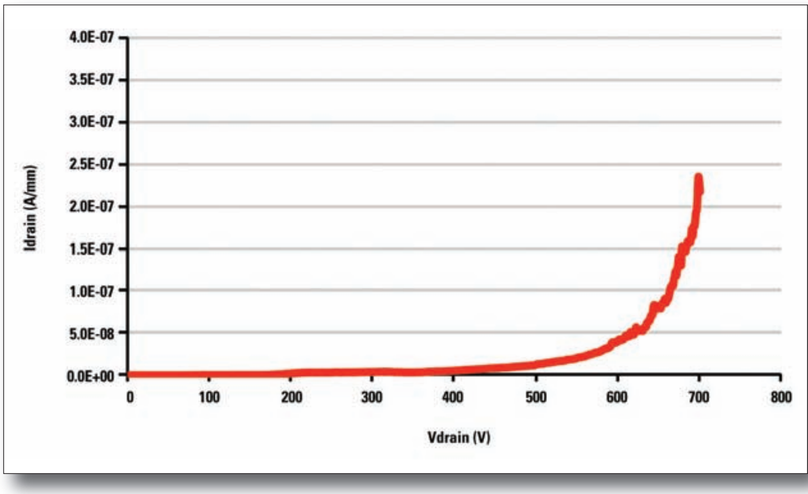


Figure 2: I_d (A/mm) vs V_{ds} (V) for early HV GaNpowIR HFET, V_{gate} = -10V

power devices is the use of thinned AlGaN buffer layers [4] and p-n junction gates using Mg doped GaN or AlGaN layers under the gate metal [5]. The first generally suffers from significant degradation in device performance (R_{dson} and I_{dsat}), and while the second suffers to a lesser extent in these FOMs, it exhibits significant gate leakage, especially when the gate junction is forward biased or at elevated operating temperatures. Several improved approaches to achieving normally-off switch performance have already been developed.

What is clearly required however, and commonly inadequately addressed, is that the leakage currents of the device be well controlled. Much of the reported constructions for GaN devices to date utilise Schottky gates and subsequently exhibit device leakage in operation of mA/mm of gate width. For a power device, which often has an effective gate width on the order of 1m, such gate leakage would result in an unacceptable power loss/heating. Similarly, the maximum operating voltage has often been specified at reverse bias source-drain current densities of mA/mm of gate width. To be commercially viable, leakage currents need to be reduced across the specified operating range to less than 1µA/mm. This has been achieved through the combined use of a proprietary insulated gate construction and improved III-Nitride epitaxial film quality. This has resulted in gate and drain-source leakages for low voltage devices of <10pA/mm, as shown in Figure1. The resulting ratio of I_{on}/I_{off} of 10^{12} is substantially better than reported elsewhere for GaN based devices and even exceeds that of comparable Silicon based power devices.

Such results are also achievable for higher voltage devices. Figure 2 shows the drain leakage current at breakdown for a 100mm wide device, capable of saturation currents of greater than 20A (V_g = 0V), is <50nA/mm at 600V. Here the ratio of I_{on}/I_{off} is 10^7, where Ioff is measured at 600V drain bias and a gate voltage of -10V.

Another salient feature of power devices is the switching performance. As has been previously reported [2], the initial GaNpowIR products are low voltage (30V) DC/DC power stage modules. In many high performance low voltage applications, it is the $R_{(on)}$ * Q_{sw} FOM which is critical to many of the low voltage applications. In this regard, the GaN HEMTs are expected to achieve more than an order of magnitude improvement over state-of- the-art Silicon devices within the next 5 years [2]. Quantitatively, this means a $R_{(on)}$ * Q_g device performance of less than 4mΩ * nC compared to next generation Silicon FOM of 45mΩ * nC.

Similarly, for many high voltage applications, the V_{ceon} * (E_{off} + E_{on}) FOM is a determanent value proposition. As in the case of Silicon Carbide (SiC) based power device, GaN based HEMT devices operate with majority carriers, making the reverse recovery switching times and associated losses far lower than the alternatives provided by Silicon based, Superjunction and Bipolar devices. Figure 3 shows a comparison in turn-off behaviour for early IR GaNpowIR 600 V rated devices, best in class Superjunction FETs and IGBTs. As can be seen, the GaN based devices represent over an order of magnitude reduction in E_{off} compared to IGBTs and nearly a factor of 2 compared to Superjunction devices. Together with significant improvements in R_{dson}, GaN based power devices provide far superiour performance compared to Silicon based alternatives. IR will release its 600V GaN based power device technology platform to production by the end of 2011. The first products will include normally-off power switches and rectifiers for use in applications such as PFC AC/DC converters, motor drives, solar inverters and lighting.

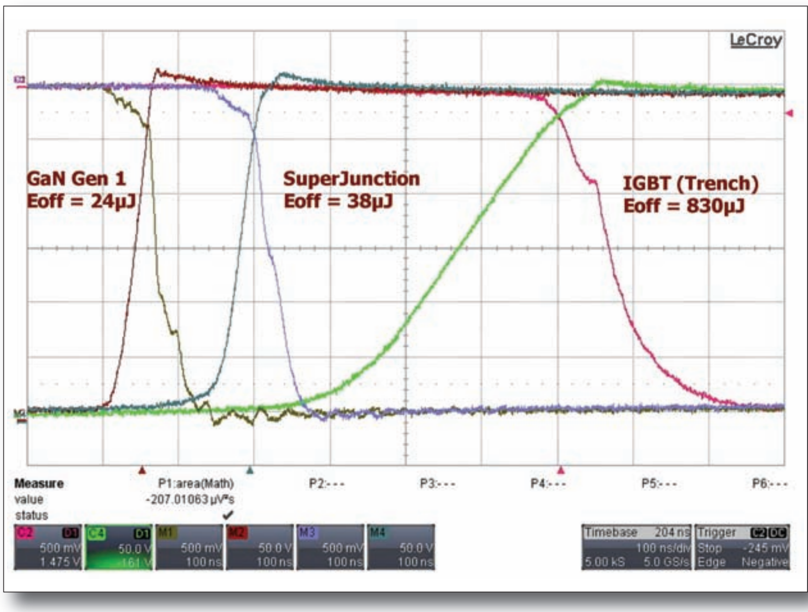


Figure 3: Turn-off waveforms for 600V rated IR GaNPowIR HEMT, Superjunction and IGBT devices (measured E_{off} are 24µJ, 38µJ and 830µJ, respectively)

Minimising parasitics in packaging

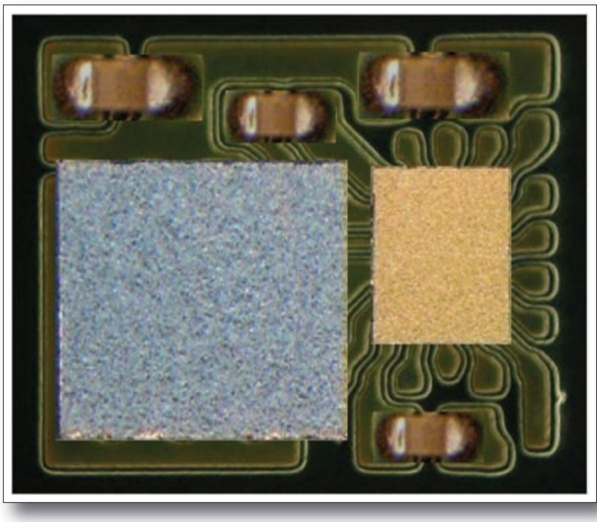
Another challenge for the realisation of commercially viable low voltage GaN devices is the effective conduction of the source-drain current from the internal to the external device terminals. This has been accomplished through a flip-chip die, eliminating wire bonding and minimising other package related parasitics (see Figure 4).

