POWER ELECTRONICS EUROPE

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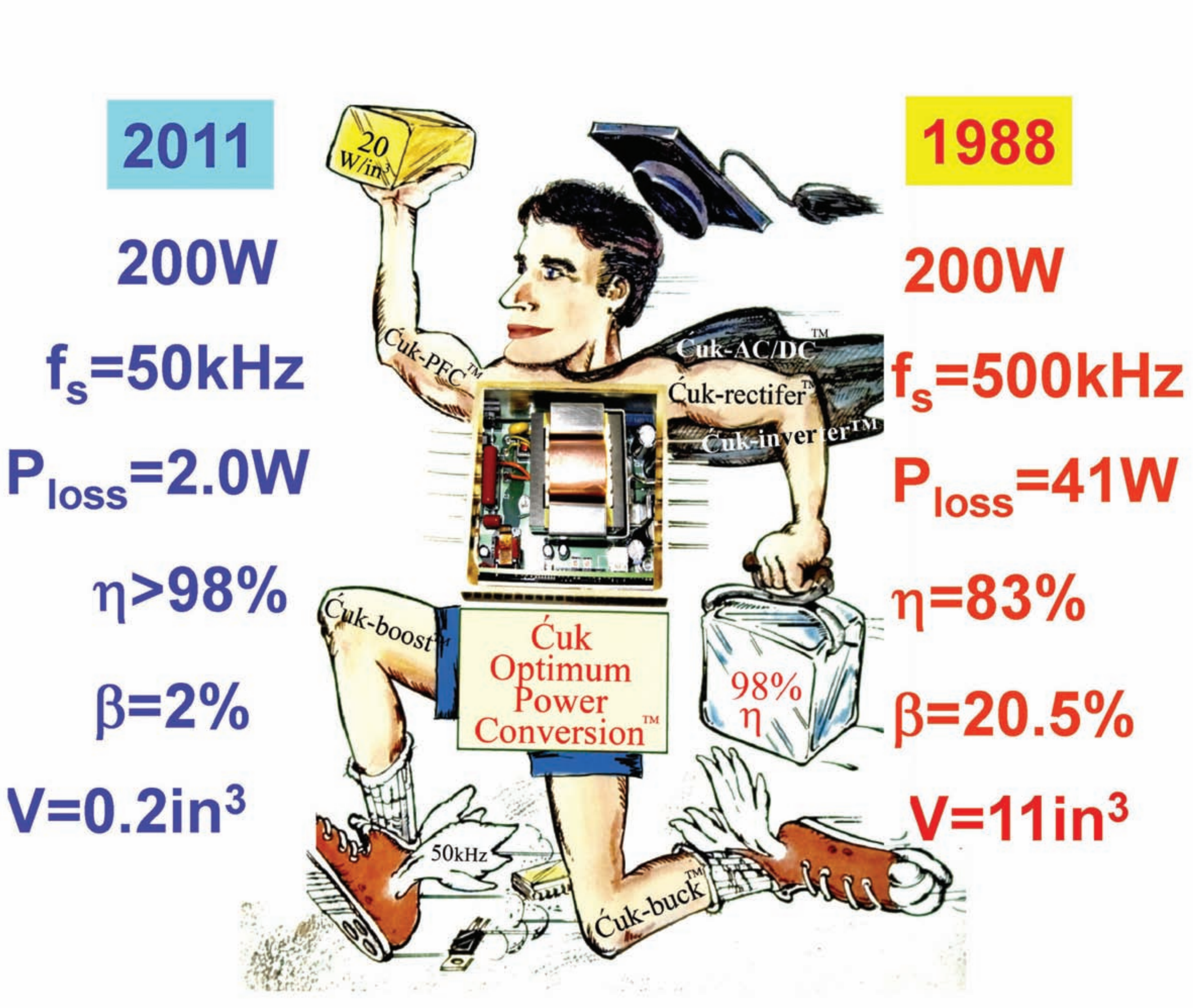
POWER CONVERTERS

98% Efficient Single-Stage AC/DC Converter Topologies



THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

Also inside this issue

Voltage & current range

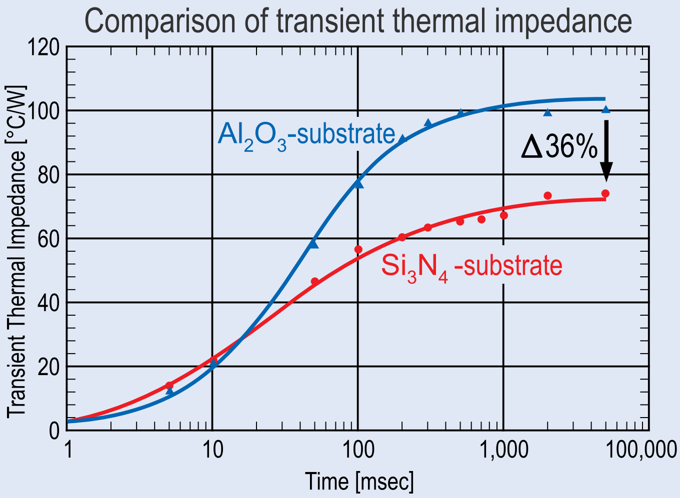
I_C	1200V	1700V
225A	●	●
300A	●	●
450A	●	●
550A		●
600A	●	

SiN-DCB & thicker Cu pattern

Lower thermal impedance
Higher bending strength & fracture toughness

Higher thermal cycling capability
Higher reliability

- $T_{j\,(op)}$ = 150°C continuous operation
- $T_{j\,(max)}$ = 175°C
- New solder material for higher reliability
- Low switching losses & low over voltage spike



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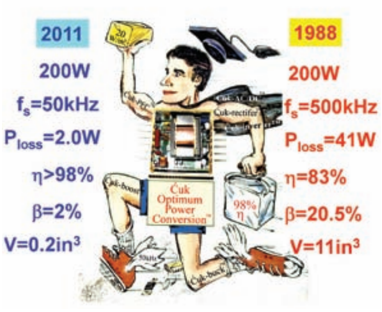
COVER STORY



98% Efficient Single-Stage AC/DC Converter Topologies

The goal of developing AC/DC converters with Isolation and Power Factor Correction (PFC) feature in a single power processing stage and without a mandatory full-bridge rectifier has for years eluded power electronics researchers (see Figure 1). Present AC/DC converters operated from a single-phase AC line are based on conventional Pulse Width Modulation (PWM) switching method and process the power through at least three distinct power processing stages: full-bridge rectifier followed by boost PFC converter and another cascaded isolated full-bridge DC/DC converter stage, which together use a total of 14 switches and three magnetic components resulting in corresponding efficiency, size and cost limitations.

The new Hybrid Switching Method enables new Single-Stage AC/DC converter topology, the True Bridgeless PFC Converter consisting of just three switches and a single magnetic component albeit at a much higher efficiency approaching 98% and having a 0.999 power factor and 1.7% total harmonic distortion. Three-Phase Rectifier consisting of three such Single-Phase Rectifiers takes for the first time a full advantage of Tesla's three-phase transmission system to convert constant instantaneous input power of a three-phase system directly to a constant DC output power, albeit isolated at high switching frequency, with near unity power factor (0.999), low total harmonic distortion (1.7%), smaller size and lower cost but at ultra high efficiency of 98%. Full story on page 16

Cover supplied by TESLAco, Irvine, USA

More Power for Renewables

The demand for power electronics is set to increase with the increased usage of electricity. The International Energy Agency anticipates that global energy consumption will increase by over 35% in the next 20 years. About one third of the energy used worldwide is consumed in the form of electricity. This electric power is transmitted over long distances and often a great deal of energy is lost in the process. The intelligent deployment of power semiconductors counteracts this energy loss by enabling energy to be generated, distributed and converted with minimum loss, particularly with the more widespread use of regenerative energies such as Wind and Solar Power in the upcoming Smart Grids.

One of the sub-segments of the Smart Grid is Electromobility. Transportation currently accounts for around 4% of electricity consumption in Germany, all of this is for rail transport, of which 90% is electrified. Vehicles equipped with internal combustion engines are responsible for around 20% of total CO2 emissions worldwide. Given climate change, however, and the increasing difficulty of tapping the earth's remaining oil reserves, researchers and also industry confidently predict the coming of age of the electric automobile. According to Renault in the year 2020 around 10% of automobile production or seven million will be electric vehicles. Electrical vehicles have really to be considered in the global context of electricity production and distribution. Communication between car and infrastructure as well as control of EV charge through optimized strategies are also key issues in order to take advantage as much as possible of a large EV fleet, from a technical point of view but also from an environmental one. This is also a big challenge, especially in the context of emerging smart grids.

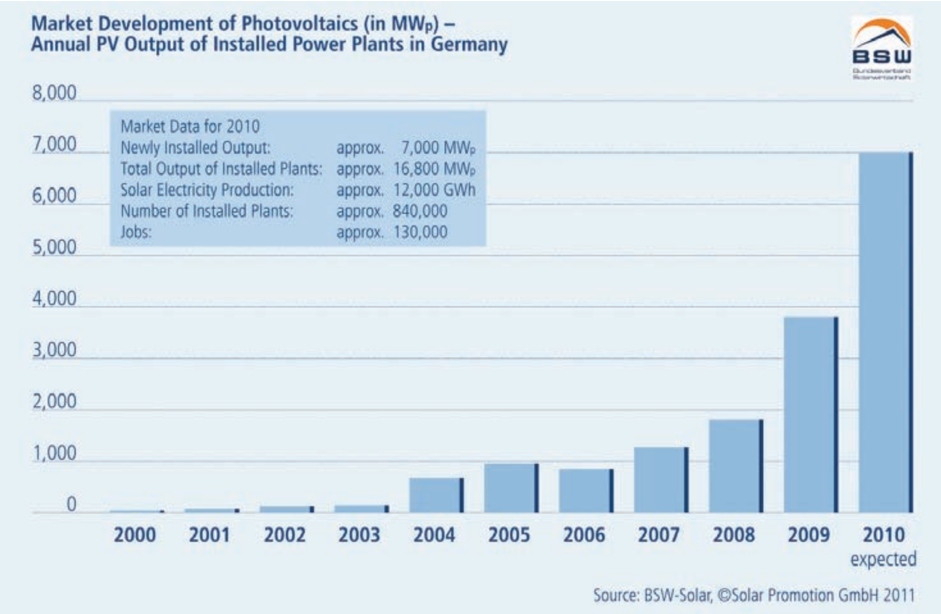
For future electric vehicles, new power electronic systems are required. Here device technologies which can withstand high temperatures such as GaN and SiC are of great interest, said Renault's Patrick Bastard in his keynote at PCIM Europe. GaN and SiC can be used for the power train, because cost decrease for the power system including cooling efforts justifies the application of these more expensive power semiconductors. Additionally, to get rid of rare earth materials for electric motors reluctance motors will be used. Beside low weight and a small volume, low losses and an excellent dynamic behavior are demanded. These requirements cannot be met with conventional converters like 2-level IGBT converters or NPCs. The new Modular High Frequency-Converter (MHF) introduced by Anna Mayer, University of Federal Armed Forces, Munich/Germany in her paper "Control Concept of the Modular High Frequency Converter for Vehicle Applications" which was awarded for PCIM's Young Engineer Award enables essential improvements of these problems. Main points are very high efficiency, ultra light weight and "fault ride through" capability. It is especially suited for future cars with multi-motor drives and integrated power electronics. For the MHF converter a new control concept, based on the modular concept of the hardware, was developed. The paper showed the results of this concept, including the main points dynamic torque control, disturbance on battery voltage, and continued (redundant) operation after defects.

PCIM's Best Paper Award has been given to Sebastian Liebig from Liebherr Electronic (Germany) for his work "Concept and prototyping of an active mains filter for aerospace application". This award sponsored by Power Electronics Europe and SEMIKRON includes a €1000,00 price and invitation to PCIM China 2012. One major topic in aerospace applications is the substitution of hydraulic or pneumatic systems with electrical systems such as electrical environmental condition system. Conventionally, the DC-link voltage is generated using state-of-the-art topologies, most commonly active power factor correction or autotransformer rectifier unit. The active parallel power filter represents an interesting alternative to these topologies, since it has to be designed only for the sum of 5th and 7th harmonic power. The switching of active filter and motor inverter is translated into a voltage spectrum, which results together with impedance matrices in distortion currents. The influence of input and output filters can be calculated by simply adding another two matrices. The full power prototype is being set up with customized SP3-modules from Microsemi using 1700V SiC MOSFET and SiC diode chips (both from Cree). The loss comparison with a 1200V NPT-IGBT in an SP3-module reveals that SiC technology leads to 64% reduced losses at 60 kHz. Even at 100kHz the MOSFET offers a 50% benefit compared to the IGBT at 60kHz. Liebherr Electronic has invested €20,000 in this project.

This was a direct link to PEE's Special Session 'High Frequency Switching Devices and Applications', attracting more than 120 conference delegates. Thus it was the major session on GaN/SiC technologies and devices. Five papers were presented by MicroGaN/Germany, ACOO-IR/USA, Cree/USA, SemiSouth/USA and Infineon-SMA/Austria-Germany. This joint paper presented a new normally-on SiC JFET with monolithically integrated body diode incorporated in a solar inverter. The standard solar inverter based on Silicon switches achieves a maximum efficiency of 98.2%. For the commercial solar inverter equipped with the new SiC JFETs 98.8% system efficiencies can be obtained, SMA pointed out. And this result will push solar technology hopefully further, particularly since Germany has decided to step out of nuclear power.

Achim Scharf
PEE Editor

Intersolar Europe presented the latest Trends in Photovoltaics



At Intersolar Europe in Munich. From June 8-10, 2011, around 2,000 companies showcased the latest trends and developments in solar technology, with photovoltaics once again occupying a large part of the exhibition.

Faced with the environmental challenges that go hand in hand with supplying energy to an increasing global population, numerous incentive programs across the globe have emerged for developing renewable energy - most recently in India and China. At the same time, the German feed-in tariff is falling. Therefore, researchers and industry are working against the clock to achieve grid parity - the point at which electricity from photovoltaic installations can be sold at a competitive price.

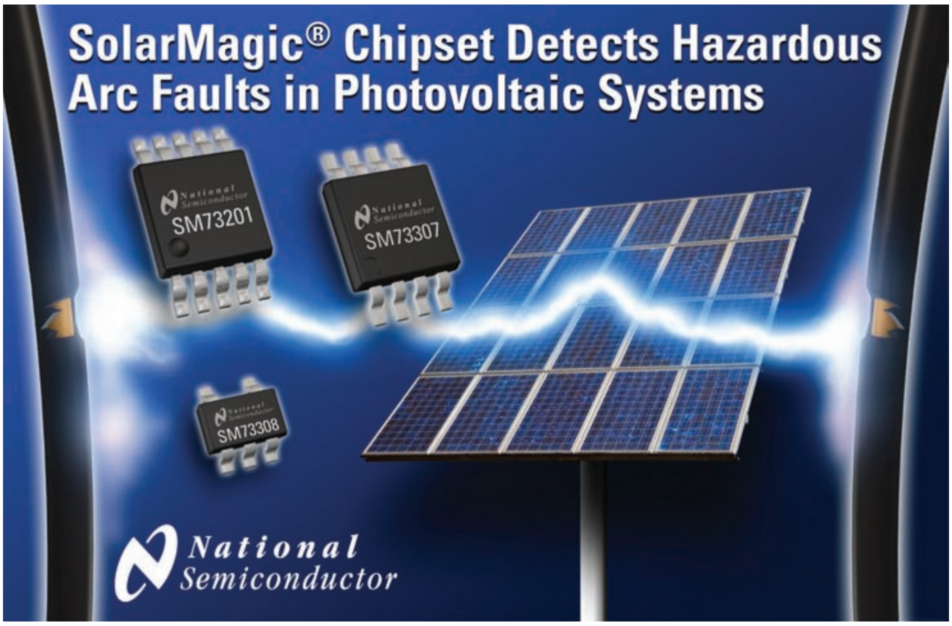
The last 20 years have witnessed some irrefutable technological advances in photovoltaics. In 1989, the world record for the efficiency of multicrystalline silicon solar cells stood at 14.5%. In 2004, this rose to 17.7% and the 20% mark is already in sight for 2011. Developments in this field are first and foremost thanks to improved production methods. For example, improved silicon crystallization processes in modern plants can alone raise module efficiency by at least 0.4%. In addition to developments in the field of crystalline silicon solar cells, an array of alternative systems, particularly thin-film technologies based on CIS/CIGS, cadmium telluride and the new copper zinc tin sulfide (CZTS) is available.

The rise in solar module efficiency is particularly encouraging. As recently as February, researchers at Fraunhofer Institute for Solar Energy Systems ISE (Freiburg/Germany) posted a new record for the efficiency of large-area, easy-to-manufacture silicon solar cells, reaching 19.3% - these cells could soon emerge on the market. Researchers are pursuing different avenues to increase solar cell efficiency. Selecting optimal silicon material and developing new innovative production methods and technologies both play their role in boosting efficiency. Such methods include improving emitters, for example, which collect the electric charge carriers. This was also the approach adopted by researchers at Fraunhofer ISE, who developed an aluminum-doped emitter for their record breaking module. Nanotechnology and pioneering laser processing techniques, which are used for example in optimizing the rear surface structure of the solar cell, are also paving the way for innovative and highly efficient systems.

Some of the power semiconductor vendors took the opportunity to demonstrate their latest developments for photovoltaic applications.

National Semiconductor (**www.national.com**) demonstrated the SolarMagic PV Safety System. "Comprised of analog front-end integrated circuits and multi-band dynamic filtering firmware, the PV safety system is the first commercially-dedicated chipset to detect hazardous DC arc faults in PV systems", commented Business Development Manager Mike Polacek. The demonstration featured an interactive arc fault generation and shut down of a PV panel simulated in an operational string. The SolarMagic RF Communications System reference design showcased a low-cost RF bi-directional communication scheme that enables per panel monitoring and safety shutdown in a PV system. The remote shutdown can be used during installation, maintenance or emergency situations to stop powering the PV system. The SM3320-BATT-EV charge controller finally provides maximum charge current using MPPT control methodology from a PV module. The demonstration will highlighted the quick-charge capability of a 12V lead acid battery with state-of-charge indicator and auto shut-off.

www.intersolar.de



Solar Impulse Supports Clean Energy for Europe

The Solar Impulse team has concluded by end of May a week of meetings with European political authorities, based around the solar aircraft, to promote new technology and renewable energy with the aim of reducing dependence on fossil fuels.

Solar Impulse has achieved some important objectives on its first European flight to Brussels, where it was a guest under the patronage of the President of the European Parliament, the President of the European Council, and of the European Commission. "This solar plane is an extraordinary example of what can be done with stored energy. "The welcome in Brussels is a great source of motivation for the team as we enter the next phase of the project which involves building a second plane to circumnavigate the globe", commented André Borschberg, CEO of Solar Impulse.

"This week revealed the European authorities' willingness to set ambitious energy and environmental objectives despite resistance from certain quarters", declared Bertrand Piccard, project initiator and chairman of Solar Impulse. "The solar aircraft demonstrates that alternatives exist and I am convinced that it will contribute to shaping the future by its very example. Presenting it at the heart of the European institutions provides members of parliament with a concrete example as motivation", said Jo Leinen, President of the Committee on the Environment. Jerzy Buzek, President of the European Parliament, made the point that it is possible to innovate while using existing technology, "for example by developing more efficient and cheaper solar panels linked to better batteries. This sort of progress will enable reductions in CO_2 emissions while preserving economic development. That is what your project expresses. Your plane is a technological marvel; it is also the result of an exemplary European collaboration."

André Borschberg will fly the HB-SIA to Paris where Solar Impulse will be a special guest at the International Air and Space Show in Paris-Le Bourget from 20-26 June. Solar Impulse HB-SIA, the first aeroplane designed to fly day and night without requiring fuel and without producing carbon emissions, demonstrates the enormous potential held by new technologies in terms of energy savings and renewable energy production. Seven years of intensive work, calculations and tests by a team of 70 people and 80 partners have contributed to producing this revolutionary carbon fibre aeroplane, with a wingspan as wide as that of an Airbus A340 (63.4m) and a weight equivalent to that of an average family car. It is the largest aeroplane of its weight ever to have been built. The 12,000 solar cells integrated into the wing supply four electric motors (maximum power 10CV each) with renewable energy and charge the 400kg lithium polymer batteries during the day, enabling the aircraft to fly at night.

www.solarimpulse.com

HB-SIA has a wingspan of 63.4m, 12,000 solar cells are integrated into the wing to supply four electric motors

Low Lead Times for Power Semiconductors

Advanced Power Electronics Corporation has become a leading supplier of MOS power discretes, IGBTs and Power ICs which enable cost-effective efficient solutions for new and existing power applications. The company targets the computing, consumer electronics, display, communications and industrial segments with competitively pricing and lower lead times in particular.

"We have been successful, trading profitably since our inception in 1998 - even through the recession - so, recognizing the cyclical nature of our business, we have made strategic investments and agreements with our manufacturing partners in Taiwan. Therefore, where other makers have seen shortages and price increases we have been able to maintain attractive lead times and pricing, even during periods of tight supply", said Ralph Waggitt, CEO, Advanced Power Electronics Corp. (USA) at PCIM.

As example the company's AP98T07GP-HF-3 range of power MOSFETs is available on short leadtimes of just eight weeks compared to an industry norm of 12-14 weeks. Available in the popular industry standard TO-220 package as a pin-to-pin, drop-in replacement and upgrade, the new parts have a low on-resistance of 4.5mΩ maximum, delivering high efficiency for DC/DC conversion and motor drives. Applications include point-of-load DC/DC conversion, synchronous rectifiers, electric vehicles and battery-powered tooling. The new AP1RA03GMT-HF-3 devices feature on-resistance of 1.59mΩ maximum, are simple to drive and feature a very low gate charge enabling fast switching.

Targeted at applications such as point-of-load DC/DC conversion in motherboards, notebook computers, servers, DC/DC modules, inverters, battery chargers, the new MOSFETs are available in RoHS-compliant, halogen-free packaging. The company's low profile PMPAK® 5x6mm package is specially designed for DC/DC applications and combines an industry-standard SO-8 footprint with a heatsink mounted on the underside for improved thermal performance.

www.a-powerusa.com

"Short lead times and competitively pricing, that is our business model", said Ralph Waggitt, CEO Advanced Power Electronics Corp. (USA)

EPE 2011 and ECPE SiC User Forum

The EPE 2011 conference (August 30 to September 1) is co-sponsored by the EPE Association and IEEE-PELS and will be held in the International Convention Centre of Birmingham/UK. Right after ECPE`s 4th SiC & GaN User Forum will take place.

Efficient energy usage and increased generation of electricity from renewable sources are the main concerns for today's society. Power electronics systems and adjustable speed drives, also referred to as Energy Conversion and Conditioning Technologies (ECCT) are the enabling and often only possible technologies to help us facing those challenges. All fields of the electrical world will be affected by the needed change, starting from the generation of clean, CO_2-neutral electrical energy, up to the most remote applications, in industry, households, transport systems and portable applications. To fit this changing environment, the EPE 2011 conference will highlighting smart grids and the integration of renewable energy, the automotive and the aerospace industry. The motto of this year's conference will be **'Power Electronics and Adjustable Speed Drives:Towards the 20-20-20 Target!'**

The ECPE SiC & GaN User Forum 2011 **'Potential of Wide Bandgap Semiconductors in Power Electronic Applications'** will take place right after EPE conference. Prof. Andreas Lindemann (Magdeburg University, Germany) will chair the event together with Prof. Phil A. Mawby (University of Warwick) and Thomas Harder (ECPE). This ECPE User Forum will focus on typical power electronic systems, in which the use of wide bandgap semiconductors is highly promising. Application examples will come from electric drives including converters for transportation and power supplies including inverters for renewable energy. Additionally, insights in recent SiC and GaN material and device technology - which is the base for future system development - will be given. International renowned experts have been invited to give an overview in keynotes. The SiC & GaN User Forum is this way intended as a platform to share experience and ideas, to discuss and find out which power electronic systems are predestinated for usage of wide bandgap devices and how to appropriately design-in those novel, almost ideal but also challenging components.

www.epe2011.com, www.ecpe.org

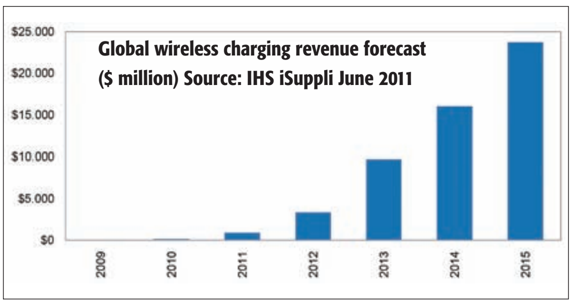
Wireless Charging Market Soars in 2011

Consumers weary of the tangled cords and cumbersome adapters that come with their portable electronics devices are turning to wireless charging devices, which will help revenue from shipments of such products to surge by an astonishing 600% in 2011, according to new IHS iSuppli research.

The wireless charging market is set to soar this year to $885 million, up more than sevenfold from $123 million in 2010. The massive upsurge this year of wireless charging will dwarf the market's 60% expansion attained in 2010, the first year of meaningful growth for the space, and also will tower above next year's sizable 275% increase. Growth then will begin to taper off, slowing to a still-robust 48% in 2015 when revenue hits around $24 billion. "Wireless charging offers a viable alternative to recharge electronic devices without the need for dedicated power adapters. With the appeal of such solutions, companies are lining up to offer wireless charging despite various technological and standardization issues slowing mass-market adoption", said senior analyst Tina Teng. "Given the projected growth for the space, wireless charging devices will continue to make their way into an array of products, including mobile phones, portable media players, digital still cameras and mobile PCs, although penetration at the moment remains miniscule for all sectors".

Among the products, mobile phones will contribute the largest share of revenue to wireless charging, not only because of the large volume of mobile devices expected to benefit from the technology, but also because of participation by name brands in manufacturing, providing much-needed market recognition in the process. Of the four current wireless charging technologies in place today, inductive coupling is the most widely adopted. Other wireless charging technologies include conductive, near-field magnetic resistance and far-field magnetic resonance. A common goal of the wireless charging industry also is to provide greener, more environmentally friendly solutions. A universal solution not only will fit the power profiles of various devices, the solution itself will be intelligent, shutting down a device automatically after it is fully charged, not wasting power when no transmitters are detected on the surface, and flexible enough to be placed anywhere on a charging pad.

Until the industry finds a standard to follow, the wireless charging industry will be fragmented, IHS maintains, and consumers will hesitate to embrace any solution that might not be promoted in the long term. On the other hand, an open, standardized system will create a healthier competitive environment and prompt manufacturers to join forces, which will enhance consumer awareness and lead to adoption in the markets.



Global wireless charging revenue forecast ($ million) Source: IHS iSuppli June 2011

www.isuppli.com

Best PCIM Ever

PCIM 2011 from May 17 - 19 attracted more than 730 conference delegates (2010: 619), 6600 exhibition visitors and 298 exhibitors with additionally 67 represented companies. With these figures PCIM is growing from year to year (20% in exhibitors,) and among the largest power electronic events worldwide. PCIM Europe 2012 will take place from May 8 -10 again in Nuremberg.

"With these figures this is the best PCIM in history", Mesago's president Udo Weller pointed out. "In particular the increase of conference delegates backs us as the leading power electronics conference in Europe". The economical environment for this year's event couldn't have been better. In 2010 all of the PCIM exhibitors experienced extraordinary growth (+40% and more) after the downturn in 2009 (-24% down to $10 billion for discrete power semiconductors and modules).

And the demand for power electronics is set to increase with the increased usage of electricity. The International Energy Agency (IEA) anticipates that global energy consumption will increase by over 35% in the next 20 years. About one third of the energy used worldwide is consumed in the form of electricity. This electric power is transmitted over long distances and often a great deal of energy is lost in the process. The intelligent deployment of power semiconductors counteracts this energy loss by enabling energy to be generated, distributed and converted with minimum loss. Using these energy-saving chips can also significantly increase the energy efficiency of electronic devices and machinery to secure maximum energy savings. The importance of thrifty energy use is gaining momentum as the world population continues to grow: it represents one of the largest energy resources available.

Awards for outstanding papers

Three Young Engineer Awards (€1000,00 each) have been handed over at the opening ceremony sponsored by ECPE, Infineon Technologies and Mitsubishi Electric.

Anna Mayer, University of Federal Armed Forces, Munich/Germany was awarded for her paper "**Control Concept of the Modular High Frequency Converter for Vehicle Applications**". For future electric vehicles, new power electronic systems are required. Beside low weight and a small volume, low losses and an excellent dynamic behavior are demanded. These requirements cannot be met with conventional converters like 2-level IGBT converters or NPCs. The new Modular High Frequency-Converter (MHF) enables essential improvements of these problems. Main points are very high efficiency, ultra light weight and "fault ride through" capability. It is especially suited for future cars with multi-motor drives and integrated power electronics. For the MHF converter a new control concept, based on the modular concept of the hardware, was developed. The paper showed the results of this concept, including the main points dynamic torque control, disturbance on battery voltage, and continued (redundant) operation after defects.

Hitoshi Uemura, Mitsubishi Electric Japan, received the YEA for the paper "**Optimized design against cosmic ray failure for HVIGBT Modules**". The newly developed HVIGBT has been improved the robustness against cosmic ray induced failure in comparison with conventional IGBT. The key factors are the distribution of electric field strength by LPT structure with optimized carrier lifetime control and minimized crystal defect in silicon by the strengthened gettering during wafer processing. Consequently the SEB failure spot moved from the collector side to emitter side proved by the analysis of the neutron irradiation experiment and investigation of failed HVIGBT chips.

Finally Johannes Kolb, Karlsruhe Institute for Technology, received the YEA with "**A novel control scheme for low frequency operation of the Modular Multilevel Converter**". The paper presented a coherent control strategy for the Modular Multilevel Converter (MMC) which is able to generate output voltages at low frequency. Here the challenge of balancing the capacitor voltages in this operation mode has to be met. The solution consists by the derivation of the decoupled current control on the one hand and the balance of active power on the other hand. The combination of these fundamentals leads to a feedforward control which includes a modulation scheme for balancing the energies in the cells. This approach has been tested in a simulation. The results demonstrate the basic functions and the high quality of the input and output waveforms. A symmetrical energy distribution in the arms is achieved and simultaneously no AC currents occur in the DC source. This technique is qualified to control a

PCIM's Young Engineer (€1000.00) and BEST Paper (€1000.00 + PCIM China trip) Awards were handed over at the opening ceremony by Achim Scharf (PEE, left), Uwe Scheuermann (SEMIKRON), Thomas Harder (ECPE), Sebastian Liebig (BPA), Gourab Majumdar (Mitsubishi), Anna Mayer (YEA), Hitoshi Uemura (YEA), Johannes Kolb (YEA), and Leo Lorenz (Infineon, right)

MMC at low output frequency for feeding a three-phase motor in the start-up period.

The Best Paper Award (BPA) has been given to Sebastian Liebig from Liebherr Electronic (Germany) for his work "**Concept and prototyping of an active mains filter for aerospace application**". This award sponsored by Power Electronics Europe and SEMIKRON includes a €1000,00 price and invitation to PCIM China 2012.

One major topic in aerospace applications is the substitution of hydraulic or pneumatic systems with electrical systems such as electrical environmental condition system (E-ECS). Conventionally, the DC-link voltage is generated using state-of-the-art topologies, most commonly active power factor correction (APFC) or autotransformer rectifier unit (ATRU). The active parallel power filter (APF) represents an interesting alternative to these topologies, since it has to be designed only for the sum of 5th and 7th harmonic power. This promises less weight and volume, which is a crucial topic for all aerospace systems. Due to high supply frequencies, which can vary between 360 and 800Hz, the use of active filters in airplanes is more complex. The current control algorithm has to be robust and accurate during steady state conditions. During frequency steps or ramps, the active filter must remain stable and follow with reasonable compensation performance but without faults or control loss. To ensure that both requirements are met, the control algorithm is split into two main parts - robust reference current generation based on instantaneous power theory and accurate harmonics regulation, which ensures the power quality. For the EMC design, the entire power electronic device is divided into several impedance matrices. The switching of active filter and motor inverter is translated into a voltage spectrum, which results together with impedance matrices in distortion currents. The influence of input and output filters can be calculated by simply adding another two matrices.

The full power prototype is being set up with customized SP3-modules from Microsemi using 1700V SiC MOSFET and SiC diode chips (both from Cree). The loss comparison with a 1200V NPT-IGBT in an SP3-module reveals that SiC technology leads to 64% reduced losses at 60 kHz. Even at 100kHz the MOSFET offers a 50% benefit compared to the IGBT at 60kHz.

Responding to the question why the press is sponsoring the BPA, PEE editor-in-chief Achim Scharf pointed out: "As with PCIM also PEE is a marketplace for information exchange about new technologies and applications and with that we are looking always for developments in power electronics or power systems and support that as best as we can".

GaN and SiC gain great interest

Also in future electric vehicles device technologies which can withstand high temperatures such as GaN and SiC are of great interest. "In the year 2020 around 10% of automobile production or seven million will be electric vehicles. GaN and SiC can be used for the power train, because cost decrease for the power system including cooling efforts justifies the application of these power semiconductors. Additionally, to get rid of rare earth materials for electric motors reluctance motors will be used", said Renault's Director of Advanced Technologies Patrick Bastard in his keynote. Through Renault's partner Nissan SiC power modules made by Rohm are already applied in vehicles.

Thus technical progress will go on in order to improve more and more performances and economics efficiency of electrical vehicles. Furthermore, in addition to technical progress concerning the car itself, it is important to keep in mind that electrical vehicles have really to be considered in the global context of electricity production and distribution. Communication between car and infrastructure as well as control of EV charge through optimized strategies are also key issues in order to take advantage as much as possible of a large EV fleet, from a technical point of view but also from an environmental one. This is also a big challenge, especially in the context of emerging smart grids.

With the acquisition of TranSiC, a Swedish Silicon Carbide (SiC) power transistor company based in Kista, Fairchild Semiconductor (**www.fairchildsemi.com**) widened at PCIM its power semiconductor offering. TranSiC's high gain SiC bipolar devices are suited for high-power conversion applications in down-hole drilling, solar inverters, wind-powered inverters, electric and hybrid electric vehicles, industrial drives, UPS and light rail traction applications. These markets are projected by Yole Development to approach $1 billion by 2020. Fairchild is sampling initial 1200V products up to 50A ratings in targeted applications. Future offerings are in development to expand the voltage and current range, and to continue to drive improved energy saving.

"In the year 2020 around 10% of automobile production or seven million will be electric vehicles. GaN and SiC can be used for the powertrain, because cost decrease for the power system including cooling efforts justifies the application of these power semiconductors", said Renault's Patrick Bastard

Thus IMS Research forecasts that all the new activity will push the global market for Silicon Carbide power devices to $100 million in 2011.

PEE's Special Session '**High Frequency Switching Devices and Applications**' was another event for supporting new technologies/ applications attracting more than 120 conference delegates. Thus it was the major session on GaN/SiC technologies and devices. Five papers were presented by MicroGaN/Germany, ACOO-IR/USA, Cree/USA, SemiSouth/USA and Infineon-SMA/Austria-Germany.

The first two papers covered GaN power technology. Especially for mains voltage applications, new efficient 600V class devices are required. These devices are within the main product focus of MicroGaN (**www.microgan.de**). "Two basic elements are developed which will enable the layout of all required power circuits - the power diode and the power switch. Additionally, a unique fabrication technology has been developed to reduce chip area, chip price and device parasitics as well as providing compatibility to standard PCB to be competitive on the market", MicroGaN's Ertugrul Sönmez stated.

The second GaN paper by ACOO-IR (**www.irf.com**) described the evolution of this technology up to 600V and possibly beyond. Device ruggedness in application conditions must remain uncompromised with respect to expectations established by the incumbent silicon based technology. "Large forward biased safe operating area is an important indication of such robustness and has been demonstrated on GaN 600V prototype devices to 10A at 600V for 100ns. Device stability under accelerated stress conditions for extended periods of time is

PEE's Special Session participants Regine Mallwitz/SMA (left), Ertugrul Sönmez/MicroGaN, Michael Briere/ACOO-IR, Robert Callanan/Cree, Mike Mazzola/SemiSouth, and Gerald Deboy/Infineon Technologies (right)

essential for acceptance in the power electronic community. To date, over 10,000,000 device hours of reliability data has been collected on the low voltage devices released to production by IR in early 2010, with up to 10,000 hours per device. No intrinsic premature device failures have been found to date and parametric stability has been excellent. In addition, initial reliability studies of high voltage GaN based devices have also shown excellent parametric stability to 2000 hours", Michael A. Briere stated.