In addition to issues in placement and handling, there are several performance issues that must be addressed to fully realise the advantages of such GaN based flip-chip power devices. The spreading resistance of the substrate used to interpose the device in the application circuit can represent a 20 to 50% addition to the intrinsic (die) device FOM. Parasitic inductance in the substrate layout can produce undesirable ringing. An integrated approach which optimises the power switch interface with the application board, as well as the gate driver and minimises parasitic related behaviour is provided by the iPowIR product platform. An optimised driver also provides for achieving the maximum performance benefits afforded by the GaN based power devices, through intelligent deadtime control. For these reasons, the first GaNpowIR product is the iP 2010, a fully integrated and performance optimised solution, as shown in Figure 5. The target of a useable FOM of 30mΩ * nC for this first generation technology platform as packaged in the

Figure 4: Topside view of a flip-chip GaNpowIR device

iP2010 has been achieved [2].

Finally, the stability of device in-circuit performance is a prerequisite to commercialisation. The stability of all critical FOMs for the GaNpowIR technology platform is excellent under accelerated conditions for > 4000 hrs. In fact, over 2,000,000 device hours of reliability testing has shown performance in line with silicon based device specifications. Tests have included gate stress, reverse bias stress, constant current (2x specification),



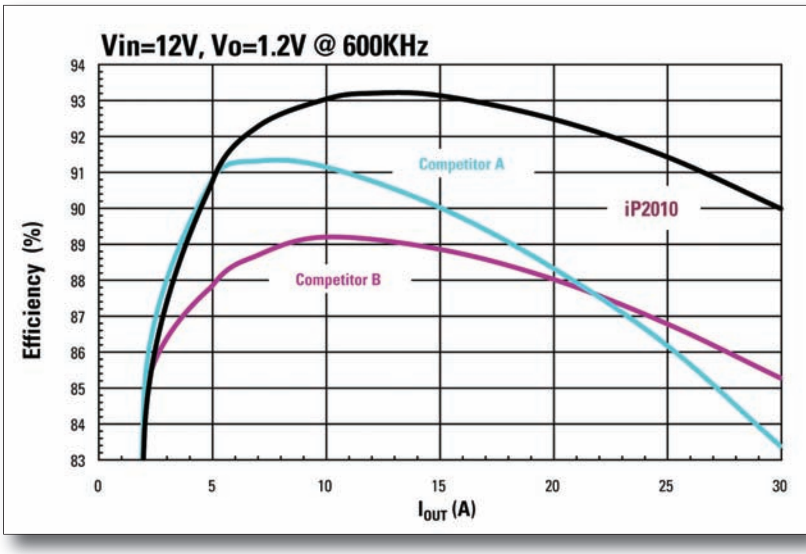


Figure 6: Measured power conversion efficiency for initial GaNpowIR product (iP2010), a 12V_{in} to 1.2V_{out} POL converter power stage operating at 600kHz compared to two Silicon based alternatives

temperature humidity bias, package testing for MSL and temperature cycling, high temperature operating life and intermittent operating life tests.

First GaNpowIR release

The first product release to production on the IR GaNpowIR technology platform is a 30A capable 12V buck converter power stage product. It incorporates the control and synchronous rectifying switches together with the intelligent gate driver in a low parasitic LGA package. Figure 6 shows the measured power conversion efficiency for this first generation GaN product compared to competitive silicon based solutions.

Here it can be seen that the GaN based power devices provide up to 4.5% improved conversion efficiency over state-of-the-art Silicon FETs. In addition, by enabling this high efficiency at 600kHz, this GaN based power solution enables the use of all ceramic capacitors in the power converter, thereby enhancing system reliability. As has been previously discussed [2] further improvements in LV GaN based power devices (e.g. RQ < 5) will allow for truly revolutionary performance of efficient (85 to 90%) single stage power conversion (e.g. 12V to 1.2V) at >50MHz frequencies, eliminating much of the output filter components, significantly reducing costs, and shrinking the converter size by more than a factor of 10. The resulting simultaneous improvement in power conversion density, efficiency and cost represents the true value of GaN based power device development for LV applications.

Figure 5: iP 2010 product layout, including an all flip-chip design with monolithic control and synchronous FETs and intelligent driver IC, as well as local charge storage for optimal performance

Perhaps even more importantly, the IR GaNpowIR technology represents a cost effective platform for power integrated circuits, incorporating a range of voltage capable devices with best in class performance. This will allow system on a chip integration, such as complete AC/DC LV conversion and high power monolithic inverters for motor drives and power distribution. More than the replacement of Silicon discrete devices with GaN based devices, this platform opens a new era for integrated power conversion.

Conclusion

IR has released its first commercially viable GaN based power device platform to production, overcoming several significant barriers, particularly cost. First products focus on low voltage applications, though expansion into high voltage device products is expected by the end of 2011. More than the replacement of Silicon discrete devices with GaN based devices, this platform opens a new era for integrated power conversion.

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Solar Power Conversion – a System Solution to Alternative Energy Demand

Power electronics design plays a key role in the performance of a solar power system, as design engineers first look at maximum conversion. Since PV modules have very low conversion efficiency from solar to electrical energy (in the range of 20 percent), the efficiency of a power inverter is meaningful to minimize solar module area and volume of the entire system. Additionally, power loss of devices generates heat on silicon dies that causes temperature rise and must be effectively dissipated. These losses lead to a thermal stress that a high reliability design struggles with and heatsink is necessitated to address. Minimum power loss not only saves energy, but also enhances system reliability, making the system more compact and less costly. **Chang Qian, Applications Engineering Manager, Microsemi's Power Products Group, Bend, USA**

With the ever-increasing demand for "green" energy, solar power has drawn a lot of attention by its rapid growth in recent years. It has been reported that worldwide solar system demand is predicted to continue to grow more than 30% annually for the next three years for the following reasons: excess manufacturing capacity has helped push down average photovoltaic (PV) system prices by more than 25%; the ongoing reduction of PV system installation cost; and the positive incentive movement in multiple regions.

Converter topologies

To convert the fluctuating direct current (DC) output voltage from solar modules into a well- regulated sinusoidal alternating current (AC) voltage, the architecture of a typical solar power conversion system is either two-stage or single-stage, with or without, DC/DC converter. The existence of a DC/DC stage can maintain the input voltage of inverter at a constant and controlled level, and decouple the control of voltage and power flow. However, an extra conversion stage can have a negative effect on system efficiency. Because of this, more solar inverter manufacturers are evaluating and adopting single stage architecture, even when the inverter control is more complicated and voltage rating of power devices can increase. Among the recently introduced inverter topologies, two are considered to have the most potential for grid-tied centralised inverters in the future - HERIC® (Sunways) and multilevel inverters.

HERIC, shown in Figure 1, is structurally different than a conventional full-bridge

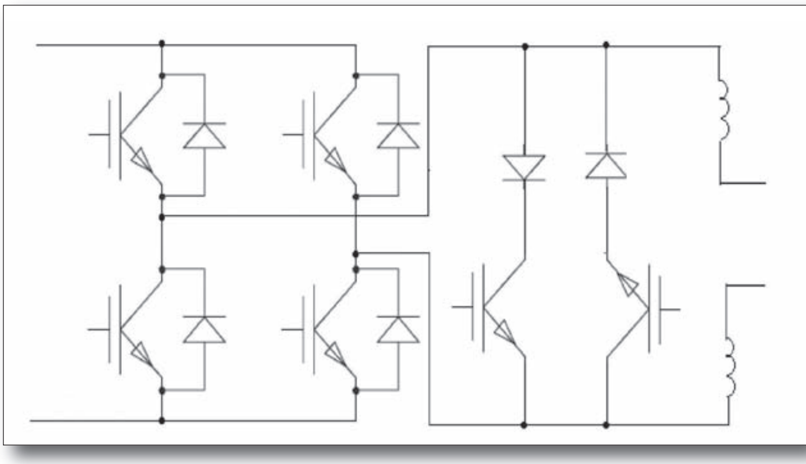


Figure 1: Schematic of HERIC® inverter

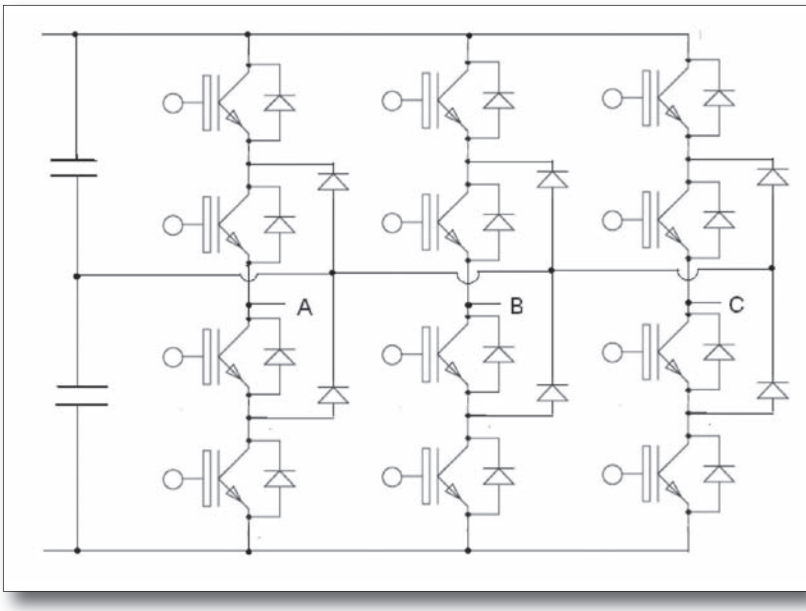


Figure 2: Schematic of three-level inverter

Device Technology		MOSFET	IGBT	Super Junction FET
600V/50A Devices	Conduction Loss	1	0.36	0.7
	Switching Loss	1	2.3	1.3
	Cost	1	0.5	0.86
1200V/25A Devices	Conduction Loss	1	0.17	X
	Switching Loss	1	2.2	X
	Cost	1	0.33	X

Table 1: Comparison of different device technologies (numbers normalised on MOSFETs)

inverter, incorporating an extra switch and diode pairs at the output. With these added devices and appropriate control, HERIC inverters are capable of boosting the system efficiency by effectively handling the reactive power flow.

Three level inverters, shown in Figure 2 is a specialised topology targeted at centralised solar power applications with higher voltages. Compared to its traditional counterpart, these inverters have only one-half of voltage stress on each switch so that devices with much lower voltage can be used. This leads to higher efficiency and lower device costs. In addition, the electromagnetic interference (EMI) level and output filter size can be reduced, thus lowering the overall cost of the system. It is important to note that this topology is more complex in its structure and control. Microsemi PPG offers a full line of three-level inverter modules in compact packages, which are extremely suitable for this application.

Power device selection

Selecting a MOSFET, Super Junction MOSFET or an IGBT) power device for solar inverters is decided by trade-offs between performance and cost. In general, IGBTs are a less expensive solution than MOSFETs, which are more efficient at higher frequencies. To select the best choice to meet the needs of the system designer, Table 1 lists a comparison of multiple devices regarding conduction loss, switching loss and cost. It is important to note that device selection ultimately depends on system performance requirements and cost structure.

Advantages of discrete power devices are:

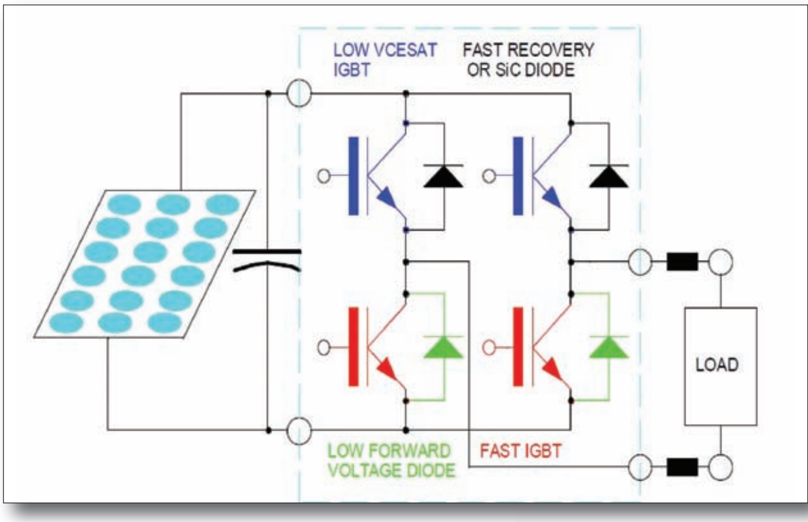
- Lower cost at volume
- Flexibility in component selection
- Low power and simple topology applications.

Advantages of modules are:

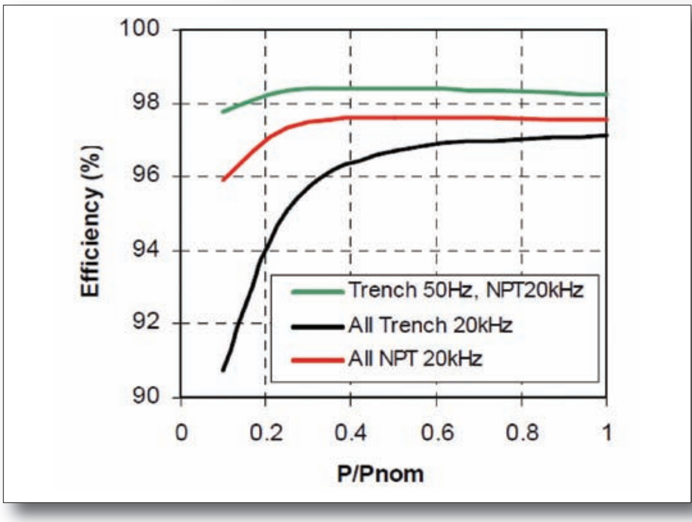
- Space savings
- Wide selection of topologies
- Ease of manufacturing
- Voltage isolation
- Short development time.

Control methods

Maximum Power Point Tracking (MPPT), has been used to optimise solar conversion for more than 20 years. Another instance is the application of unipolar PWM (Pulse Width Modulation) control for H-bridge inverter with mixed devices (Figure 3). The goal of unipolar PWM is to arrange faster devices and slower devices to switch at high frequency and low frequency, respectively, to maximise efficiency and reduce overall costs. Figure 4 demonstrates the increased efficiency of solar power modules that utilise PWM. The combination of slow IGBT (field stop trench) and fast IGBT (Non Punch Through) yields a 98% efficiency along light to full loads.