Cree's (**www.cree.com**) Robert Callanan introduced the new 1.7kV SiC MOSFET which has been used also in the active filter described in PCIM's Best Paper. The demonstrator shows how two of these 1.7kV SiC MOSFETs can easily realize a 10kW, 1kV hard-switched DC/DC converter operating at 32kHz with an efficiency of 97.1% without extensive optimization. Higher efficiency can be achieved through some basic modifications. The modest switching loss of the SiC MOSFET allows higher switching frequencies using hard-switched topologies is definitely possible. This technology enables substantial improvements in size, weight, and efficiency in all aspects of power conversion such as 690V motor drives, auxiliary power converters for traction, solar inverters and wind applications to name a few. This performance utilizing a very simple and robust half-bridge hard-switched topology would be difficult, if not impossible, using Silicon IGBTs.

As SiC devices continue to mature and are integrated in more applications their attractiveness in higher power applications will continue to grow. Thus the need for higher power level, multi-chip power modules must be available packaged in reliable, standard module packages, as shown by Michael Mazzola from SemiSouth (**www.semisouth.com**). However, in order for users to achieve the maximum high speed transients capable with SiC power JFETs at high voltages and currents careful design considerations must be followed for gate drive, wiring, layout, and module parasitic. It is critical to minimize all possible contributors to parasitic inductance within both the power circuit as well as the gate driver that can potentially "ring" with the low device capacitance of the SiC JFET. This concept is not new and is consistent with requirements experienced during the first introduction of the MOSFET. "However, high frequency oscillations experienced during the switching transients of the high-speed normally-off, half-bridge, 1200V, 100A SiC VJFET SP1 module can be significantly reduced and in some cases eliminated with a few strategically placed RC snubbers. This approached allowed for the observation and measurement of record low switching losses of 1.25 mJ at 150°C", Mazzola underlined.

Finally, a joint paper by Infineon and SMA Solar Technology (**www.infineon.com**, **www.sma.de**) presented a new normally-on SiC JFET with monolithically integrated body diode. The device concept achieves ohmic characteristics in forward and reverse direction (when driven in a "synchronous rectification" mode) and extremely low switching losses. It shows a nearly zero reverse recovery performance of its monolithically body diode.

Safety requirements can be fulfilled by combining the direct driven normally-on SiC JFET with a low-voltage MOSFET in a Cascode arrangement. This pair of switches operates like one normally-off switch in critical situations. "The new SiC JFET allows full usage of the integrated body diode. It saves anti-parallel diodes in the topology, which are otherwise required in the case of reactive power", explained Infineon's presenter Gerald Deboy. "The standard inverter based on Si switches achieves a maximum efficiency of 98.2%. For the inverter equipped with the new SiC JFETs 98.8% system efficiencies can be obtained", SMA's Regine Mallwitz pointed out.

The presented papers will be published in this and the following issue.

News from the exhibition

Speaking about recovering from the crisis in 2009, according to local sources Nuremberg-based SEMIKRON (**www.semikron.com**) faced a loss of 30% down to €325 million in 2009. "But we grew by almost 70% in 2010", Head of Product Management Thomas Grashoff underlined. The privately-held company is one of the major power module suppliers and as such a indicator of how the market develops. Wind and solar power as well as automotive were and are the major growth drivers for SEMIKRON as well for the European power electronics industry in general.

At PCIM Semikron introduced a space-saving packaging technology which removes bond wires, solders and thermal paste. The new SKiN Technology is based on a flexible foil and sintered connections, doubling the current density to 3 A/cm^2 compared with 1.5 A/cm^2 achievable with standard wire bond technology. "The converter volume can therefore be reduced by 35%. This reliable and space-saving technology is the optimum solution for vehicle and wind power applications", Grashoff commented.

Wire bonding has been the main method of connecting the chip upper to a DBC substrate for the past 25 years. Wire bonding is not up to the higher current density that technical advances have brought about, meaning reliability is impaired by bond lifting. With the new so-called SkiN packaging, a sintered foil replaces the wire bonds on the chips, and the underside of the chip is sintered to the DBC. This results in better thermal and electrical chip connection, since sintered layers have a lower thermal resistance than

"Our SkiN technology features sintering instead of soldering and a flexible foil instead of bonding resulting in 30% higher current carrying capability and higher reliability by a factor of 10", stated SEMIKRON's Thomas Grashoff

solder equivalents. The sintered foil connects the chip across its entire surface, whereas bond wires connect the chips at the contact points only.

This results in a higher current carrying capacity and 10 times the load cycle capability - unthinkable with the restrictive wire bonding used in power electronics in the past. "We are approaching with SkiN 2 million load cycles to failure compared to 200,000 in standard technology. Thanks to the high load cycle capability higher operating temperatures are possible. Given the move towards new materials such as SiC and GaN, these elevated temperatures can then be fully exploited as well as higher switching frequencies up to 70kHz", Grashoff pointed out. With SKiN technology it is now possible that a 3MW wind power converter can be fit into a single switch cabinet. Another example is a 90kW converter for hybrid and electric vehicles which can be 35% smaller than the smallest converter on the market today.

Vincotech (**www.vincotech.com**), another Germany-based power module maker recently acquired by Mitsubishi Electric, reported growth of 110% in sales of power modules in 2010 and 74% in the first Quarter of 2011. "Since end of December 2010 we are part of Mitsubishi Electric, but we operate independently and stay with Infineon Technologies as main IGBT supplier, though we now have access to Mitsubishi's chips", CEO Joachim Fietz pointed out.

At PCIM Vincotech has introduced power modules equipped with Normally-Off SiC JFETs from SemiSouth. Engineered for highly efficient solar inverters, these new products feature a 1200V dual booster input stage and a 1200V MNPC (1 module per phase) inverter stage housed in a flow0 package with just 12mm assembly height. The modules support highly efficient, three-phase solar inverters ranging up to 30kW combining multiple 10A diodes and 100mΩ JFETs. The on-board, high-frequency DC link capacitors enhance fast-switching, low-inductive designs and help minimize voltage overshoots. Due to the acquisition by Mitsubishi the company announced that it will add the latest Mitsubishi IGBT technology to its range of MiniSKiiP® PIM modules. The new modules ranging from 15A/1200V to 100A/1200V in three different housings. All modules feature a 3-phase input rectifier, a 3-phase output inverter, a brake chopper, and an added thermistor to measure temperatures (PIM topology). Pins match the previous version's array to enable easy upgrading. The modules will also be offered with pre-applied thermal grease. Samples are in the works for September 2011, with serial production slate for Q1 2012. "Our MiniSKiiP business in total makes 20% of our revenues or 200,000 modules quarterly", VP R&D Peter Sontheimer emphasized.

High growth is also expected at Geneva-based LEM (**www.lem.com**) , the leading manufacturer (1,300 employees) of current transducers. "Our guidance for fiscal year 2010/11 is around CHF300 million", said CEO Francois Gabella at PCIM. In 2008/9 LEM reported sales of CHF186 million.

At PCIM LEM has introduced the CTSR family of current transducers for use in a range of safety-critical applications including solar installations. Two transducers in the new series measure AC or DC leakage nominal currents, from values as small as 300 and 600mA RMS, with spectral components up to 9.5kHz. The residual or leakage currents that the CTSR family is designed to measure can arise in fault conditions in a number of industrial or power-generation scenarios. Examples include solar panels that are coupled to an earthed grid, or in failure modes such as a short circuits or earth faults. The connection of a solar panel to the grid raises safety concerns; if a fault occurs there is a potentially serious safety issue around any human in contact with the system. Models with higher nominal current range up to 3A RMS to meet the needs of specific customers can be developed on request. As well as ensuring safety in solar inverter installations, LEM's CTSR range is also suited for a range of applications that includes symmetry fault detection in medium power inverters or failure detection in power sources.

Also International Rectifier (**www.irf.com**) reported impressive figures. Revenues for the third quarter fiscal year 2011 was $296.7 million, a 5.3% increase from $281.7 million in the second quarter

"Since end of December 2010 we are part of Mitsubishi Electric, but we operate independently and stay with Infineon Technologies as main IGBT supplier, though we now have access to Mitsubishi's chips", Vincotech's Joachim Fietz pointed out

fiscal year 2011 and a 22.7% increase from $241.9 million in the third quarter fiscal year 2010. "For the June quarter, we expect revenues of $320 million", CEO Oleg Khaykin stated.

At PCIM the company introduced the AUIR3330S Intelligent Power Switch (IPS) with a proprietary active di/dt control feature that reduces conducted EMI and switching losses to simplify design in automotive motor drive applications. The new 40 V high-side device combines bootstrap regulator, charge pump and high-side driver into a single package. The load can be driven up to 40kHz at 100% duty cycle. Additionally, the IPS features programmable over-current and over-temperature protection required by applications operating in harsh automotive environments such as pumps and fans, and current sensing feedback, a diagnostic function, very low current consumption in sleep mode and ESD protection. "Our new active di/dt control drastically reduces conducted EMI on the input supply without increasing switching losses, enabling a reduction in the size of the EMI filter and the heat sink for more efficient compact motor systems", said Marc Legrain, IR's Executive Director Automotive Product Business Unit.

Fuji Electric Co., Ltd. (**www.fujielectric.com**) and Freescale Semiconductor (**www.freescale.com**) entered into an alliance on IGBT technology and products for HEVs and EVs. Working with Fuji Electric, Freescale will add high-power IGBT products to its existing portfolio of solutions for electronic powertrain applications, market those products to its automotive customers and define and produce new products based on customer input. "We are pleased to work with Freescale on IGBT technology and draw on their automotive capability", commented Kuniaki Yanagisawa, General Manager of Fuji Electric's Electronic Devices Business Headquarters.

SemiSouth (**www.semisouth.com**) launched the TO-247 SDP60S120D 1200V, 60A SiC power Schottky diode, featuring a positive temperature coefficient for ease of paralleling and temperature-independent switching behavior. "The new Schottky diode also exhibits a zero reverse recovery current and zero forward recovery voltage and can replace three paralleled 20A parts reducing power dissipation by over 12% as well as saving space and cost", commentd Dieter Liesabeths, Director of Sales. The company also launched new 45mΩ, 1200 V, normally-on trench SiC power JFETs. These devices target a range of application spaces, including solar inverters, SMPS, induction heating, UPS, wind applications, and motor drives. Featuring a positive temperature coefficient, the SJDP120R045 JFETs also offer fast switching with no 'tail' current - even up to its high 175°C maximum operating temperature in a TO-247 package. The device is also available in bare die form (SJDC120R045) for module partners.

IR's Marc Legrain showing demo board featuring AUIR3330S Intelligent Power Switch with a proprietary active di/dt control feature that reduces conducted EMI and switching losses to simplify design in automotive motor drive applications

Infineon Technologies (**www.infineon.com**) has purchased real estate and manufacturing facilities from the insolvency Qimonda for a total of €100.6 million. The deal covers cleanroom and manufacturing facilities as well as 300mm manufacturing equipment for potential volume processing of thin 300mm power semiconductor wafers. For this purpose a pilot line is set-up at the company's site in Villach/Austria. Some of the new machinery will be used for completion of the pilot line in Villach. About the start and the location of a 300mm volume production the company will decide during the current fiscal year.

At PCIM the company announced the expansion of its Reverse Conducting (RC) 600V IGBT with two new switching power devices that achieve up to 96% efficiency in target applications. The new devices allow design of energy efficient, electric-motor driven consumer appliances that use smaller components and thus have a lower overall cost compared to alternative systems.

Also the 1200V SiC diode portfolio has been extended with 1200V diodes in the new TO-247HC (High Creepage) package. This new package layout is fully compatible with the industry standard TO-247 and can therefore easily be placed in already existing designs, without extra efforts. The higher creepage distance increases the safety margin against the risk of short circuits, especially arcing, which might be triggered by the presence of dust or dirt inside the system. This reduces the need of additional chemical (silicone gel or cream) or mechanical solutions (sheaths or foils) needed to avoid any pollution between the package leads, with all the benefits of a lean and fast manufacturing process.

In higher power ranges Infineon has launched 4.5kV IHV modules combining TrenchSTOP™ and FieldSTOP™ technology and complement the modules in the 3300V and 6500V ranges. While the FieldSTOP structure ensures a significant reduction in switching losses, the TrenchSTOP cell minimizes on-state power losses because of its low saturation voltage. This results in lower losses and reduced cooling requirements, which ultimately decreases the system costs. The advantages of the TrenchSTOP technology furthermore include good ruggedness and short circuit behavior, increased reliability and low electromagnetic interference (EMI). Infineon will sampling the 4.5kV IHV modules for IGBT3/EC3 initially in the IHM-B housing with a storage temperature down to -55°C and an operating temperature up to 150°C by end 2011, and secondly in the highly insulated 6.5kV housing by mid 2012. ABB (**www.abb.com/semiconductors**) presented a newly developed 3.3kV high-temperature module generation rated at 1500A, which combines the dynamic properties of the previous SPT+ version with the 150°C operation capability. This high-temperature operation was previously not possible due to the high leakage currents generated in the IGBTs and the diodes. In the new version the leakage current for the IGBT by optimizing the buffer and anode design results in an overall reduction by at least 30%, while keeping the bipolar gain and therefore also the important dynamic properties similar. The main improvement step has been taken on the diode-side. "Although the radiation lifetime control has been identified being rather prone to leakage current, we were able to reduce the leakage current by at least a factor of 2 by carefully adjusting the irradiation conditions to the newly developed buffered anode doping profile. This anode-design separates the radiation defects generated by the local lifetime control laterally from the space charge region formed during blocking. The challenge has been to maintain the high safe-operating area of the previous diode generation and combine it with the desired high temperature operation. The diode is able to withstand a very high dI/dt of more then 7kA/µs and the peak power is exceeding 5.6MW", explained ABB's speaker Sven Matthias.

98% Efficient Single-Stage AC/DC Converter Topologies

A new Hybrid Switching Method is introduced in this article which for the first time makes possible AC/DC power conversion in a single power processing stage providing both Power Factor Correction and isolation at high switching frequency. This single-phase rectifier is extended to a three-phase rectifier, which for the first time enables direct conversion from three-phase input power to output DC power resulting simultaneously in the highest efficiency and lowest size. **Slobodan Ćuk, President TESLAco, Irvine, USA**

The goal of developing AC/DC converters with Isolation and Power Factor Correction (PFC) feature in a single power processing stage and without a mandatory full-bridge rectifier has for years eluded power electronics researchers (see cover image). Present AC/DC converters operated from a single-phase AC line are based on conventional Pulse Width Modulation (PWM) switching and process the power through at least three distinct power processing stages: full-bridge rectifier followed by boost PFC converter and another cascaded isolated full-bridge DC/DC converter stage, which together use a total of 14 switches and three magnetic components resulting in corresponding efficiency, size and cost limitations.

The new Hybrid Switching Method enables new Single-Stage AC/DC converter topology, the True Bridgeless PFC Converter* consisting of just three switches and a single magnetic component albeit at a much higher efficiency approaching 98%, having a 0.999 power factor and 1.7% total harmonic distortion. Three-Phase Rectifier* consisting of three such Single-Phase Rectifiers* (*US and foreign patents pending) takes for the first time a full advantage of Tesla's three-phase transmission system to convert constant instantaneous input power of a three-phase system directly to a constant DC output power, albeit isolated at high switching frequency, with near unity power factor (0.999), low total harmonic distortion (1.7%), smaller size and lower cost but at ultra high efficiency of 98% [6].

Serbian-American inventor Nikola Tesla in 1879 invented the three-phase) transmission system, which together AC three-phase motors and AC generators enabled a very efficient worldwide electric power transmission and utilization, which is still unsurpassed today. One of the key properties of Tesla's three-phase system is that it consists of three AC voltages each displaced from the other by 120 degrees. When each phase is delivering the current in phase and proportional to its respective AC line voltage (unity power factor operation on each phase), the instantaneous power from each phase is positive (active) and is time varying. Nevertheless, the sum of the powers of all three phases is constant in time (see Figure 1). As this property is available on both three-phase AC generator side and three-phase AC load side there is no electrical energy storage needed in such a three-phase long distance transmission system. Yet, availability of the AC voltages on each side, make possible use of the three phase AC transformers for stepping up the AC voltage on generator side and stepping-down AC voltage on the users load side.

New boost converter topologies

The new Hybrid Switching Method can best be explained by way of an example. Shown in Figure 2a is the Ćuk converter [1,2] modified by the insertion of the current rectifier CR_1 in series with the output inductor which is now designated as L_r where index r signifies a qualitatively changed role of that inductor: from a PWM inductor in Square-Wave switching Ćuk converter to the resonant inductor. The elimination of the PWM inductor also eliminates the inherent step-down conversion characteristic of the Ćuk converter and leaves only its step-up DC voltage gain, albeit with the polarity inversion of the Ćuk converter remaining intact. Thus, the new DC voltage gain is

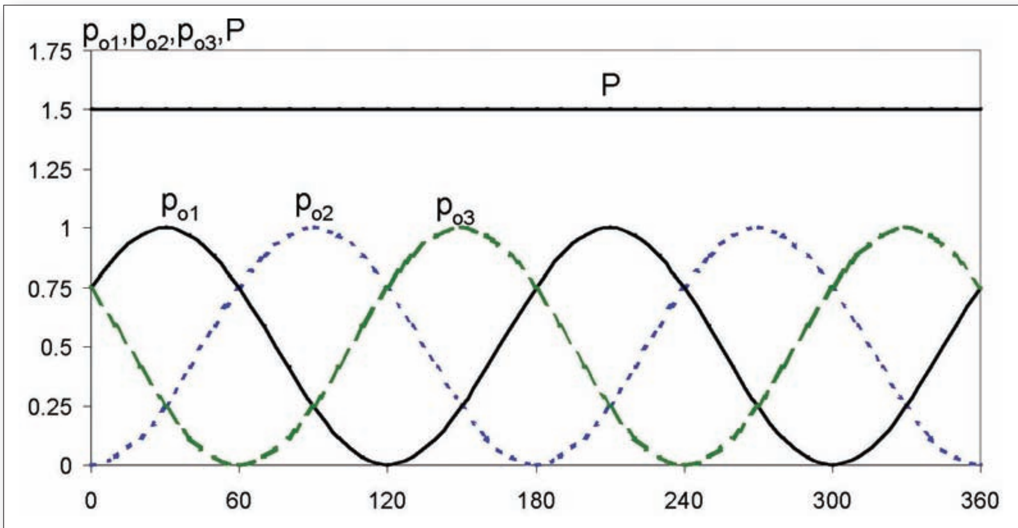


Figure 1: **In Tesla's three-phase system the sum of the power of all three phases is constant in time**

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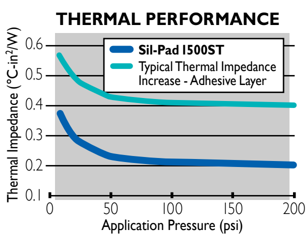

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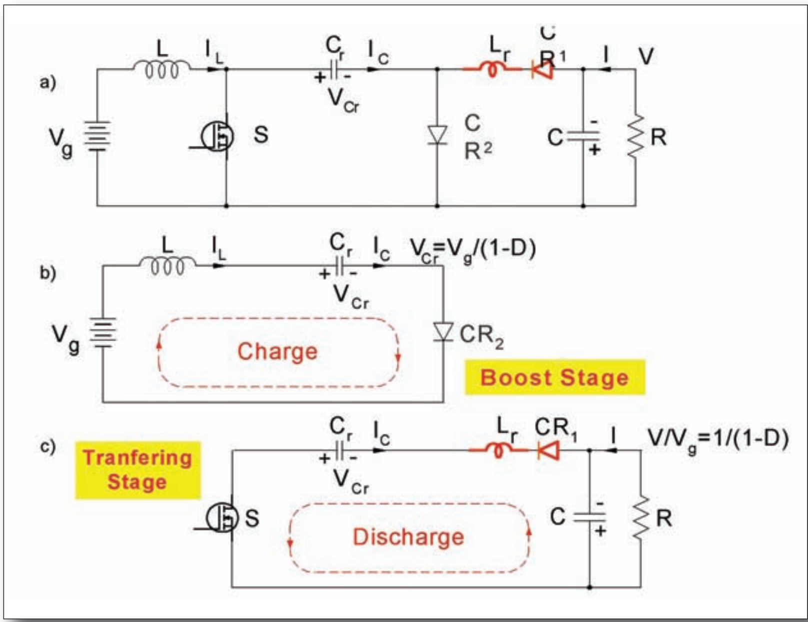


Figure 2: **Hybrid Switching Method with (a) Ćuk converter modified by the insertion of the current rectifier in series with the output inductor, (b) controlling switch S for the boost stage, and at the same time also a controlling switch for the translation stage (c)**

according to equation 1:

$$\frac{V}{V_g} = -\frac{1}{1-D} \qquad (1)$$

Thus, we already obtained a new polarity inverting type of the boost converter, which did not exist before. Let us now examine a more closely the operation of the polarity inverting boost converter. First, it consist of three switches, one active controlling switch S (MOSFET) and two current rectifiers CR_1 and CR_2. This is already in contrast to all existing conventional Square-wave PWM switching converters which explicitly exclude odd number of switches such as 3 in this case, as the switches must come in complementary pairs, hence 2, 4, or more but even number of switches.