ABOVE Figure 3: H-bridge inverter module with mixed devices



LEFT Figure 4: Efficiency enhancement by mixed device inverter under unipolar PWM

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Application Considerations for Silicon Carbide MOSFETs

The SiC DMOSFET has definite system advantages over Silicon switching devices. However, its unique operating characteristics need to be carefully considered to fully realise these advantages. The gate driver needs to be capable of providing 20V drive with minimum output impedance and high current capability. The parasitics between the gate driver and SiC DMOSFET need to be minimised to assure that the gate pulse has a fast rise and fall time with good fidelity. The fast switching speed of the SiC DMOSFET can result in higher ringing and voltage overshoots. The effects of parasitics in the high current paths need to be carefully assessed. **Bob Callanan, Cree Inc., Research Triangle Park, USA**

The Silicon Carbide (SiC) DMOSFET has unique capabilities that make it a superiour switch when compared to its Silicon counterparts. The advantages of SiC DMOSFETs have been documented extensively in the literature [1]. However, there are some unique operating characteristics that need to be understood so that the device can be used to its full potential.

In this article, the characteristics of a typical 1.2 kV, 20 A SiC DMOSFET will be discussed. Comparisons will be made with other similar Silicon devices along with application implications. The intention of this comparison is to illustrate the differences in operating characteristics, not to pick the best device.

The devices selected for comparison are representative of commercially available Si IGBTs and MOSFETs with voltage and current ratings similar to the SiC DMOSFET. The TFS IGBT [3] is representative of a low on-voltage device and the NPT IGBT [4] is representative of a low turn-off loss device. The Si MOSFET [5] is representative of a commercially available 1.2kV Si MOSFET. Lastly, although not a 1.2kV device, the 900V SJMOSFET data [2] was included for comparison purposes. All comparisons were made with measured data except in the case of the SJMOSFET. Data sheet values were used.

Switching characteristics Silicon vs SiC

Consider the output characteristics of a typical 1.2 kV 20 A SiC DMOSFET as and the Si TFS IGBT shown in Figure 1. For the SiC DMOSFET, transition from triode (ohmic) to saturation (constant current) regions is not clearly defined as it is for the Si TFS IGBT. This is a result of the modest transconductance of the device. The modest amount of transconductance causes the transition from triode to saturation to be spread over a wider range of drain current. The result is that the SiC DMOSFET behaves more like a voltage controlled resistance than a voltage controlled current source.

The modest transconductance and short-channel effects are important to consider when applying the device. SiC DMOSFET needs to be driven with a higher gate voltage swing than what is customary with SJMOSFETS or IGBTs. Presently, 20V gate drive is recommended. The rate of rise of gate voltage will have a greater effect on the rate of rise of the drain current due to the lower transconductance. Therefore, the gate drive needs to supply a fast rise and fall time gate pulse to maximise switching speed. The SiC DMOSFET also has a threshold voltage similar to the Si SJMOSFET (2V nominal). Like the Si SJMOSFET, considerations need to be made for the lower threshold voltage, especially at high temperatures. Negative gate bias of up to -5V can be used if needed.

The rather large triode region can have impacts on certain types of fault detection schemes, chiefly the active de-saturation circuits. Some of these designs assume that the switching device enters a fairly high impedance constant current and/or transconductance saturation region during over-current faults. In the SiC DMOSFET case, the output impedance is lower and the device does not go into a clean constant current region during this type of over-current fault, especially under moderate over-currents. Therefore, the drain to source voltage will not increase as much. These characteristics of the SiC DMOSFET need to be carefully considered in fault protection schemes.

The forward conduction characteristics of the SiC DMOSFET along with the Si SJMOSFET, TFS, and NPT IGBTs are presented in Figure 2. The Si SJMOSFET's relatively high temperature coefficient of $R_{DS(on)}$ has considerable effect on its conduction losses. At 25°C, Si SJMOSFET and SiC DMOSFET were somewhat similar. At 150°C, $R_{DS(on)}$ of the SiC DMOSFET increases only about 20% from 25°C to 150°C whereas both the Si SJMOSFET and the Si MOSFET devices increases by 250%. This has a significant effect on system thermal design. The obvious advantage is that a smaller device can be used at higher

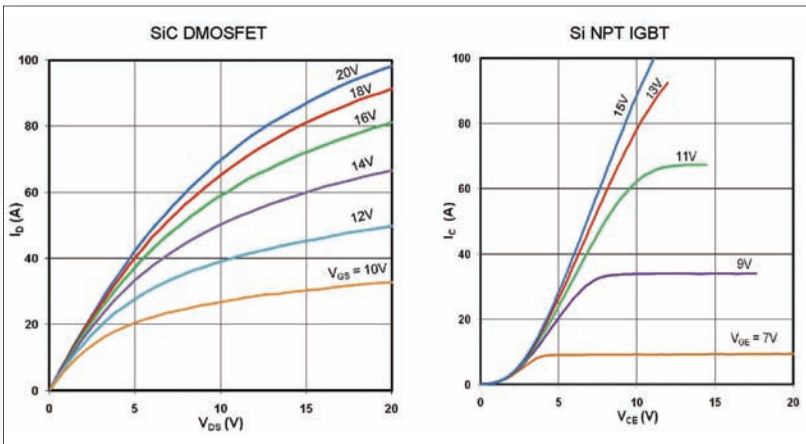

Figure 1: **Output characteristics comparison (T_J = 150°C)**

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operating temperatures, higher than what is possible with Silicon.

One of the key advantages to SiC is the high temperature capability afforded by the wide bandgap. This is clearly reflected in the leakage current comparison at elevated temperature shown in Figure 3. The SiC DMOSFET has about 20x lower leakage current at 150°C. At 200°C, the Si comparison parts leakage current increases drastically, to the point where the device fails due to excess power dissipation. The SiC DMOSFET leakage current is still acceptable and over 100x lower than the Si devices.

As previously mentioned, the recommended gate drive voltage for the SiC DMOSFET is 20V. However, the amount of gate charge required to switch the device is low. The ramifications of the modestly higher gate voltage and lower gate charge can be reconciled by using the product of gate charge and gate voltage as a metric of gate energy. The gate charge and gate energy comparison is shown in Figure 4.

Even though the operating conditions are not exactly matched, the results of this comparison show that the SiC DMOSFET gate energy are comparable to or lower than the other devices. Therefore, the higher voltage swing does not adversely affect gate drive power requirements. The SiC DMOSFET V_{GS} versus gate charge characteristics are somewhat different from what is usually experienced with other gate controlled Silicon devices. The Miller plateau is not as flat as observed in typical Silicon MOSFETs and IGBTs. Once again, this is primarily due the modest amount of transconductance.

A popular figure of merit when comparing MOSFETs is the product of $R_{DS(on)}$ and total gate charge Q_g [6]. Minimisation of the figure of merit is an indicator of the superiour part. A comparison between the SiC DMOSFET and the other Si MOSFTs is shown in Figure 5. The Si SJMOSFET has a figure of merit of 32.4Ω*nC. The figure of merit of the SiC DMOSFET is 7.12Ω*nC. Furthermore, the SiC DMOSFET is a 1.2 kV part whereas the Si SJMOSFET is rated at 900V.

The inductive turn-off losses versus temperature of the SiC DMOSFET compared with the TFS and NPT IGBTs are shown in Figure 6. The freewheeling diode used with all devices was a 1.2 kV, 10A SiC Schottky diode. The turn-off losses of the IGBTs are significantly higher than the SiC DMOSFET and strongly increase with temperature. This is due to the tail loss inherent with IGBTs. The NPT IGBT is significantly better than the TFS IGBT. However, the NPT IGBT conduction losses are much higher than the SiC DMOSFET.

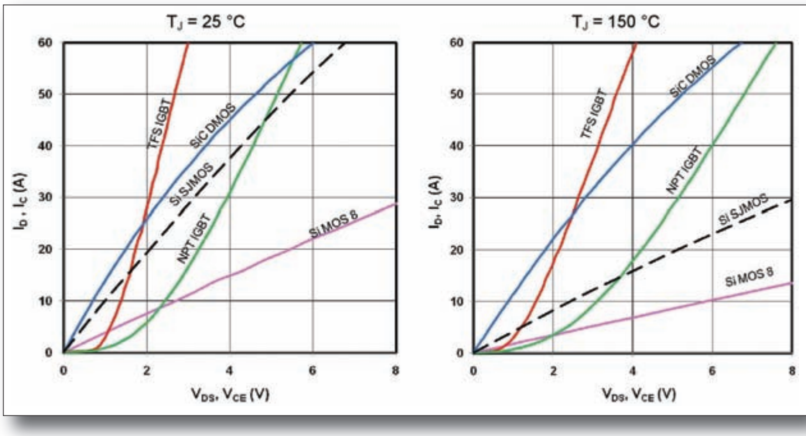

Figure 2: **Forward conduction characteristics comparison (V_{GS} = 20V, V_{GE} = 15V)**

The TFS IGBT conduction loss is lower than the NPT IGBT, but the switching loss is the highest of the three.

Gate driver requirements

To achieve fast switching time, the gate drive interconnections need to have minimum parasitics, especially inductance. This requires the gate driver to be located as close as possible to the SiC DMOSFET. Care should be exercised to minimise or eliminate ringing in the gate drive circuit. This can be achieved by selecting an appropriate external gate resistor. The silicon IGBT current tail provides a certain amount of turn-off snubbing that reduces voltage overshoot and ringing. As with any majority carrier device, the SiC DMOSFET has no tail, so the amount of drain voltage overshoot and parasitic ringing is noticeably higher. The higher ringing is of concern because of the SiC DMOSFET's lower transconductance and low threshold voltage reduces gate noise immunity. The high level of drain current di/dt can couple back to the gate circuit through any common gate/source inductance. A Kelvin connection for the gate drive

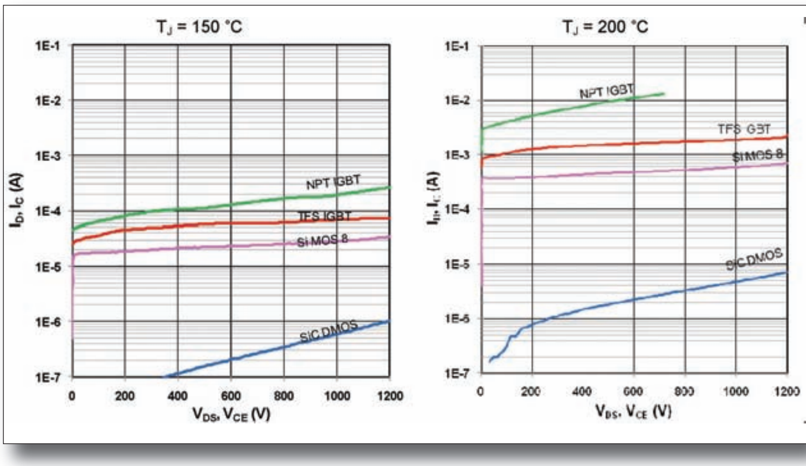

Figure 3: **High temperature leakage current comparison**

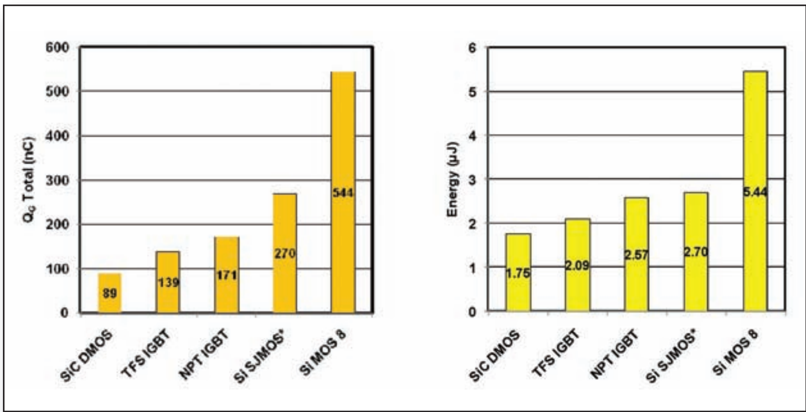

Figure 4: **Gate charge and energy comparison**

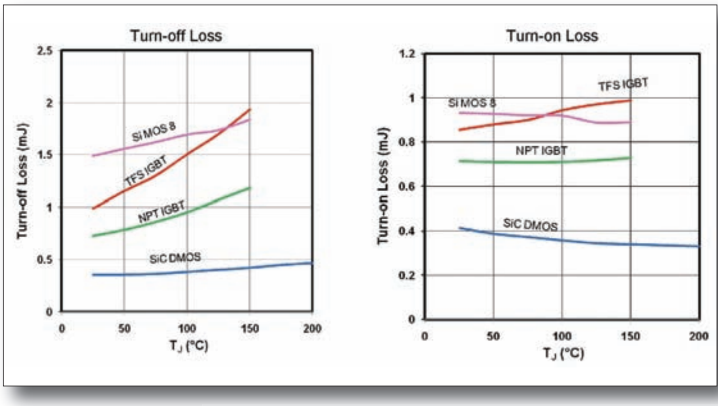

Figure 5: **Figure of Merit comparison (Q_g * $R_{DS(on)}$)**

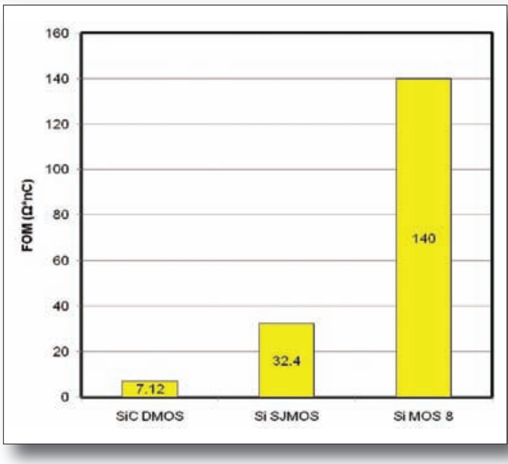

Figure 6: **Switching loss vs. temperature comparison (V_{DD} = V_{CC} = 800V, I_D = I_C = 20A, R_G = 10Ω)**

recommended, especially if the gate driver cannot be located close to the SiC DMOSFET. Ferrite beads (nickel-zinc recommended) in lieu of or in addition to an external gate resistor are helpful to minimise ringing while maintaining fast switching time.

Like any other power MOSFET, the SiC DMOSFET has a body diode. The body diode is a SiC PN diode that has a 2.5V - 2.7V built-in voltage, but a substantially lower reverse recovery charge when compared to a Si SJMOSFET. Use of this diode is not recommended due to its high forward drop. An external SiC Schottky diode is suggested.