Note a dual role of the controlling switch S: it is the controlling switch for the boost stage highlighted in Figure 2b but at the same time also a controlling switch for the translation stage highlighted in Figure 2c. Note also the role of the resonant capacitor C_r connecting two stages, the boost and transferring stage: as an output PWM capacitor of the boost stage charging linearly during the OFF-time interval by the input inductor current source, and as a resonant capacitor discharging resonantly during the subsequent ON-time transferring stage into the load.

Figure 3 shows the resonant circuit model and corresponding resonant capacitor waveform for entire switching period. The instantaneous resonant capacitor voltage is continuous at the switching instants (no jump in voltages at those instances) with a superimposed DC voltage level equal to V_{Cr}. As the resonance of this capacitor is clearly contained exclusively during the ON-time discharging interval DT_s the resonant circuit model imposes that flux balance on the resonant inductor must be fulfilled during this interval alone, resulting in steady-state condition according to equation 2:

$$\int v_{Cr}\,dt = V_{Cr} - V = 0 \qquad (2)$$

This now also puts a spotlight on the significance of the role of the resonant inductor. In its absence, this transfer of charge will be taking place but in a dissipative way thus resulting in much reduced efficiency and in additional spike voltages on switches. The resonant inductor L_r solves both of these problems.

From (2) the resonant capacitor voltage in Figure 3 has a DC voltage V_{Cr} superimposed on the AC ripple voltage Δv_{Cr}. As the output capacitor C is much larger then resonant capacitor C_r their series connection results in a resonant model of Figure 4, which has resonant capacitor C_r only left in the resonant model. Moreover, the net voltage on this resonant capacitor is a ripple voltage Δv_{Cr} as the DC voltages subtract as per (2). The corresponding time domain waveform of the resonant capacitor current is as in Figure 4.

From Figure 2a the capacitor resonant discharge current has a diode CR_1 in the

Figure 3: **Resonant circuit model and corresponding resonant capacitor waveform for the entire switching period**

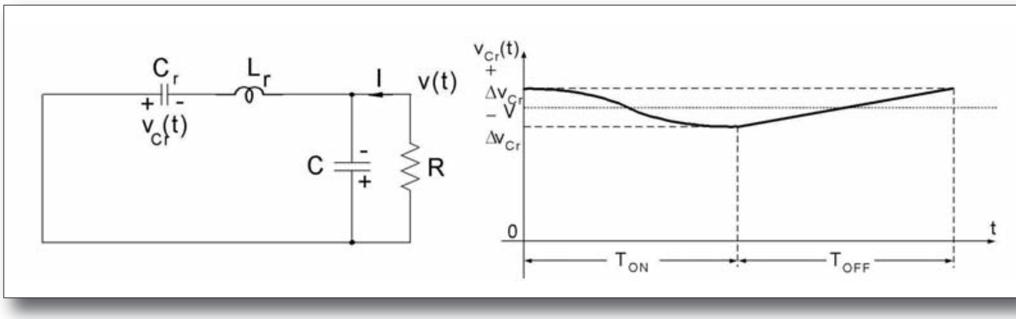
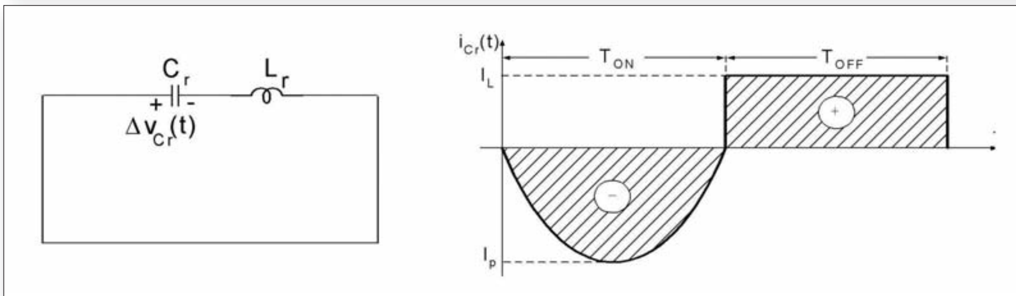


Figure 4: **Corresponding time domain waveform of the resonant capacitor current**



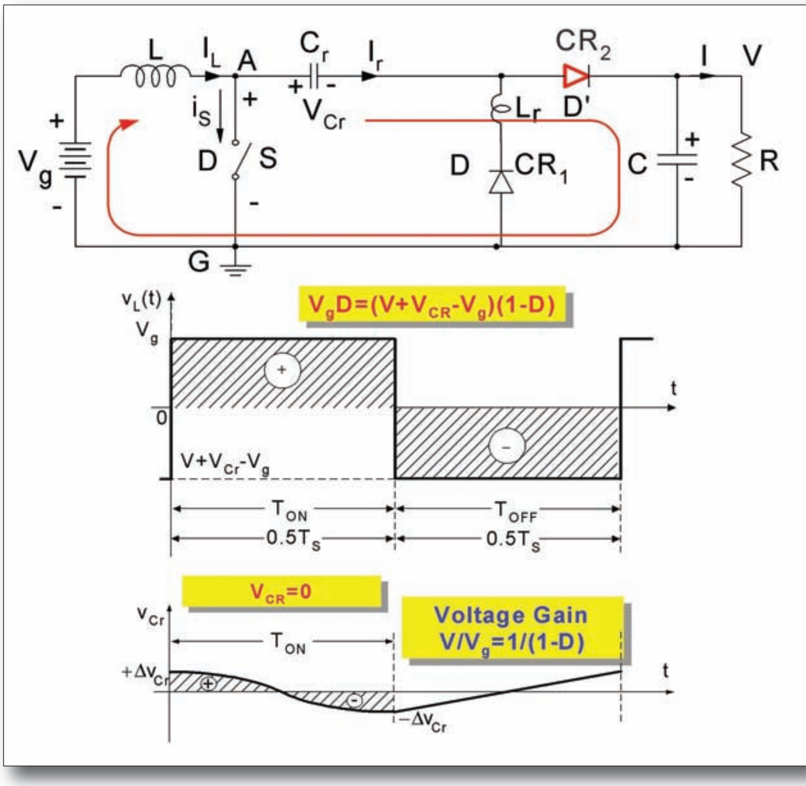


Figure 5: Companion polarity non-inverting boost converter with (a) relocated resonance inductor and (b) flux balance on resonant and PWM inductor

discharge loop. This diode permits only the positive flow of current in the direction dictated by the diode. Moreover, the diode cannot turn-OFF until the resonant inductor current is reduced to zero at the end of ON-time interval, hence resonant capacitor current is also zero as illustrated in the resonant capacitor current waveform in Figure 4. Since the resonant current is full-wave sinusoidal waveform, the resonant capacitor current also must start at zero current level at the beginning of the ON-time interval as illustrated in Figure 4 as well.

From the resonant AC circuit model in Figure 5 the solutions for resonant current and voltage are according to equations 3/4:

$$i_r(t) = I_p \sin(\omega_r t) \quad v_{Cr}(t) = \Delta v_{Cr} \cos(\omega_r t) \quad (3)$$

$$\Delta v_{Cr} = I_p R_N \quad R_N = \sqrt{L_r / C_r} \quad \omega_r = \frac{1}{2\pi\sqrt{L_r C_r}} \quad (4)$$

A companion polarity non-inverting boost converter can be easily obtained by simply inverting the polarity of the two output current rectifiers in Figure 2a and relocating L_r to result in the converter of Figure 5a. Note that current rectifiers are also changing designation since CR_2 rectifier is now conducting during OFF-time interval just as in conventional boost converter. The flux balance on resonant inductor and PWM inductor as shown in Figure 5b results according to equations 5/6 in:

$$V_{Cr} = 0 \quad (5)$$

$$V_g = \frac{1}{1 - D} \quad (6)$$

Yet another converter topology is shown in Figure 6a in which the input voltage source has a negative polarity resulting in positive polarity of the output DC voltage and corresponding AC flux balance shown in shaded areas in Figure 6b. Note that this converter topology is analogous to the original polarity inverting boost topology of Figure 2a but with the source voltage being negative. Therefore the same results as previously derived are obtained for steady-state DC voltages. Note the change of the placement of the resonant inductor to the branch with the rectifier CR_2. As the resonant capacitor ripple voltage Δv_r is an order of magnitude smaller than DC voltage V_r, the flux of the resonant inductor is some 50 times smaller than that of PWM inductor as seen by comparing shaded areas of the PWM inductor and resonant inductor. Clearly this results in resonant inductor physical size and losses being negligible compared to PWM input inductor.

True bridgeless PFC converter topology

Comparison of the converter topologies in Figures 2a/6a reveals that the polarity change of the input source voltage results

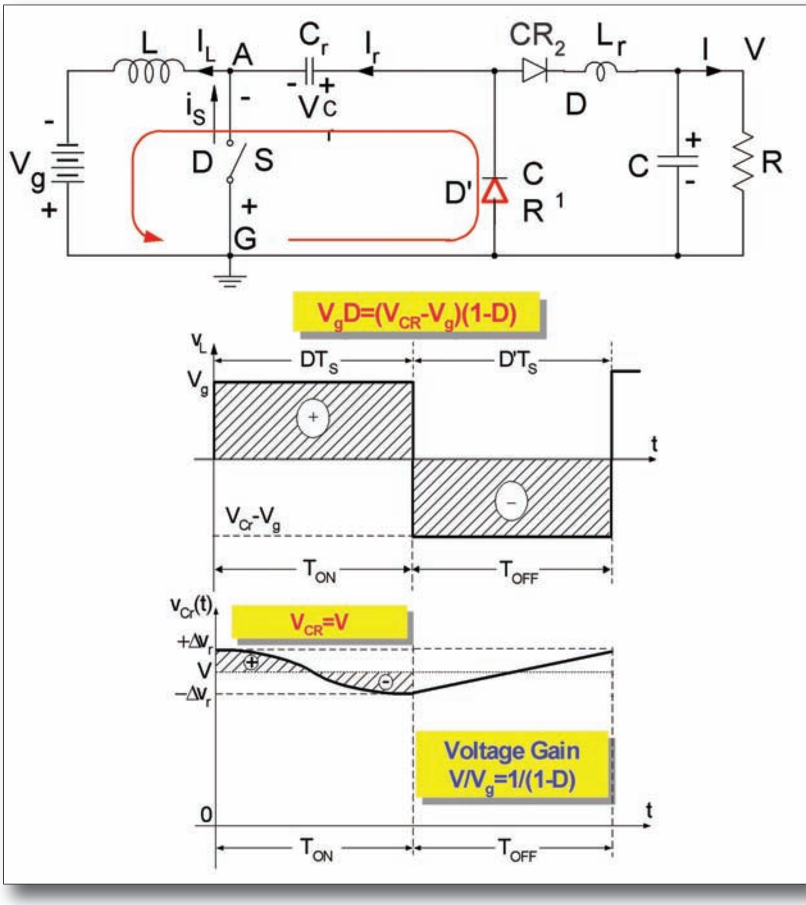


Figure 6: Inverting boost topology of Figure 3a but with the source voltage being negative (a) and AC flux balance shown in shaded areas (b)

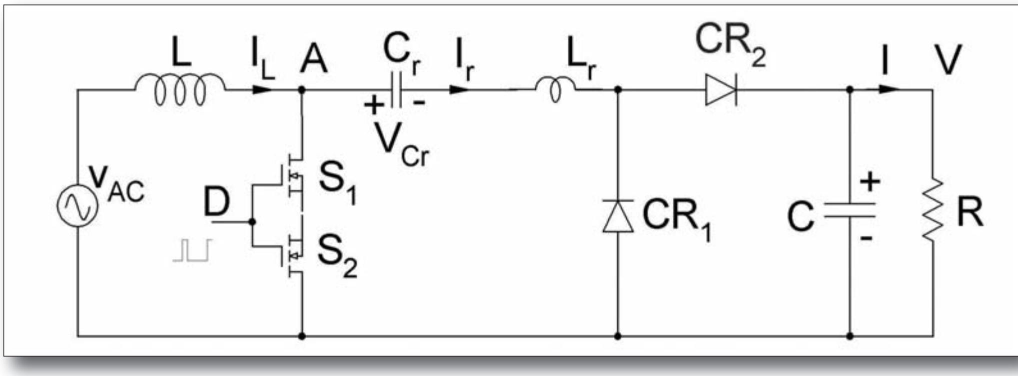


Figure 7: Topologically invariant converter which does not change its structure irrespective of the polarity of the source voltage

in positive and equal output DC voltages given by (1) and (6), respectively. However, only one obstacle remains to make these two topologies invariant relative to the polarity change of the input voltage source and that is switching of the resonant inductor L_r placement from one diode branch to another. This problem can be solved by placing resonant inductor for both cases in branch with the resonant capacitor C_r as illustrated in the converter of Figure 7. This now results in topologically invariant converter of Figure 7, which does not change its structure irrespective of the polarity of the source voltage. Therefore, the source voltage can be an AC voltage v_{AC} which changes its polarity as shown in Figure 7.

Note how the polarity of the input source automatically dictates which of the two rectifiers should be conducting during which interval. Stated alternatively, the full-bridge rectifier on the front end is not needed any more since the new converter topology operates as the first true AC/DC converter with the same DC voltage gain for either polarity of input voltage. As the result we obtained an AC/DC single-stage True Bridgeless PFC converter which can operate directly from the AC line and without front-end bridge rectifier common to conventional PFC boost converters. As the controlling switch S must change its current direction and voltage blocking capability depending on the polarity of the AC line voltage, it is implemented by a series back-to-back connection of two MOSFET switches.

In conventional boost converters there are no good ways to introduce the isolation. The most popular is the Full-Bridge Isolated Boost converter, which consists of four active controlling MOSFET switches on the primary side and four-diode bridge on the secondary side. The isolation transformer in the True Bridgeless PFC converter, however, is introduced in Figure 8 which preserves the original three-switch configuration and other advantageous of the original non-isolated configurations, such as low voltage stresses on all switches.

By controlling the input AC line current (at 50/60Hz) so that it is in phase and

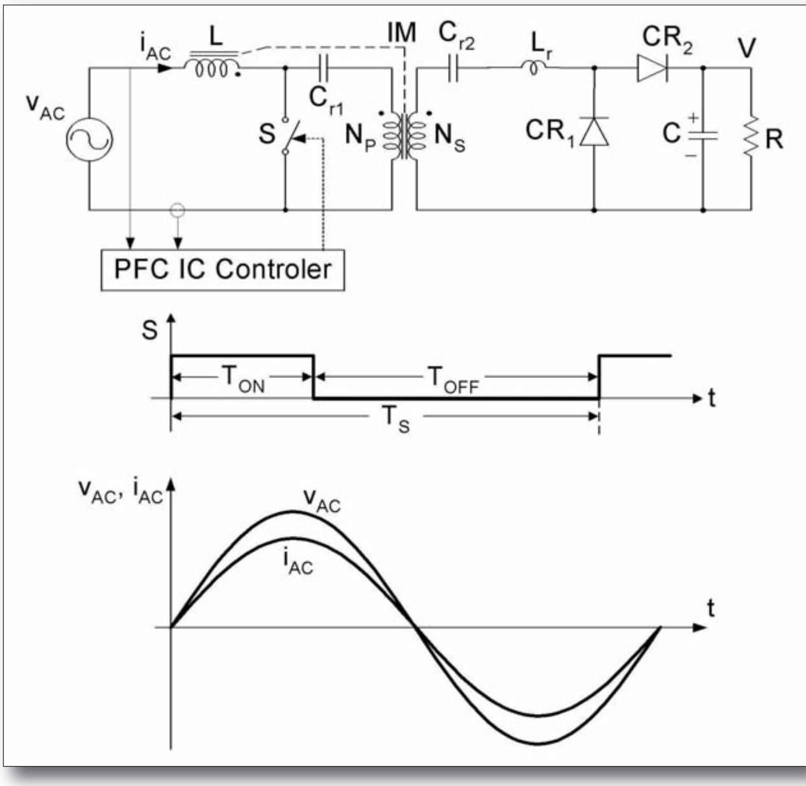


Figure 8: True Bridgeless PFC Converter with isolation

proportional to input AC line voltage (Figure 8), the unity power factor and low total harmonic distortion can be obtained. Note also that the PFC IC controller must also be a True Bridgeless PFC controller, as it needs to accept as its inputs the full-wave AC line voltage and full-wave AC line currents. Current PFC IC controllers, on the other hand have as input rectified AC line voltage and rectified AC line current. These conventional PFC IC controllers could still be used but with additional signal processing circuitry converting full-wave AC voltage and full-wave AC line current into half-rectified ac waveform for use with standard PFC IC controller.