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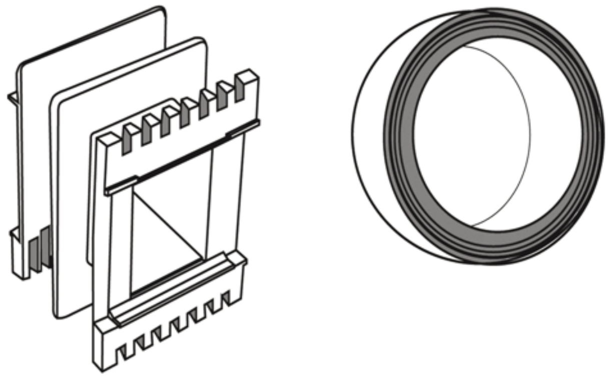

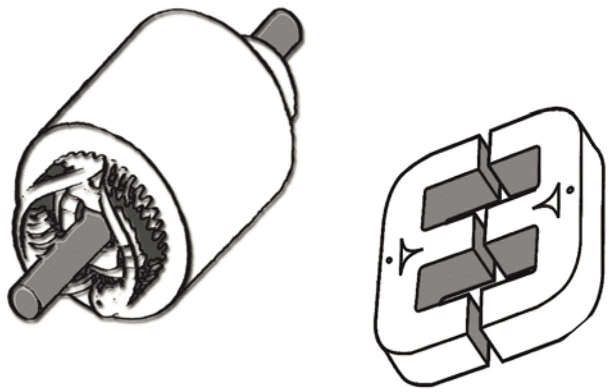

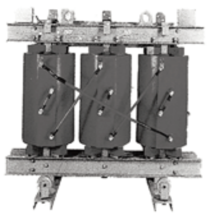

Expanded Digital Signal Controller Portfolio for Digital Power

Fairchild Semiconductors has developed a portfolio of PWM controllers, which enable notebook power-supply designers to meet the stringent international energy-saving regulations. These include the ENERGY STAR External Power Supply (EPS) version 2.0 requirement
that mandates 87% average active-mode efficiency to obtain compliance.

To meet these requirements, Fairchild has developed integrated PWM controllers, like the FAN6754, which offers designers high-voltage start-up to improve energy savings at light load by 25%. It also eliminates external protection circuits by incorporating over-voltage, over-current and over-temperature protection plus brownout and line-compensation functions. Other advantages include frequency hopping, which reduces EMI emissions by as much as 5-10 dB, and internal soft
start (8 ms) to reduce voltage stress on the MOSFET at start up.

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Intelligent Power Modules for Solar Power Generation Systems

Mitsubishi Electric launches its new SeriesQUOT intelligent power modules (IPM), mainly for use in residential photovoltaic (PV) inverters. The six models, which can also be used in inverters for fuel cell systems, each measure 90mm × 50mm, contributing greatly to PV inverter miniaturisation. This is about 30% less than that of Mitsubishi Electric's current PV series IPMs launched in 2005. The six models in the new PV series suit the various types of circuits in PV inverters, such as single output inverter, single output inverter with one chopper, as well as single output inverter with two choppers. The lineup consists of 4-chip, 5-chip and 6-chip modules, each with a choice of one of two types of current rating - 50A and 75A. The new PV Series is compliant with the RoHS directive.

www.mitsubishichips.com **PCIM 12-421**

PV Protection Products

Helio Protection is the global brand name of solar power protection developed by Ferraz Shawmut that includes Helio Fuse, Helio Switch, Surge-Trap and Helio Box.

PV cells and panels are DC generators. Fuses used to protect loads powered by AC in large grids react to very high fault currents, but the ones used in PV are very different. Ferraz Shawmut has taken a position on this fast-growing market with specific products that can clear fault currents as small as 2 to 3 times rated current. The Helio Fuse line offers devices for 600VDC to 1200VDC. The selection of the correct fuse depends on the open-circuit voltage of the solar panel in standard test conditions and on the geographical location of the equipment. The Helio Switch is a DC switch for solar PV protection and specially fitted for the safety of people servicing the installation. The Surge-Trap line offers thermally protected surge protective devices, type 2 according to IEC, for solar power applications, ensuring an excellent level of protection against over-voltages for PV systems. The core of Surge-Trap is a thermally protected metal-oxide varistor (a patented technology named TPMOV). Because of their high withstand to short circuit current, these surge suppressors require no additional protection from over-current. Solar PV applications demand two types of Surge Protective Devices (SPDs), one for the protection of the DC side of the PV inverter and one for the protection of the AC side. The first DC type protects against the transient over-voltages due to lightning strokes nearby the installation of PV cells. The AC type protects against over-voltages caused by grid operating or by lightning on downstream AC lines. Surge suppressors for PV applications are designed to be mounted on 35mm DIN rails. The Helio Surge Protection Box is dedicated to residential and commercial markets with a Surge-Trap in a safe box.

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Automotive-Qualified Power MOSFETs

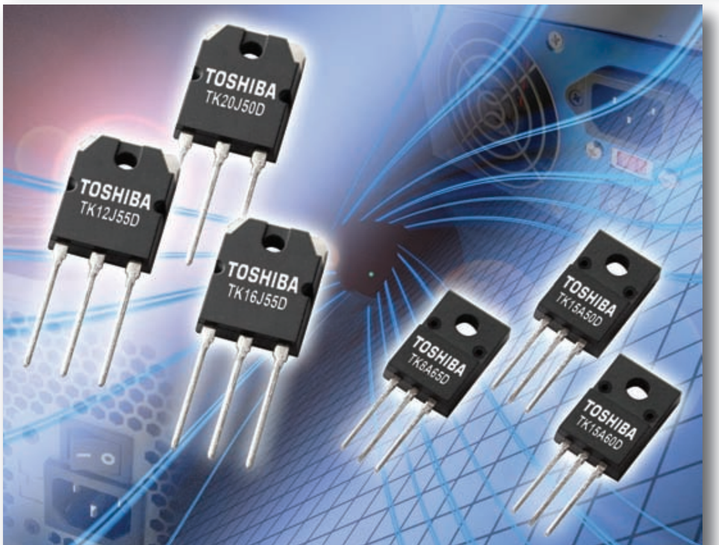
International Rectifier introduces the company's first dedicated family of automotive qualified MOSFETs for a range of applications requiring low on-state resistance including Electric Power Steering (EPS), Integrated Starter Alternator (ISA) pump and motor control, DC/DC conversion, battery switch, and other heavy loads on Internal Combustion Engine (ICE) and hybrid vehicle platforms. The new devices, built on IR's proven Gen 10.2 technology, deliver on-state resistance as low as 1.0m_ (maximum), and are available across a range of voltages from 24V to 100V in a variety of SMD and through-hole packages. Several of the devices feature revised maximum current ratings of up to 240A in a D2Pak-7P and 195A in a D2Pak. IR's automotive MOSFETs are subject to dynamic and static part average testing combined with 100% automated wafer level visual inspection. AEC-Q101 qualification requires that there is no more than a 20% change in on-resistance after 1,000 temperature cycles of testing. However, in extended testing, IR's new AU Bill of Materials demonstrated a maximum shift of less than 10% at 5,000 temperature cycles, showing the strength and ruggedness of the Bill of Materials.

www.irf.com **PCIM 12-202**

Current Sensors for PV Applications

VAC showcases AC/DC-sensitive differential current sensors which form the basis of residual current monitoring units (RCMUs) compliant with the VDE 0126 standard for transformer-less solar inverters. Using VAC DI sensors, the use of expensive DC-sensitive RCMUs can be avoided. The supply and return current conductor and, where necessary, external test current are routed through the sensor, which thus records only the current difference, i.e. the residual current, to an accuracy of 1.5% of the maximum safe residual current of 300mA. Output is a voltage proportional to the differential current. DI sensors offer a range of additional functions, including sensor core demagnetisation which can be triggered by supply voltage or as required. Other functions include self-testing with fault signal in case of defects or low supply voltage and self-testing with internally generated test current. The sensors are available with primary conductor opening or with integrated primary current conductors. Current sensors for PCB assembly with integrated electronics feature a signal conditioning IC having compact dimensions and measure high maximum and continuous current. Models available include sensors for measuring unipolar and bipolar current and with selectable output voltage and current.

www.vacuumschmelze.de **PCIM 12-130**



Power MOSFETs for 650V and 20A Applications

Toshiba Electronics Europe (TEE) introdces a new family of power MOSFETs that will deliver improved efficiency and faster switching speeds to applications operating with voltages up to 650V and currents to 20A such as PFC designs and lighting ballasts.