The isolation transformer is of the best kind (single-ended transformer of the Ćuk converter type) having magnetic core with the BH loop as illustrated in Figure 9 with bi-directional flux capability and square-loop characteristic, as there is no DC-bias in the transformer operation. Therefore, the design could be scaled up to high

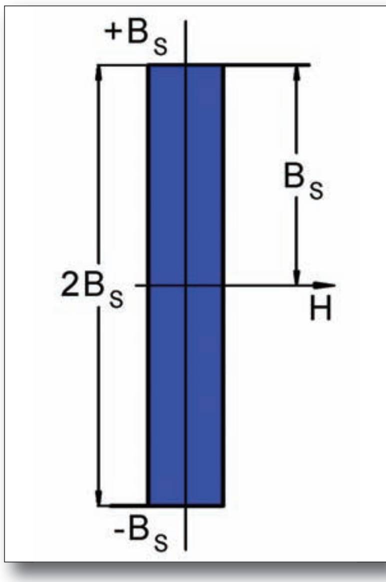


Figure 9: Isolation transformer having magnetic core with bi-directional flux capability and square-loop characteristic

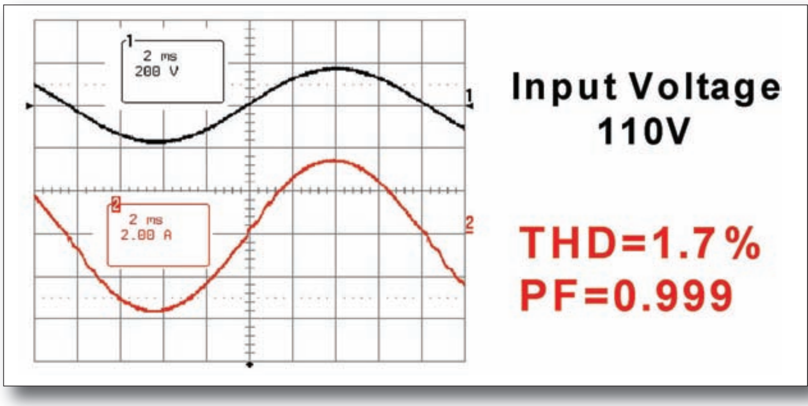


Figure 10: PFC performances measured on the prototype of a 400W, AC/DC Bridgeless PFC converter and the measurement results obtained at 300W power level

power without the degradation of the performance or the large size of magnetic core. In fact, the isolation transformer has AC flux, which is at least four times lower than the flux in, for example, forward converter and bridge-type isolated converters. This directly translates in proportionally reduced size of the magnetics and increased efficiency.

Further improvements are obtained by integration of the input inductor onto a common core with the isolation transformer [1,2,3, 5]. The placement of the air-gap on the magnetic leg with isolation transformer winding results in shifting of the input inductor high switching frequency ripple to the isolation transformer resulting in ripple-free input current as seen in Figure 8 in addition to reduction of magnetics size to one magnetic core only and further efficiency improvements.

The PFC performances is measured on the prototype of a 400W, AC/DC Bridgeless PFC converter and the measurement results obtained at a 300W power level shown in Figure 10 exhibit a low total harmonic distortion of 1.7% and a power factor of 0.999. The efficiency measurements in Figure 11 show near 98% efficiency at high line of 240V AC. Most important is that at 120V AC line (US main) efficiency is also very high (97.2%) as the usual efficiency degradation of 2% to 3% at low line due to the two-diode drops of the front-end bridge rectifiers are eliminated.

Three-Phase Bridgeless Rectifier

All present AC/DC converters are based on the cascade of at least two power processing stages. The first stage converts the three-phase input voltage to intermediate high 400V DC voltage bus by use of 6 or more controllable switches. The second Isolated DC/DC converter stage then provides isolation and conversion to lower DC voltages, such as 48V or 12V. Unfortunately, all present isolated DC/DC converters must store the DC output energy in the form of output filtering inductor carrying DC load current.

The problem lies in the premature rectification of the AC line into an intermediate 400V DC voltage. The instantaneous power delivered to DC load is constant. Therefore, there is no conceptual reason, why the constant instantaneous three-phase input power could not be converted directly into a constant DC output power. The obvious added advantage is that such AC/DC conversion will completely eliminate need for energy storage. Furthermore, the power conversion will take place in a single power processing stage as seen in the new Three-Phase Rectifier illustrated in Figure 12 which consists of three Isolated Bridgeless PFC converters, one for each phase, of the type shown in Figure 8.

Additional important efficiency and size advantages are obtained as well. For example, the total power is delivered through three parallel paths so that each phase processes only one third of total output power. The overall efficiency stays the same at 98% as the efficiency of isolated converters in each phase. Similarly the same low THD distortion and high power factor of 0.999 of each phase is also preserved.

Finally, the instantaneous output currents of each phase are positive and fluctuating in time in sinusoidal manner. However, due to 120-degree displacement of the input line currents of each phase, all fluctuating output currents of each phase add up to constant output current as illustrated in Figure 1. Any remaining ripple current is on the order of 5% of the DC load current and comes at the filtering frequency, which is six times higher than the fundamental 60Hz frequency. This clearly results in much reduced size of filtering capacitors needed, hence in reduced size and cost of the three-phase rectifier.

Alternative isolated bridgeless PFC converter topologies

The converter topology of Figure 8 is not the only True Bridgeless PFC converter topology with isolation. Another Single-stage AC/DC converter topology with PFC and isolation is shown in Figure 13 which can be used either as a Single-phase Rectifier or implemented in converter of Figure 12 as a Three-Phase Rectifier. This converter has the same DC voltage gain of the boost type such as [1] and has only one magnetic piece, the two winding isolation transformer, which does have a DC bias and is therefore

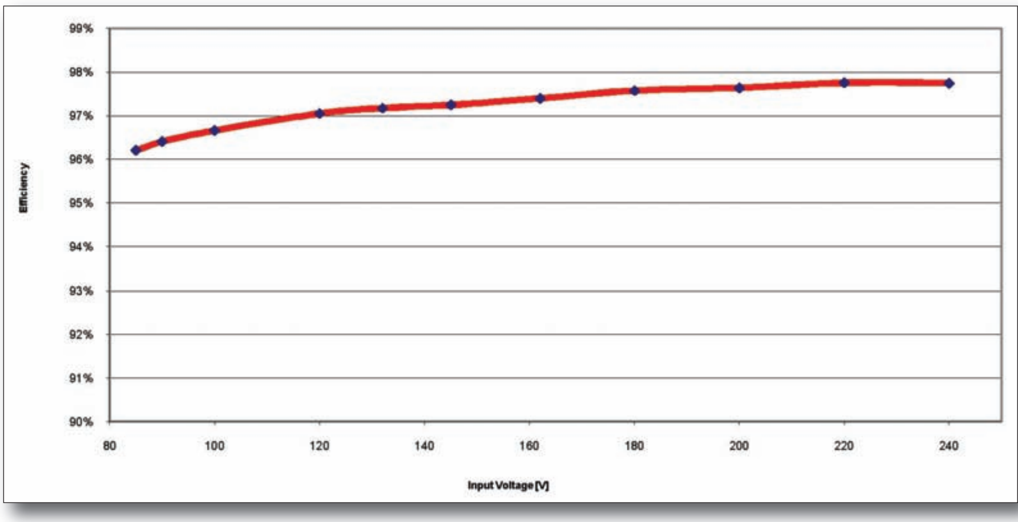


Figure 11: Efficiency measurements show near 98% efficiency at high line of 240V AC

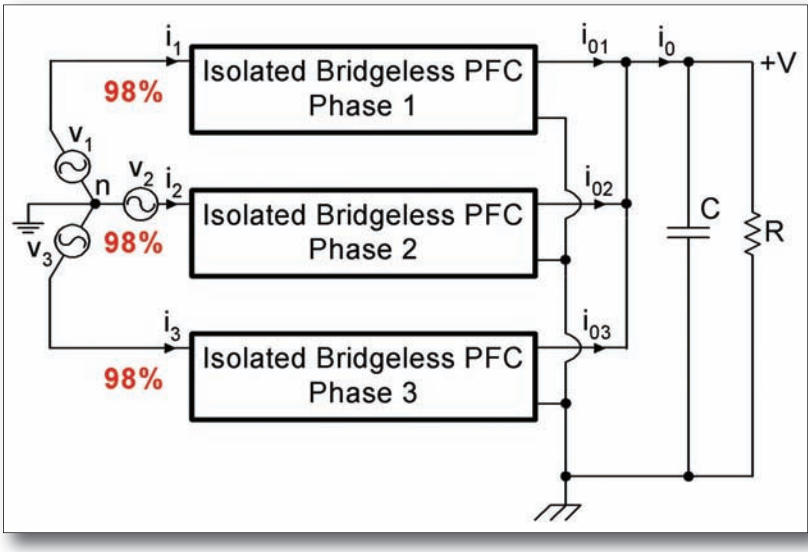


Figure 12: Three-Phase Rectifier consisting of three Isolated Bridgeless PFC converters, one for each phase, of the type shown in Figure 9

suitable for low to medium power. In addition, the input current is pulsating requiring the use of the separate high frequency filter on input to reduce ripple currents at high switching frequency.

The applications above have highlighted the use of the new boost converter topologies, the inverting and non-inverting ones, for a single-stage True Bridgeless AC/DC power conversion and their application for single- and three-phase rectifiers which include galvanic isolation at high switching frequency. However, the new boost converter topologies have also significant advantages when applied to

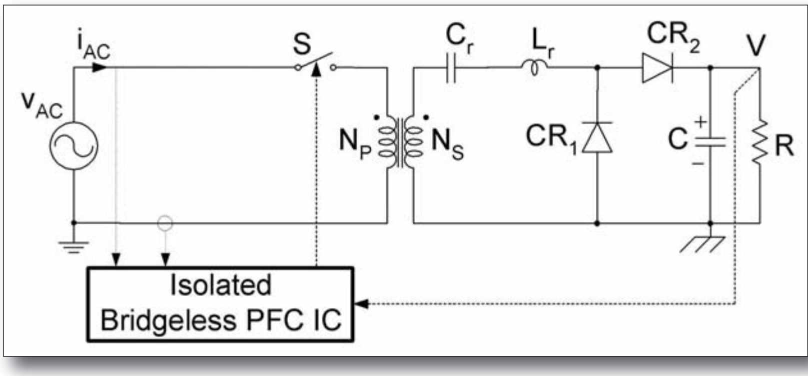


Figure 13: True Bridgeless isolated PFC Converter featuring two winding isolation transformer

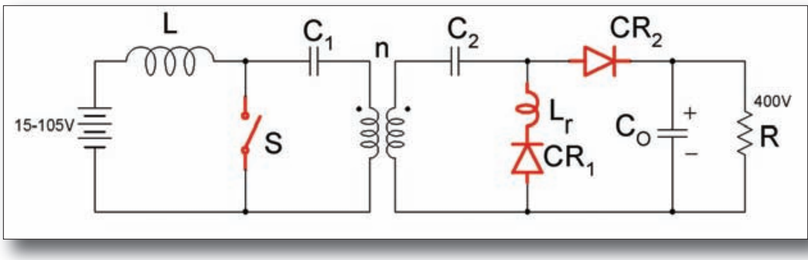


Figure 14: Isolated Boost DC/DC converter for converting solar cell input power into a high voltage 400V DC bus

isolated DC/DC conversion.

Shown in Figure 14 is the new isolated boost DC/DC converter [4] used for converting solar cell input power into a high voltage 400V DC bus. It can accommodate the wide range of the input voltage of 15V to 100V (created by the variation of solar cells voltages during the day) and generate regulated high DC voltage isolated output of 400V with efficiencies of over 97%.

In current automotive applications for hybrid and electric vehicles, the auxiliary 1kW to 2kW converters are needed to convert the 400V battery voltage of the high voltage DC bus to 14V auxiliary battery voltage and vice versa. Therefore a bi-directional buck-boost converter is needed. The converter of Figure 14 implemented with MOSFET switches instead of current rectifiers on the output is capable of such bi-directional power flow in a single power processing stage and is well suited for these applications. Once again, the use of three switches only instead of eight switches of conventional converters results in increased efficiencies and reduced cost at the same time.

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Gallium Nitride for 600V Operation

Especially for mains voltage applications, new efficient 600V class devices are required. These devices are within the main product focus of MicroGaN, as outlined at PCIM. Two basic elements are developed which will enable the layout of all required power circuits: the power diode and the power switch. Additionally, a unique fabrication technology has been developed to reduce chip area, chip price and device parasitics as well as providing compatibility to standard PCB to be competitive on the market. **Ertugrul Sönmez, Ulrich Heinle, Mike Kunze, and Ingo Daumiller, MicroGaN, Ulm, Germany**

Silicon devices are often driven at their physical limits already. In addition, combined with conventional assembly technologies, the established Si based technology is limited to provide solution to these requirements [1]. Therefore, any progress of the power electronics market requires more advanced semiconductor power devices. The required improvements in efficiency of such power circuits may be realized by new approaches only. For this, GaN based power devices are entering the power electronics market [2].

The GaN power HEMT

A lateral HEMT device technology using large area 4-inch as well as 6-inch GaN-on-Silicon wafers is utilized for power device fabrication. In order to reach high area efficient 600V devices, the proprietary 3D-GaN technology is applied. The normally-on HEMT features an output capacitance of about 30pF which leads to an output charge of only 10nC combined with an on-resistance of about 180mΩ (see Figure 1).

The corresponding product of $R_{on} \times Q_{out}$ is to our knowledge unique on the 600V device market. This GaN-HEMT is switched off for control voltage values $V_{GS} < -3V$, whereas the full on-state is reached for values above 0V at around 1V. The specific on-state resistance for the complete chip including all pad areas and even its remaining part of the dicing street is reduced to 570mΩmm², which is only achievable using 3D-GaN technology. It has been developed a technique to fold up the contact electrodes from the lateral area to above active area, including the high potential pad and via technology contacting the appropriate fingers from top (see Figure 2).

The GaN-HEMT has an additional characteristic, which makes its application beneficial: it has no build-in body diode, preventing any delay and charging/discharging losses caused by minority carrier pile up. This allows hard switched high voltage H-bridge applications delivering the additional degree of freedom in setting switching time and frequency to achieve maximum efficiency, load dependently. The very small Gate and Drain charges allows the transistor to be seen as purely voltage controlled device.

Normally-on power switch in ThinPAK

For evaluation purposes, MicroGaN's

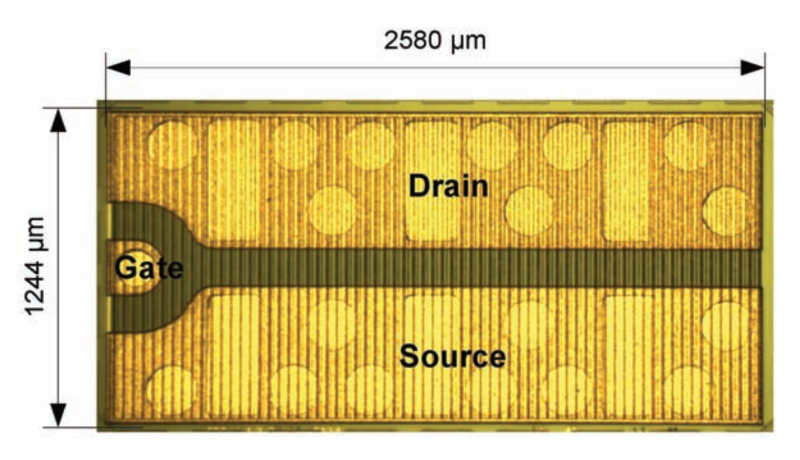

Figure 1: **Extremely area efficient Normally-On 600V 180mΩ GaN-HEMT with R_{on}•A of 570mΩmm²**

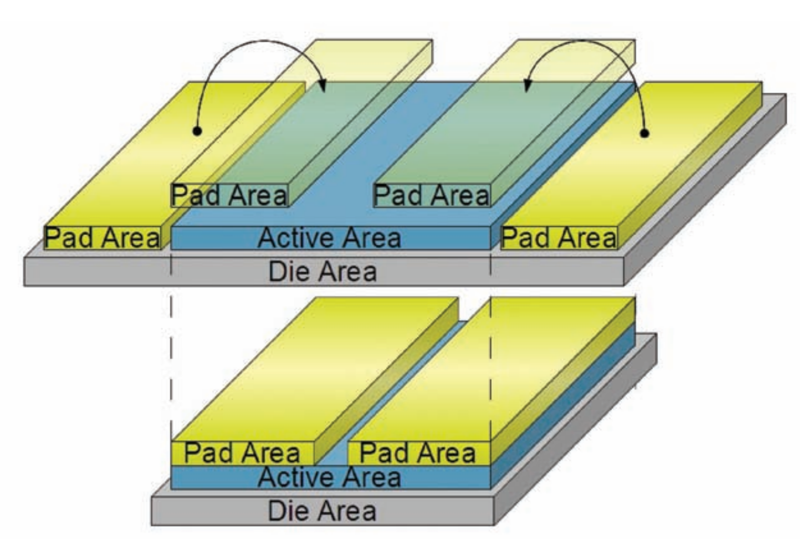

Figure 2: **Schematic of MicroGaN's 3D-GaN Technology**

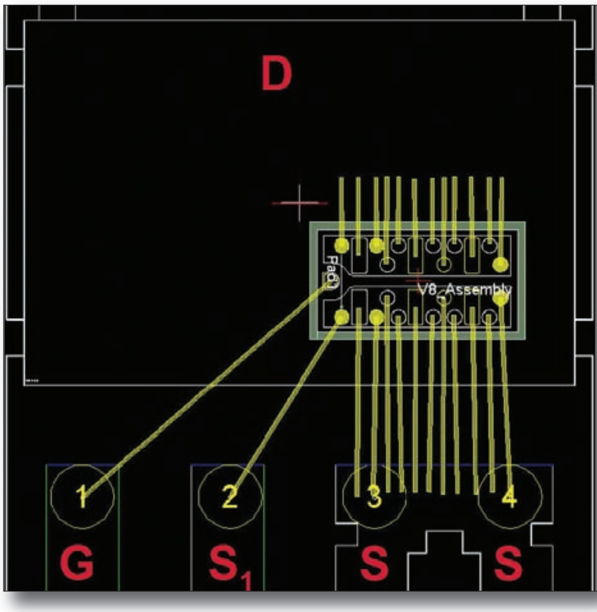

Figure 3: Normally-on power switch in Infineon's 8x8 ThinPAK

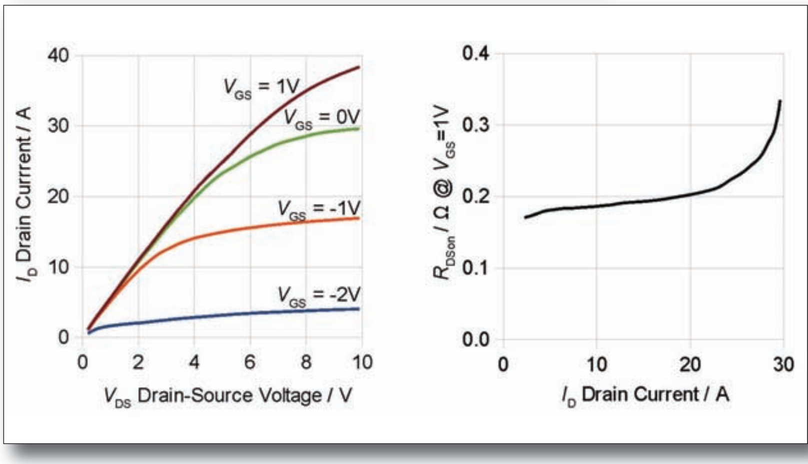

Figure 4: Output characteristics (left) and on-resistance of GaN power HEMT in ThinPAK

lateral HEMT device has been packaged in a 8x8 ThinPAK [3] at Infineon AG. This packaging technology provides low inductive parasitics and thin profile. Figure 3 shows the corresponding bonding diagram, providing an additional sense pin at the device's source electrode for accurate biasing purposes. The output characteristics and the derived on-resistance as a function of the drain current is depicted in Figure 4.

From the measurement results it can be stated that the normally-on HEMT provides an unsaturated current of more than 35A at a Gate bias of 1V, providing a comfortable head room for a 200mΩ-device for surge current levels - not limited by the device's channel properties. For the given R_{DSon} it is also an excellent result to have over 20A drain current range, for which the on-resistance keeps within a 10% deviation.

The promising DC-characteristics are paired with beneficial capacitive characteristics. This is not a straight forward result which may be expected from a material system originally used for RF applications because of the significant influence by the 3D technology approach. Therefore the result already indicates successful optimization of this technology. The input, output and reverse capacitance together with the corresponding output charge and energy are displayed in Figure 5. Here the Input-, Output-, and Reverse-Capacitance of GaN power HEMT in ThinPAK with its corresponding output charge of Q_{OSS} = 17nC and energy E_{OSS} = 3.5µJ at V_{DS} = 400V are shown.

With these values a figure of merit "output-charge • R_{DSon}" value of 3.1nCΩ is achieved leading to an extremely low time constant of 3.1ns. This value is uniquely low for packaged 600V GaN switches and indicates, that hard-switched, high-speed and efficient circuit topologies are feasible using this switch. The combination of the resulting low output energy of E_{OSS}=3.5µJ with the reverse capacitance of 8pF making the miller charge negligible and are to our knowledge unique on the wide bandgap device market.

Low barrier SiGaN power diode

The so-called SiGaN Diode consists of a low voltage (30V) Si-SBD (Schottky Barrier Diode) and a 600V GaN-HEMT (see Figure 6). The resulting behavior of this 2-port circuit is a 600V SBD with a barrier of a low voltage Si-SBD. This in-package hybrid cascade circuit provides a voltage barrier of only 0.3V with a differential resistance of about 200mΩ, which is dominated by the on-resistance of the GaN HEMT.

For the SiGaN diode operated in the reverse direction, the Si-SBD is biased in reverse direction, and also is charged to about -3.5V, which is the switch-off voltage of the HEMT. Up to only this voltage level, the capacitive parasitics of the Si-SBD do play a role. For reverse SiGaN diode voltages higher than -3.5V, the GaN-HEMT switches off and isolates the SiGaN diode cathode from the Si-SBD cathode. Therefore, the high voltage SiGaN diode capacitance and charge are dominated by the low capacitive parasitics of the GaN HEMT.

The resulting I-V and C-V characteristics

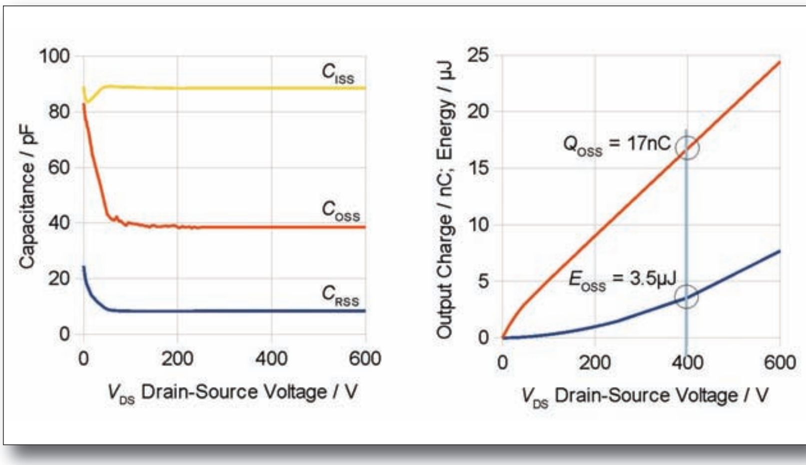

Figure 5: Input-, Output-, and Reverse-Capacitance of GaN power HEMT in ThinPAK (left) with its corresponding output charge

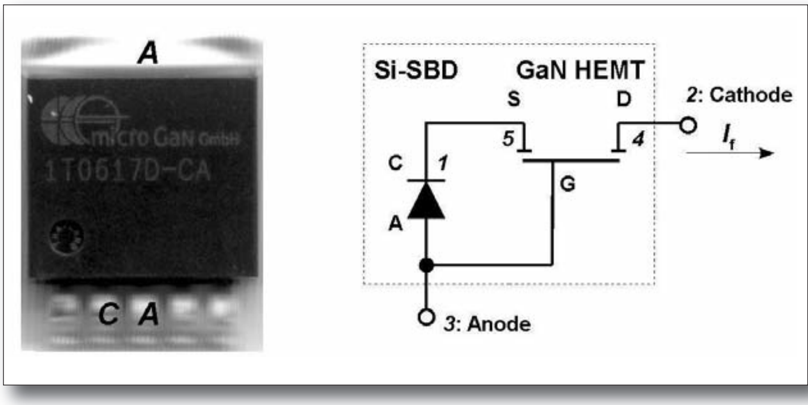

Figure 6: SiGaN Diode - cascade circuit of a low voltage Si-SBD with a high voltage GaN-HEMT

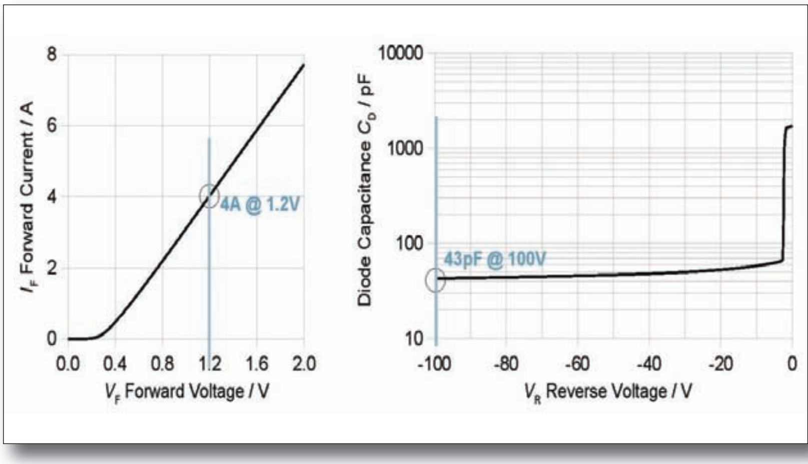

Figure 7: Power Diode forward characteristics showing its typical low on-set voltage of 0.3V (left) and its reverse C-V-Characteristics with the low capacitance of 43pF

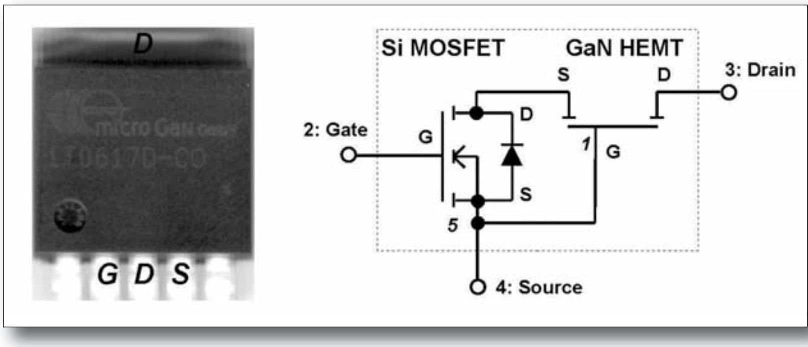

Figure 8: Normally-off power switch by cascode circuit made of a low voltage Si-MOSFET and a high voltage GaN-HEMT

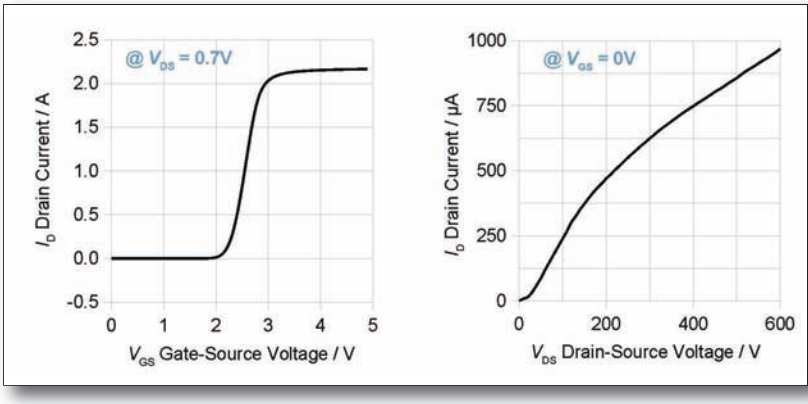

Figure 9: Transfer-characteristics of the cascode using HV GaN-HEMT (left) and its off-state characteristics up to 600V for V_{GS}=0V

of the SiGaN diode are shown in Figure 7, where the described characteristics of the SiGaN diode circuit elements can be located individually. From the SiGaN diodes forward characteristic, the typical low barrier voltage can be extracted as well as the differential resistance of about 200mΩ, resulting in 4A diode current at 1.2V forward voltage. To our knowledge this behavior also is unique for a diode missing minority carrier stored charge with just 18.6nC overall charge. With at least comparable charge values to SiC-SBD one obtains an unbeatable low onset voltage.

From the C-V-characteristics, the GaN HEMT switching off can be seen which isolates the Si-SBD during the measurement: within a few volt sweep the capacitance of the SiGaN diode drops from over 1700pF to about 60pF and reaches a value of just 43pF at -100V.

The application benefit of this cascade is manifold. Used as a PFC-Diode, it will pass current starting already at 0.3V, which gives an excellent tool for wide efficiency bandwidth solutions. The low SiGaN diode charge allows a high switching speed from this device point of view, providing the possibility to go for higher power density designs. Used as a freewheeling diode, it catches the current at already 0.3V, preventing the on-set of the body diode current flow of a Si-600V-HV device. Thus, charging of several µC and a harming recovery time of several hundred ns are prevented.

A normally-off functionality can be derived from a normally-on core unit device by an in-package hybrid cascode circuitry (see Figure 8). The cascode consists of a low voltage (30V) Si-MOSFET in common-source and a high voltage GaN-HEMT in common-gate configuration. The resulting 3-port circuit again acts as a switch. In its on-mode the parasitic on-state resistance of the Si-MOSFET (<20mΩ) and the one of the GaN-HEMT are added to about 320mΩ. The obvious increase above the expected sum value is due to the internal biasing of the GaN HEMT which leads to on-state bias condition slightly below full open channel. In the off-state of the cascode the Si-MOSFET is switching off the GaN-HEMT and is charged to about 3.5V, analog to the SiGaN diode. Here again, the Drain of the GaN-HEMT is defining the 600V behavior of the cascode.

Figure 9 displays the transfer characteristics and the off-state characteristics of the cascode. As expected, the Si-MOSFET defines and controls the drain current of the cascode, which results in an off-state for V_{GS}=0V. The high voltage off-state characteristics reveal the present leakage current level of MicroGaN's normally-on devices of around 900µA at 600V, here measured at V_{GS}=0V.

In the reverse operation mode of the cascode (V_{DS}<0V), the GaN-HEMT is in the on-state as a parasitic resistor (180mΩ) in series to the Si-MOSFET. If the Si-MOSFET is in the off-state, its body diode provides a current path at its characteristic voltage.

By using a cascode, one combines the advantages of the LV Si-MOSFET (usually a high quality body diode, low charge as operated at 3.5V) and these of the GaN-HEMT (high speed, no body diode, lowest possible charge). On the other hand, one has to pay attention to the setup parasitics of the circuit in order to prevent ringing.

The setups of the cascade and cascode are designed carefully to prevent the commonly made error of inductive setup technology ceasing the chip-device from operation at high di/dt in the package.

This cascode is predestinated to be used in hard switched high switching speed PFCs as well as in H-bridge, maintaining the high peak and wide bandwidth in efficiency.

Conclusions

The market demand for high efficient new approaches is discussed using the example of a mains voltage down-conversion and its specific need of high efficient 600V power devices. The basic circuit construction elements - the low barrier (0.3V) power diode and the normally-off power switch - were presented and discussed in detail [4] as they are derived from a unique core unit device: the GaN power HEMT, which has been packaged and tested in a 8x8 ThinPAK by Infineon AG. Next steps will be the transfer of the presented characteristics into their dynamic equivalents and the setup of application demonstration.

As a result, surpassing circuit efficiencies will be possible using the presented elements.

Furthermore, by combining the cascode and cascade, one may obtain an unique pair of design elements for realization of efficient motor drive applications, also.

We would like to acknowledge the fruitful cooperation with Infineon AG, within which MicroGaN's devices have been tested in the framework of the German subsidiary project NeuLand, which is sponsored by the Federal Ministry of Education and Research (BMBF).

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New SiC JFET Boost Performance of Solar Inverters

The article proposes a new normally-on Silicon Carbide (SiC) JFET device concept with monolithically integrated body diode. The new device combines ultra fast switching with ohmic forward characteristic and a zero reverse recovery characteristic of its body diode. It allows a significant boost of the performance of solar inverters especially in the light of new requirements such as reactive power capability and fault ride through. Best device performance is achieved with a direct driven approach, compatible with safety aspects in voltage driven topologies which is implemented in combination with a low voltage MOSFET.

Gerald Deboy, Roland Rupp, Infineon Technologies Austria/Germany, and Regine Mallwitz, Holger Ludwig, SMA Solar Technology, Germany

SiC devices are characterized by a number of promising properties like low switching losses, high rated voltages, high operating temperature, high radiation hardness, which were discussed earlier in [1,2]. In the laboratory the potential of SiC MOSFET and SiC JFETs [2-4] in solar inverters have been demonstrated concerning improvements of efficiency and size reduction. This article focuses on investigation of the new SiC JFET in an already existing photovoltaic (PV) inverter platform. Challenges here are the assessment of the safety risk due to normally-on characteristic combined with the proof of an increased efficiency under the restriction of EMI demands.

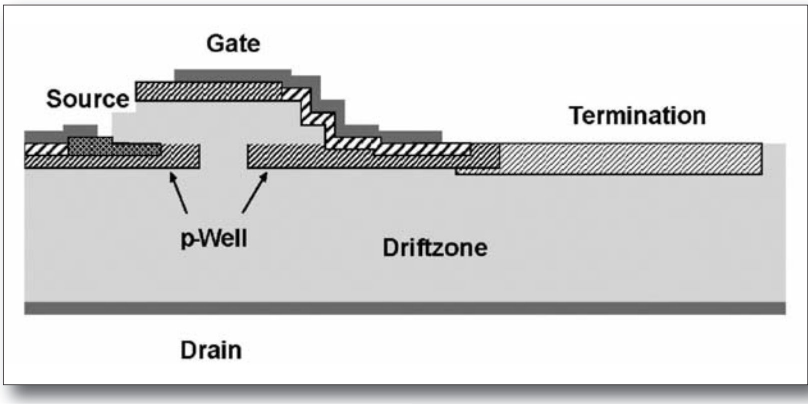

Figure 1: Cross section of the proposed SiC JFET device concept

SiC device concept with integrated body diode

We believe that a JFET structure without a channel being formed below a gate oxide as shown in Figure 1 has strategic advantages over a SiC MOSFET. First, the reliability aspect is easy to meet in a JFET structure but difficult in a MOS structure due to the still high density of extrinsic defects in the oxide. Second, the still unsatisfying subthreshold behavior of MOSFETs at high temperature does not exist in a JFET. This issue is important for the leakage current and may hurt the efficiency of the entire converter. And last but not least the structural elements of a SiC JFET are very close to the structural elements of SiC Schottky barrier diodes, which are selling in millions of pieces with proven quality in the field.