In creating the new power MOSFETs Toshiba has combined advanced packaging technology with the latest _-MOS VII semiconductor processes. The result is a range of devices that offer improved thermal dissipation and power cycling characteristics, reduced gate charge and capacitance, improved on resistance and better cost/performance ratios when compared with previous generations of devices. In addition, the avalanche durability of all of the MOSFETs is guaranteed. TK series MOSFETs are available in fully isolated TO220SIS packaging and conventional TO-3P(N) package formats. Dimensions are 10mm x 15mm x 4.5mm and 15.9mm x 20mm x 5mm respectively. All of the TO220SIS devices feature copper connectors rather than wire bonding. Devices in the new series offer voltage options of 450V, 500V, 525V, 550V, 600V and 650V and drain currents from 2A to 20A. On-resistance ratings range from 5Ω down to 0.27Ω.

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High-Voltage High-Side Gate Driver

Clare, a subsidiary of IXYS, offers the IX2127, a high-voltage, high-speed power MOSFET and IGBT driver. High voltage level shift circuitry and a floating channel allow the IX2127 to drive N-channel power MOSFETs and IGBTs in the high-side configuration operating up to 600V. Manufactured using a high-voltage BCDMOS on Silicon-on-Insulator (SOI) process, the IX2127 is extremely tolerant to negative transient voltages, while providing excellent noise immunity. Integrated protection features include supply under-voltage lockout, over-current detection and shutdown, and fault reporting. An onboard comparator can be used to detect an over-current condition in the driven MOSFET or IGBT device, and then shut down drive to that device. An open-drain output, FAULT, indicates that an over-current shutdown has occurred. The IX2127 is available in a standard pinout 8-pin DIP or an 8-lead SOIC package, saving at least 50% PCB area compared to optocoupler or pulse transformer solutions. The new driver is well suited for motor driver, switch-mode power supply, lighting and industrial applications.

www.ixys.com **PCIM 12-401**

Energy-Efficient Lighting Solutions

High brightness LEDs use a fraction of the wattage that average incandescent bulbs use, last longer than fluorescent bulbs and eliminate hazardous materials such as mercury and lead. Fairchild's PSR controllers, the FSEZ1307 and FAN102, eliminate power losses caused by the secondary side current sensing and achieve the most accurate constant current, allowing devices to accommodate different numbers of LED in series. These devices eliminate the secondary-side circuitry, and reduce the number of components, resulting in a lower Bill of Material (BOM) costs and less waste, contributing to ecodesign. The boundary mode PFC control IC, the FAN6961 or FAN7930, provide active power factor correction and component count for the power supplies that drive these LEDs.

Fairchild will also highlight its portfolio of AC/DC solutions that offer up to 96% efficiency and low standby power. Demos will feature the interleaved boundary-mode PFC controller, the FAN9612, as well as the FSFA2100, a 450W half-bridge asymmetric power switch.

or automotive Fairchild will showcase its gate drivers, which enable increased fuel efficiency. Demonstrations will include the FAN708x series of HVICs that allow engineers to develop more accurate and precise fuel injection control systems.

www.fairchildsemi.com **PCIM 12-601**

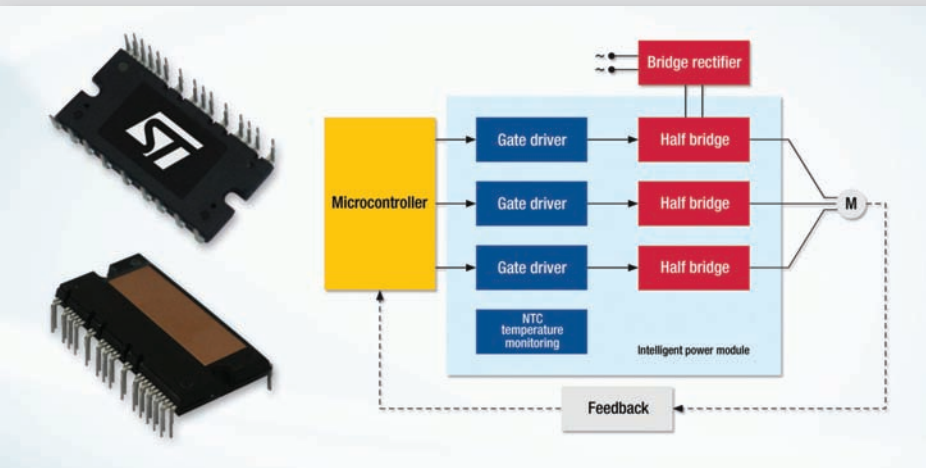
Thermally Efficient Power Modules

In appliances ST's new Intelligent Power Modules (IPMs) connect directly between the microcontroller and the machine's motor to control motor speed, and therefore support advanced features for advanced current sensing and lower energy consumption. The IPM's internal power switches (IGBTs) and dedicated controllers convert the microcontroller signals into the correct high-power waveform to drive the motor. One module can replace more than 30 discrete components. ST's four new IPMs are the STGIPS10K60A, STGIPS14K60, STGIPL14K60, and the STGIPS20K60. Each device includes three 600V IGBT half bridges with freewheeling diodes, control ICs, bootstrap diode, and protection functions including temperature control and comparators to protect against over-current and short-circuit faults. The STGIPL14K60 has the added benefit of internal op-amps, allowing designers to eliminate external current-sensing components normally required to control motor speed (Field Oriented Control). This device also has internal dead-time insertion to prevent excessive current damaging the IGBTs, as well as a smart-shutdown function also featured in the STGIPS14K60 and in the STGIPS20K60.

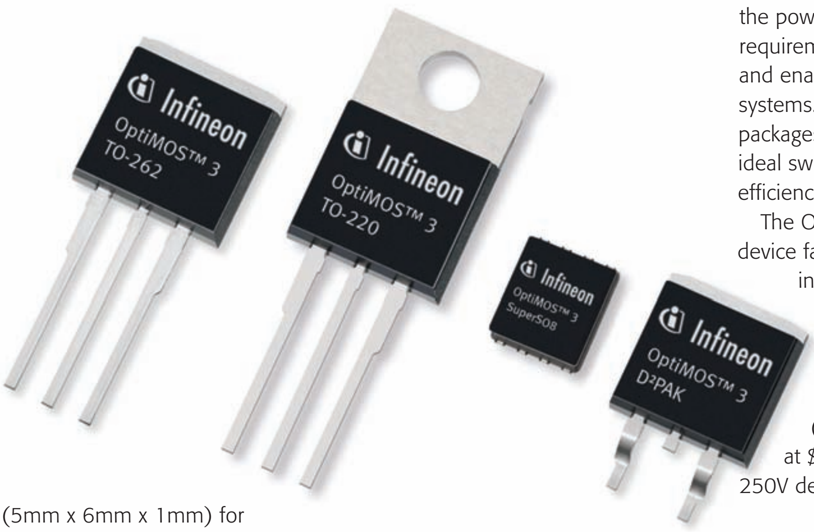
All devices use DBC packaging. The 25-lead or 38-lead molded SDIP packages have an exposed thermal pad for efficient connection to a heatsink, and achieve thermal resistance as low as 2.4K/W.