The proposed SiC JFET concept has a bipolar diode integrated between the p-well contacted by source and the backside drain contact. This diode can handle the full current rating of the SiC JFET. Beyond the obvious advantages of driving the JFET in a synchronous rectification manner the body diode is still needed for the dead time between the switching intervals of opposite devices, in an e.g. DC/AC output

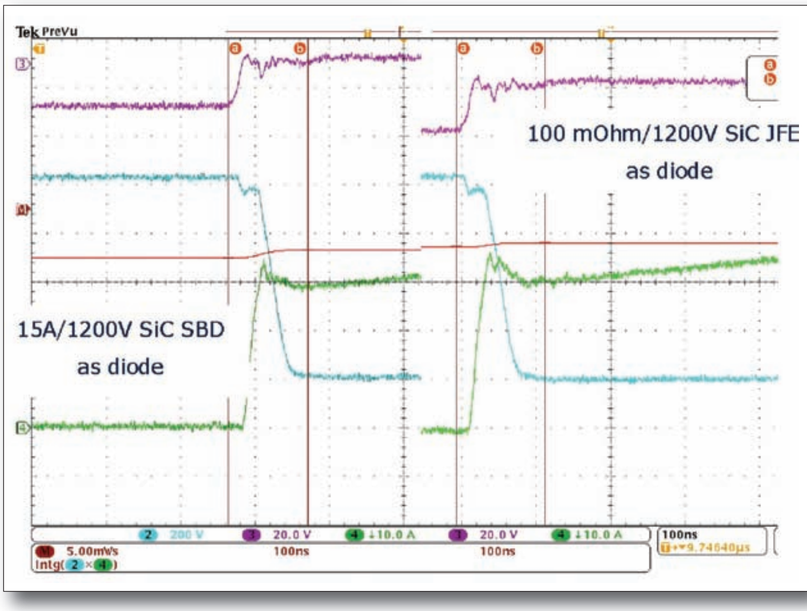

Figure 2: Comparison of hard commutation of the body diode of a 100mΩ/1200V SiC JFET (right) vs the recovery perfomance of a 1200V/15A SiC Schottky barrier diode (left) at load current I_D=30A, V_{DS}=800V, Rg=3Ω; (Channel 2: Drain voltage, Channel 3: Gate voltage, Channel 4: Current; time base 100ns/div)

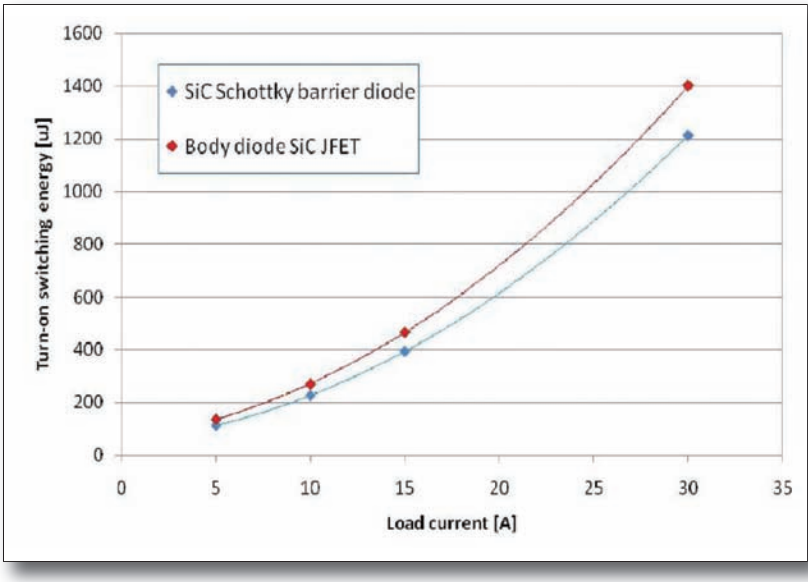

Figure 3: **Comparison of turn-on losses of the new 1200V/100mΩ SiC JFET with a 1200V/15A SiC Schottky barrier diode versus the body diode of the SiC JFET as freewheeling diode at V_{DS}=800V, T_j =75°C, R_g=3Ω**

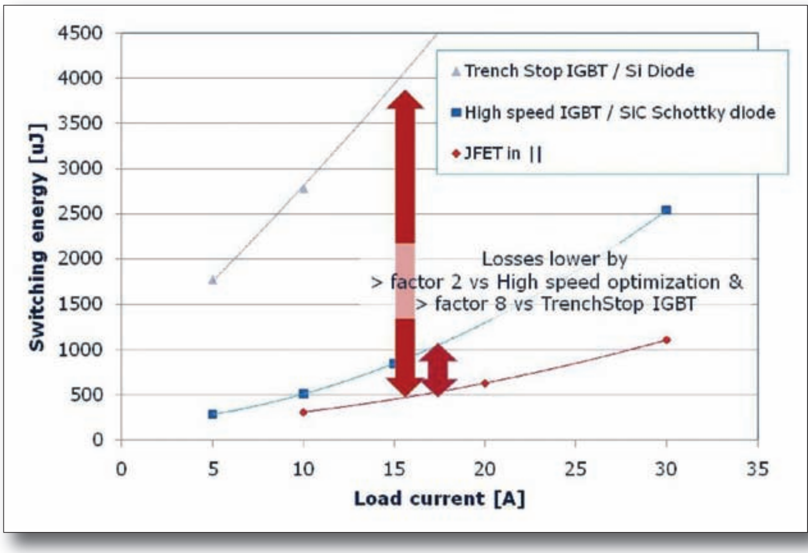

Figure 4: **Comparison of switching losses (turn-on plus turn-off) of a 1200V-50mΩ SiC JFET vs a combination of a high-speed optimized IGBT with a SiC Schottky barrier diode and a conventional 1200V IGBT combined with a fast Si pin-diode at V_{DS}=800V, T_j =75°C, R_g =3Ω**

bridge. If this diode is not present in the device structure a full current rated SiC Schottky barrier diode has to be implemented additionally for paralleling with the SiC JFET. During hard commutation the body diode of the proposed SiC JFET shows practically zero reverse recovery charge. This behavior is otherwise known only from SiC Schottky barrier diodes.

Experimental JFET results

Figure 2 compares the hard commutation of a 15A SiC Schottky barrier diode with a 100mΩ SiC JFET. Both waveforms show a very similar characteristic with the reverse recovery current flowing nearly only during the voltage rise. This is a strong indicator for a pure capacitive displacement current in both devices.

Figure 3 shows the comparison of turn-on losses in a JFET half bridge configuration versus a combination of JFET as switch and a SiC Schottky diode as freewheeling element. The switching behavior of the SiC JFET shows both very fast turn on and turn off behavior. In comparison to commercially available 1200V trench-IGBTs based on field-stop technology a reduction of both turn-on and turn-off energy of one order of magnitude has been observed. In comparison to IGBT technologies with a specific high speed optimization the switching losses are lower by a factor of 2. These ultra low switching losses are the natural key to move towards higher switching frequencies needed for the cost reduction of the magnetic components. Figure 4 shows the respective comparison.

Solar inverters and their requirements to power semiconductors

From all types of PV inverters string inverters [6] are manufactured in the highest number of pieces. Due to this market relevance a string inverter was chosen as a platform for the following investigations. String inverters are characterized by an output power range from 1kW up to about 20kW, comprising single phase or three phase topologies and showing very high efficiencies up to 98%. Typically power semiconductors with rated voltages between 600V and 1200V are being used at RMS currents between 10A and 50A. The switching frequency is in the range of 16kHz to 48kHz. Today Silicon (Si) based IGBTs and MOSFETs are commonly used in this application. However, Si diodes are already replaced step by step with SiC Shottky diodes.

For increased efficiencies suitable topologies in combination with low-loss power semiconductors are required. Over the years a number of PV specific topologies have been developed. They can be analyzed for instance by the number of phases (one, two or three phases), galvanic isolation (transformer less or with transformer), the kind of transformer (LF or HF) or which DC potential can be grounded to earth [7]. Due to the

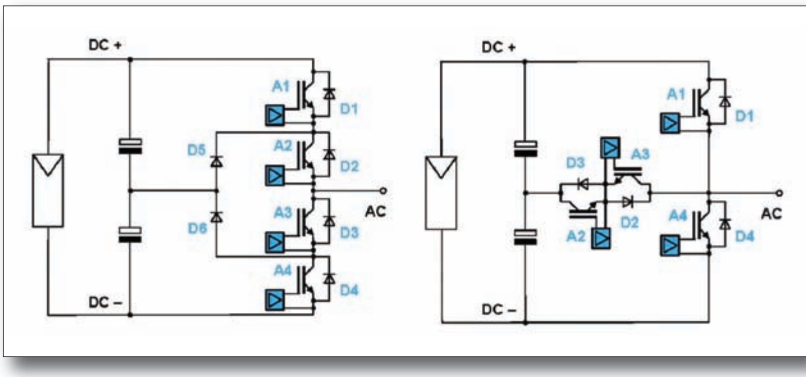

Figure 5: **Topologies for PV inverters: NPC (left) and BSNPC (right)**

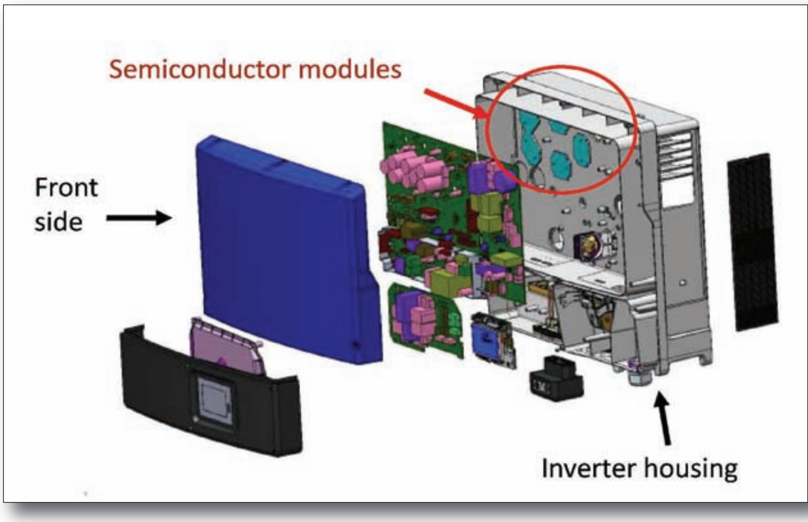

Figure 6: Exploded view to a three phase PV inverter - Sunny TRIPOWER [6]

improved flexibility for the PV module configuration on roof tops, for which a significant wider input voltage range is advantageously, often an inverter topology is combined with a boost or buck stage between PV generator and the inverter. Typical inverter topologies are the well known H-bridge, the PV specific H5 or HERIC bridges or multilevel arrangements like the Neutral Point Clamped (NPC) or Bipolar Switch Neutral Point Clamped (BSNPC) topology [8]. Figure 5 shows for each one leg: a NPC (left) and a BSNPC (right) connected to a PV generator followed by a divided DC link capacitor.

Both topologies use four switches A1 to A4. The high and low side switches A1 and A4 are switched at high frequency (e.g. 16kHz), the switches A2 and A3 operate at grid frequency. In the NPC one of the diodes D5 or D6 in combination with one of the switches A2 or A3 clamps the voltage to the half of the PV voltage if one of the corresponding switches A1, A4 is turned off. Which pair of diode and switch is active, depends on the polarity of the grid voltage. In every case the load current flows through two switches connected in series: A1, A2 or A3, A4.

In the BSNPC a bipolar switch arranged by A2, A3, D2 and D3 clamps the voltage to the half of the PV voltage if one of the previous two switches is turned off. In this case, most of the load current flows only through one switch A1 or A4. By using Si semiconductors for all switches an efficiency of 98.2% in maximum for the whole inverter system can be obtained. The use of SiC JFETs for A1 and A4 enhances the inverter efficiency in particular.

Construction and topology of PV inverter with new SiC JFET

For this research presentation existing three-phase PV string inverter SUNNY TRIPOWER with a maximum output power of 17kW by SMA acts as a platform.

Figure 6 shows an exploded drawing of the inverter assembly. The heart of the device is an integrated housing made of aluminum die cast. This housing has an inner separating wall which separates the inverter in a front and a back compartment. On the front side a compartment for sensitive electronic components like semiconductors is situated. All modules are thermally coupled to the separation wall of the housing. Mounting places are marked. On its backside cooling fins are located so that the housing acts as the cooling system. Generally on the backside heat generating components such as embedded inductive component are assembled for cooling.

The inverter uses a two-stage topology consisting of two boosters for the connection of two strings of PV modules and a three-phase BSNPC topology. All semiconductors are integrated in five Easy1b modules from Infineon Technologies: two booster modules and three inverter modules. The two booster modules include semiconductors for the booster stages. Each of the inverter modules is configured as one leg of the BSNPC topology. The configuration of semiconductors and the semiconductor module is represented in Figure 7.

High and low side transistors A1, A4 (see Figure 5) are replaced by normally-on SiC JFETs. To prevent a short circuit during start up of the system a Cascode formed by a direct driven JFET and a serial low voltage MODFET was introduced [9]. Here a low voltage MOSFET is arranged in series to one JFET. Both switches are driven

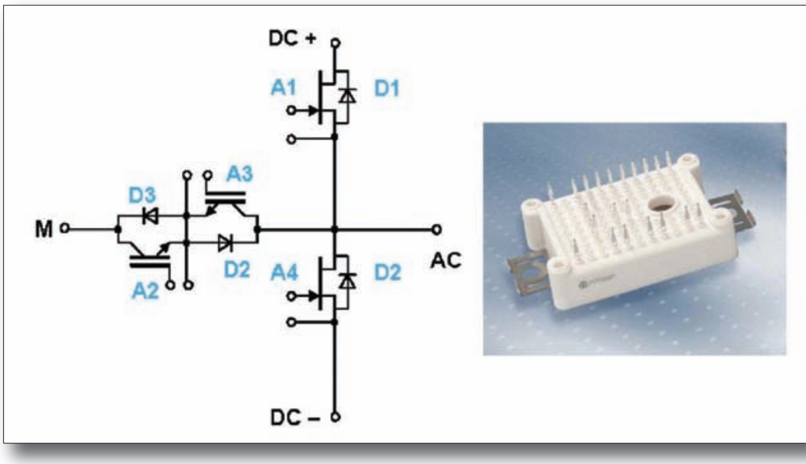

Figure 7: Semiconductor inverter module Easy1b and its PV specific equipment

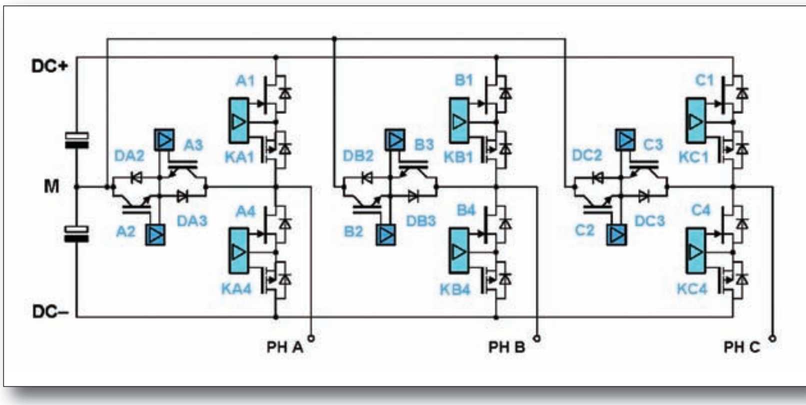

Figure 8: Three-phase BSNPC with direct driven SiC JFETs at high and low side positions in a Cascode configuration

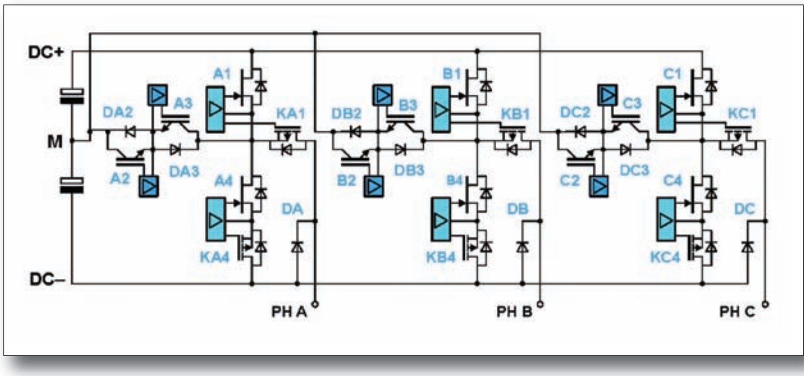

Figure 9: Three-phase BSNPC with direct driven SiC JFETs at high and low side positions in a modified Cascode configuration

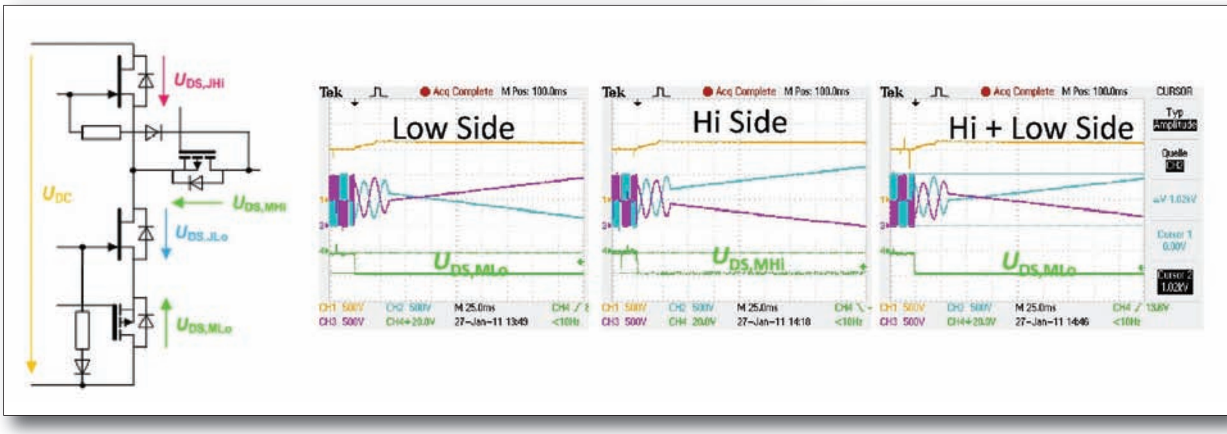

Figure 10: Results of shutdown tests induced by interruption of auxiliary driver supply per one phase at DC link voltage U_{DC}=950V and Output power P_{out}=17kW (Channel1: DC link voltage U_{DC}, Channel 2: $U_{DS,JHi}$ of high side JFET, Channel 3: $U_{DS,JLo}$ of low side JFET, Channel 4: MOSFET voltage $U_{DS,MLo}$ or $U_{DS,MHi}$; time base 25ms/div)

directly and independently. P-channel MOSFETs are advantageously because then the two driver channels for JFET and MOSFET use the same reference potential and can be operated with only one auxiliary supply voltage.

The complete three-phase BSNPC topology using direct driven SiC JFETs on high and low side in a Cascode configuration is depicted in Figure 8. By using semiconductor modules as shown in Figure 7 the low voltage MOSFETs are located outside of the module. This requires a modification of the arrangement shown above into the configuration depicted in Figure 9. Additionally diodes DA, DB and DC are necessary. They act as freewheeling elements in case of shutdown of the Cascode MOSFET. This topology has the advantage, that the Cascode MOSFETs KA1, KB1, KC1 are not a part of the commutation circuits. This results in lower losses of the systems. For the additional diodes DA, DB and DC simple and cheap rectification diodes can be used, what mitigates the disadvantage of their existence. Combining all MOSFET of the low sides to only one device is an interesting option to reduce the number of semiconductor devices.