A new current-sensing IC simplifies design of smarter and safer systems by sensing current more accurately and giving designers extra flexibility to adjust the sensor's output before inputting to the system controller. TSC102 is a high-side current-sensing amplifier with low power consumption that is designed for direct connection to a small current-sensing resistor sitting at a voltage up to 30V. This direct connection allows a system to be monitored without disturbing its ground connection, which is essential in applications such as automotive systems or for monitoring power supplies with multiple outputs. The device also has rugged inputs to survive applied voltages ranging from -16V to 60V. These voltages can arise in systems where many loads are switching continuously or there is a risk of a reverse battery connection, such as in vehicle electrical infrastructures. The TSC102 integrates two op-amps and provides full access to the pins of the second op-amp. This access allows to implement a variety of signal-conditioning functions such as gain adjustment to optimise the range of the output signal. The op-amp can also be configured as a comparator to implement over-current protection, or as a first- or second-order low-pass filter to promote stable sensing in systems where noise is present.

www.st.com **PCIM 12-414**



200V and 250V MOSFETs



Infineon Technologies expanded its range of OptiMOS(tm) power MOSFETs by introducing a family of 200V and 250V devices well-suited for synchronous rectification in 48V systems, DC/DC converters, UPS and inverters for DC motor drives. Featuring a very low FOM, OptiMOS 200V and 250V technology slash conduction losses in system designs by one-half. The device family allows system cost improvement through reduced device paralleling; the ability to use smaller heat sinks as a result of the low on-state resistance; and a fast and low complexity design process due to optimised switching behaviour. The characteristics allow use of a slim SuperSO8 package (5mm x 6mm x 1mm) for applications that previously required bulky D_PAK devices (9mm x 10mm x 4.5mm). Going from D_PAK to SuperSO8 reduces the power semiconductor space requirement by more than 90% and enables higher power density systems. Additionally, using leadless packages like SuperSO8 provides ideal switching behaviour and high efficiency levels.

The OptiMOS 200V and 250V device family includes components in TO-220, TO-262, D_PAK and SuperSO8 packages in on-resistance classes of 10.7, 20, 32 and 60m_. For small quantity (10k units), pricing begins at $1.2 for 200V and $1.4 for 250V devices.

www.infineon.com

PCIM 12-404

New Line of Linear MOSFET Power Modules

Richardson Electronics offers linear MOSFET Power Modules (APTMLxxx...) from Microsemi which are used to provide a wide range of solutions in any linear, high-power density application where conventional switch-mode operation is either not allowed or not possible. This 10 module product line (100V, 200V, 500V, 600V and 1000V) is suited for circuits in which power devices must operate with high voltage and high current simultaneously, in near DC conditions. These MOSFET power modules are specifically designed to meet a wider guaranteed Forward Safe Operating Area, ensuring improved system reliability, with the minimum number of devices (to achieve given power levels). With their positive temperature coefficient thermistor included, these new linear MOSFETs are more stable and much less prone to thermal runaway. The included series shunt resistors allow current to be precisely controlled. This allows the modules to be easily used in parallel with an equal power dissipation balance. There is no need for additional safety margin judgement, which is usually required when switch-mode devices are used in parallel. Modules may be connected in series for greater than 1000V operation.

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PCIM 12-235

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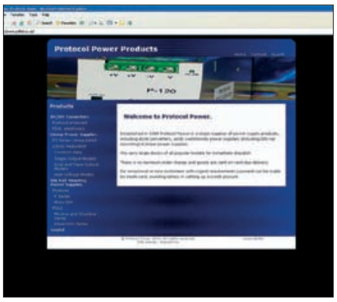

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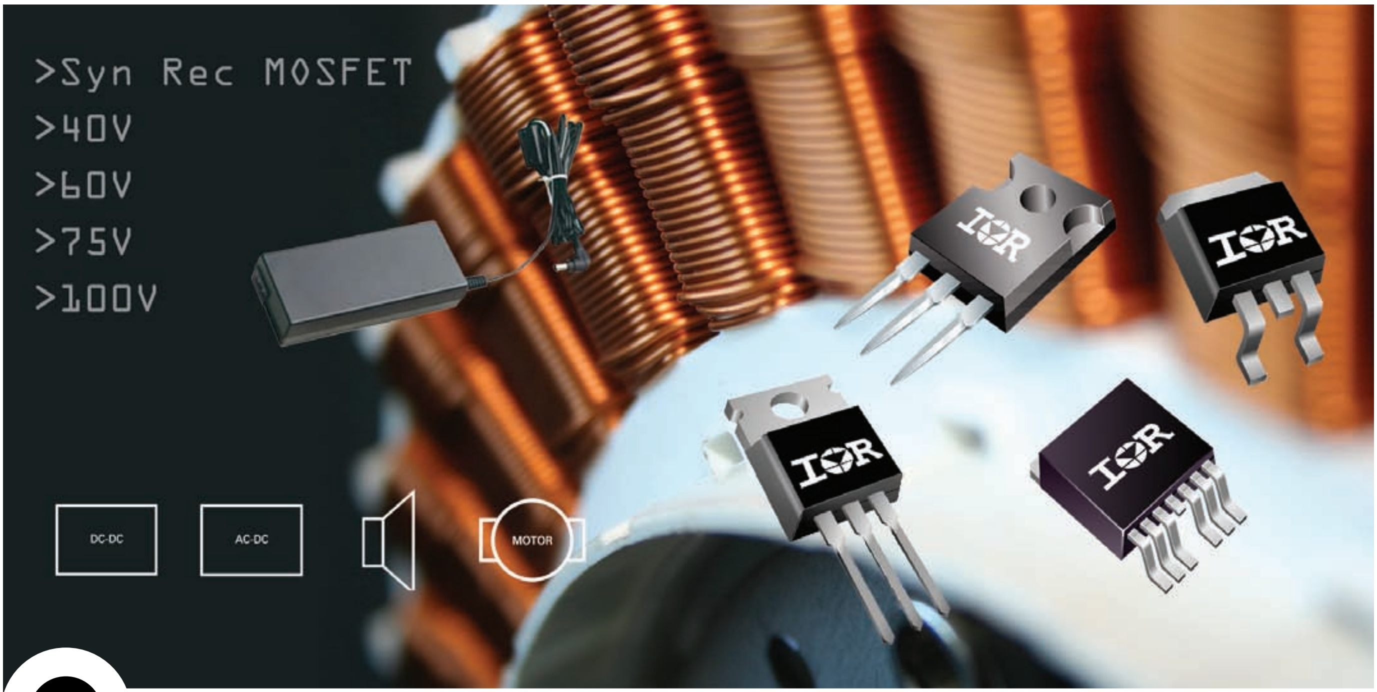

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IRFP4004PBF	40	195	1.7	220	TO-247
IRFS3004PBF/ IRFB3004PBF	40	195	1.75	160	D²PAK/ TO-220
IRFR4104PBF	40	30	5.5	59	D-PAK
IRFS3006-7PPBF	60	240	2.1	200	D²PAK-7
IRFS3006PBF/ IRFB3006PBF	60	195	2.5	200	D²PAK/ TO-220
IRFB3206PBF	60	210	3.0	120	TO-220
IRFS3206PBF/ IRFP3206PBF	60	210	3.0	120	D²PAK/ TO-247
IRFR1018EPBF	60	79	8.4	69	D-PAK
IRFP4368PBF	75	195	1.85	380	TO-247
IRFS3107-7PPBF	75	240	2.6	160	D²PAK-7
IRFS3107PBF	75	195	3.0	160	D²PAK
IRFB3077PBF	75	210	3.3	160	TO-220
IRFR3607PBF	75	80	9.0	84	D-PAK
IRFP4468PBF	100	195	2.6	360	TO-247
IRFS4010-7PPBF	100	190	4.0	150	D²PAK-7
IRFB4110PBF	100	120	4.5	150	TO-220
IRFS4010PBF	100	180	4.7	143	TO-220
IRFP4568PBF	150	171	5.9	151	TO-247
IRFB4115PBF	150	104	11.0	77	TO-220
IRFS4115PBF	150	99	12.1	77	D²PAK

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