Results of shutdown tests are depicted in Figure10. During shutdown DC voltage and voltages across all switches have been measured. This is illustrated on the left side of Figure10, where one leg of the investigated topology is represented. The resistor and the diode pull the gate of the JFET to the lowest potential. The waveforms show the results of several shutdown tests. The supply voltage of the driver of the low side JFET (A4), of the high side JFET (A1) and of both JFET (A1 and A4) has been interrupted in these cases. Shutdowns at several combinations of DC link voltage and output power have been investigated, results are represented at a DC link voltage of 950V and 17kW output power.

As long as the JFETs are actively switching the Cascode MOSFET is in an always-on conductive mode. With the interruption of the supply the voltage across the low voltage MOSFET changes.

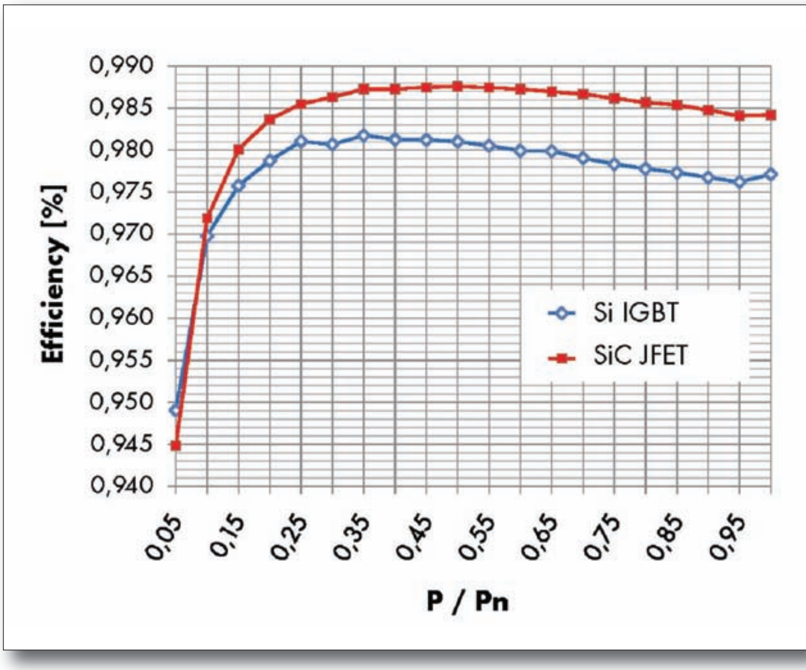

Figure 11: Measured system efficiencies at optimum operation point

The MOSFET turns-off immediately, which puts the entire Cascode formed by the JFET and the low voltage MOSFET into the off-state. Later on after one and a half period of the AC voltage the relay between inverter and grid opens and realizes the disconnection from the grid. After opening the relay the voltage over the JFETs rises slowly up to their stationary value. With these pictures the safe operation of the direct driven Cascode in the application is demonstrated.

Experimental inverter results

Figure 11 shows efficiencies of the inverter system at optimum operation point over several output power levels. A significant difference between both solutions can be seen. The standard inverter based on Si switches achieves a maximum efficiency of 98.2%. For the inverter equipped with the new SiC JFETs 98.8% system efficiencies can be obtained.

EMI and efficiency tests have been done for several current rise rates. In principle a shorter switching time and hence a further increase of efficiency is possible. But this is in contradiction with EMI demands. An improvement of the EMI behavior is expected with an optimization of the PCB and semiconductor module layout, which will allow further increase the efficiency.

Conclusions

This article presents a new normally-on SiC JFET with monolithically integrated body diode. The device concept achieves ohmic characteristics in forward and reverse direction (when driven in a "synchronous rectification" mode) and extremely low switching losses. It shows a nearly zero reverse recovery performance of its monolithically body diode.

Safety requirements can be fulfilled by combining the direct driven normally-on SiC JFET with a low-voltage MOSFET in a Cascode arrangement. This pair of switches operates like one normally-off switch in critical situations. Topology and functionality tests have been presented in this paper. The influence of the Cascode MOSFETs on the system efficiency is extremely low.

SiC JFETs reduce static and dynamic losses significantly in comparison to Si-based switches resulting in a clear improvement of the PV inverter efficiency. Experimental results demonstrating this have been presented and discussed showing that efficiencies as high as of 98.8% could be reached. All required EMI tests have been passed. Further improvements are expected by an optimization of PCB and module layout. The new SiC JFETs are suitable for an improvement of efficiency or output power of PV inverters. Even an increasing of switching frequency can be expected at the same level of losses compared to the existing solution, based on Si transistors. This leads to a reduced size of inductive components. Smaller inductive components can make a significant contribution to cost reduction of PV systems.

The new SiC JFET allows full usage of the integrated body diode. It saves anti-parallel diodes in the topology, which are otherwise required in the case of reactive power. Due to the relatively high on-state voltage of the body diodes the turn-on of the channel in parallel to the diode in a synchronous rectification mode is strongly recommended. The new SiC JFET is hence an ideal choice in both forward and reverse operation, as outlined at PCIM 2011 [10].

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Efficient LED Heat Management

LEDs are being used in more and more ways. Due to their brightness, high efficiency and long life expectancy, they continue to conquer domains that only recently were reserved for traditional light sources. This means that driver electronics must be adapted to an ever-increasing number of applications.

Markus Eißner, Ingenieurbüro Eissner for Kerafol, Eschenbach, Germany

This raises the question of how the components' lost heat enters the heat sink. For this, a good thermal transition must be found. Because SMD components are used in most applications, the heat must be brought to the heat sink through a printed circuit board (PCB). This produces two step heat transfers that make up the greater part of the system's overall heat resistance.

Heat transfer characteristics

An LED can have an average lifetime of about 50,000 hours when $T_J = 25°C$. When $T_J = 125°C$, the average lifetime shortens to 25,000 hours. When $T_J = 175°C$, a lifetime of only 100 hours is specified. This is why careful heat management is very important for LEDs.

The printed circuit board is a very bad heat conductor, with heat conductivity (λ) of about 0,3W/m·K when FR4 printed circuit board material is used. The resulting temperature increase through the PCB during induced heat output is calculated as

$$\Delta T = (Q \cdot d) / (\lambda \cdot A) \text{ [K]}$$

where d is the thickness of the PCB in [m], and Q is the heat output in [W].

To increase the PCB's heat conductivity, vias are placed in a hexagonal pattern in the PCB. The vias partially increase the heat conductivity. The costs incurred during PCB production are minimal. If the created heat is high, copper rivets are used. For this, the round notches in the PCB are milled and the copper rivets are inserted. The SMD component is soldered onto the rivet, which has good heat conductivity.

The next important transfer is from the PCB to the heat sink. For this there are several possibilities. One good solution is to lay a heat-conductive film between the PCB and the heat sink. This performs several tasks at the same time. The first task is to conduct heat away continuously. The second task is to even out the irregularities between the printed circuit board and the heat sink. This is achieved by a soft film. The elasticity evens out the various expansion coefficients of the heat sink and the PCB. For example, an aluminum heat sink has an thermal coefficient of expansion (TCE) of $\alpha = 23 \times 10^{-6}$ [1/K], the FR4 PCB of $\alpha = 14 \times 10^{-6}$ in the X, Y direction and of $\alpha = 70 \times 10^{-6}$ in the Z direction. If the PCB is rigidly attached, waves result between the attachment points from the various expansion coefficients. This should even out by the elastic film.

LED module design

When designing the LED module, strict care must be taken to make sure the heat is transferred away. Particularly LEDs are more heat sensitive than IGBTs or FETs, because the maximum junction temperature should not exceed $T_J = 125°C$. The height of the junction temperature influences the LED's lifespan, brightness and emitted light color.

A sample solution is the module shown in Figure 1. The LEDs and the power source are soldered onto a very thin FR4 printed circuit board. The PCB is stuck onto the heat sink with KL 90 heat-conducting film that is self-adhesive on both sides. The KL 90 takes on several tasks. Those are heat conduction, mechanical attachment of the printed circuit board to the heat sink, evening out irregularities, and electrical insulation of the heat sink. It is a very cost-effective solution for producing such a module.

KL 90 is a very soft elastomer film that is filled with heat-conductive ceramic material. It has heat resistance of 0.52K/W and a thickness of 300µm. It reaches a dielectric strength of 3kV. On the other hand, KL 91 film has an inserted fiberglass web, and has more rigid behavior than KL 90. The technical data for KL 91 are almost identical to those of the KL 90 film.

The question arises as to how the adhesive behaves in combination with

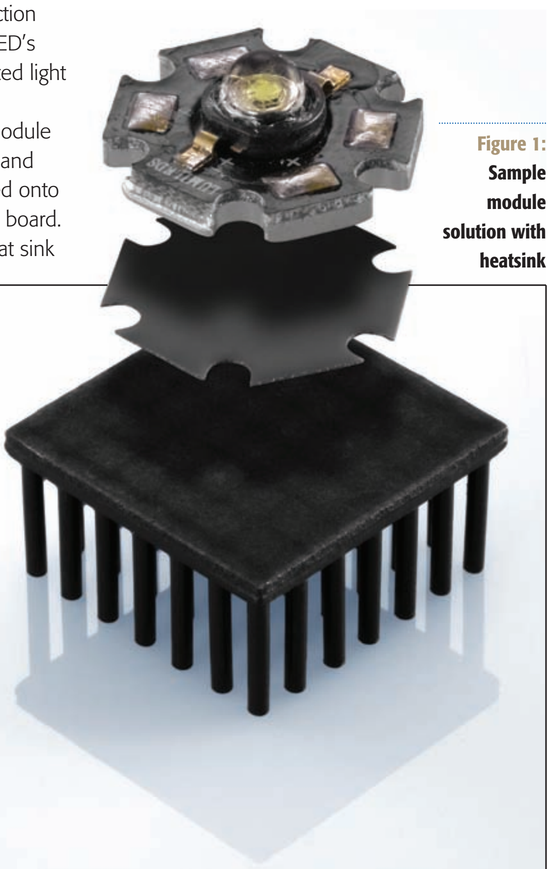


Figure 1: Sample module solution with heatsink

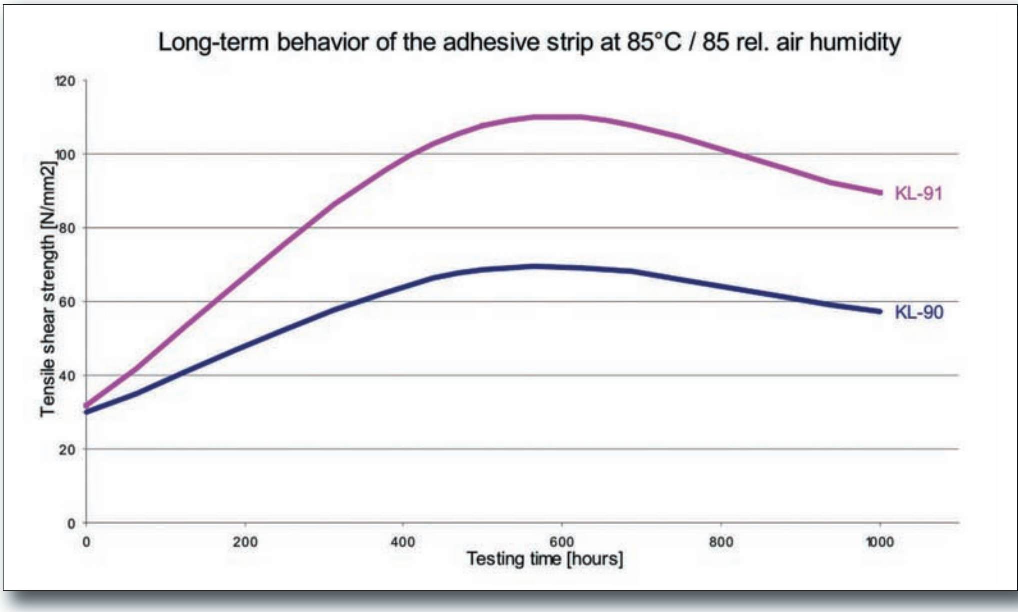


Figure 2: Tensile shear strength at 85°C of materials KL 90/91

heat over time. When the KL 90 and KL 91 films were developed, explicit care was taken to ensure that the adhesive would not degrade with time. Studies have shown that at 150°C, the adhesive has a degradation rate of 4% after 10,000 hours. Thus, the adhesive does not age, and the area of adhesion does not detach from the PCB or the heat sink. After the film is applied, its adhesive strength even increases, as shown in the tensile shear strength curve in Figure 2.

The films even cover applications in which they are exposed to mechanical shocks. Tests according to IEC 60068-2-6 in combination with IEC 60068-2-2 and IEC 60068-2-47 have shown that the KL-90 and KL-91 films withstand accelerations of 50 m/s² and 100 m/s² in all three axes. The values were determined with a design consisting of a PCB and a CPU aluminum heat sink.

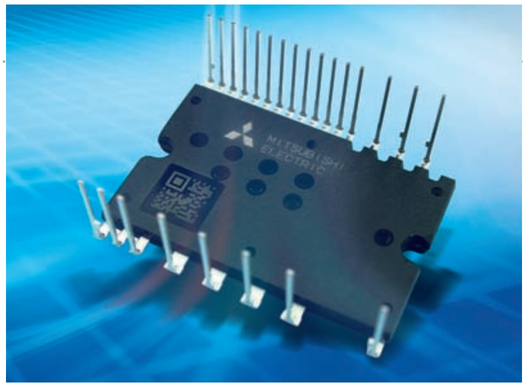
Conclusion

The KL 90 and KL 91 films have very good heat conductivity, with the added advantage of being self-adhesive. The goal in developing these films was to attach the heat-generating components to heat sinks very simply.

125V Tantalum Polymer Capacitor

AVX has announced the capability to manufacture a 125V tantalum polymer capacitor, more than twice the rated voltage of similar products on the market today. Passing the 100V milestone for the first time represents a significant development in the field of high voltage tantalum capacitors. AVX developed the new high voltage tantalum capacitor by optimizing processes which enhance capacitor performance and working in close co-operation with polymer suppliers. Conductive polymer has been proven to provide low ESR and reduced ignition failure mode solution. In addition, due to the nature of polymer capacitors surge robustness, lower derating of 20% can be used. However, the working voltage of tantalum-polymer capacitors was limited until now due to the maximum achievable breakdown voltage. AVX's new developments in polymer technology addresses these limited working voltage issues and is expected to result in even higher-rated products in the future. Engineering samples in limited quantities of the new TCJ 6.8µF/100V (V case) and 3.3µF/125V (D case) high capacitance, high voltage tantalum capacitors will be available from July onwards, with volume production starting in 2012.

tomas.zednicek@eur.avx.com, www.avx.com



Super IGBT Mini-DIPIPM

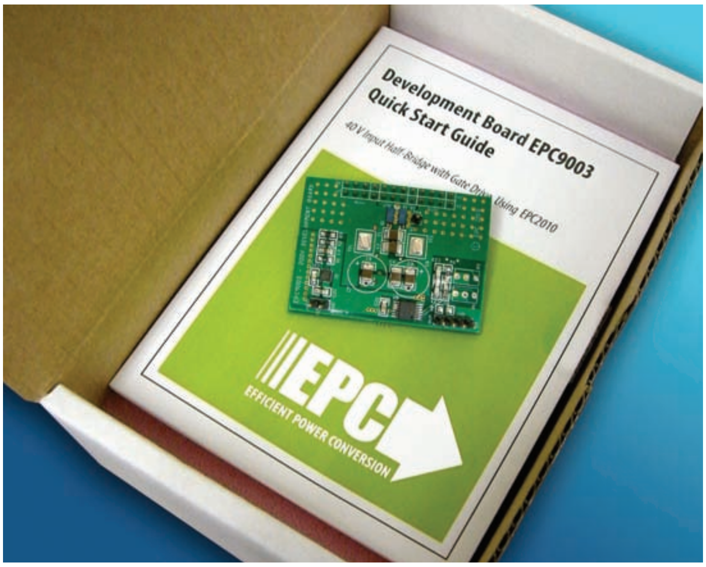
Mitsubishi Electric is introducing its 5th generation of Super Mini-DIPIPM family for 3-phase DC/AC conversion targeting low power applications like white goods and small power drives. They come with ratings from 5A to 15A/600V by using the 6th generation Full Gate CSTBT (Carrier Stored Trench Gate Bipolar Transistor) technology resulting in low power loss. The new family can easily replace the previous 4th generation Super Mini-DIPIPM family due to pin compatibility with an outline of 38mm by 24mm. The new modules feature implemented bootstrap diodes as well as N-side open Emitter. Furthermore, protection functions against short circuit, under-voltage and over-temperature with fault signal output in case of a failure are integrated.

http://global.mitsubishielectric.com

GaN Development Board

Efficient Power Conversion Corporation (EPC) offers the EPC9003 development board to make it easier for users to start designing with EPC's 200V enhancement-mode gallium nitride (eGaN) FETs in applications such as solar microinverters, class D audio amplifiers, Power over Ethernet (PoE), and synchronous rectification. The development board is a 200V maximum input voltage, 5A maximum output current, half-bridge with on board gate drives plus supply, the EPC2010 200V eGaN FET, and bypass capacitors. There are also various probe points to facilitate simple waveform measurement and efficiency calculation. The purpose of this development board is to simplify the evaluation process of the EPC2010 eGaN FET by including all the critical components on a single board that can be easily connected into any existing converter. Priced at $95.00, the EPC9003 is available for immediate delivery from Digi-Key.

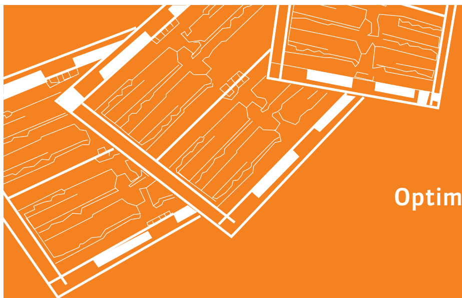
www.epc-co.com

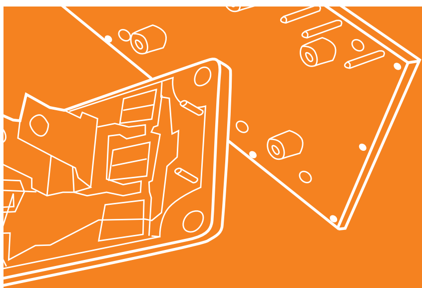


100/150V Trench MOSFETs

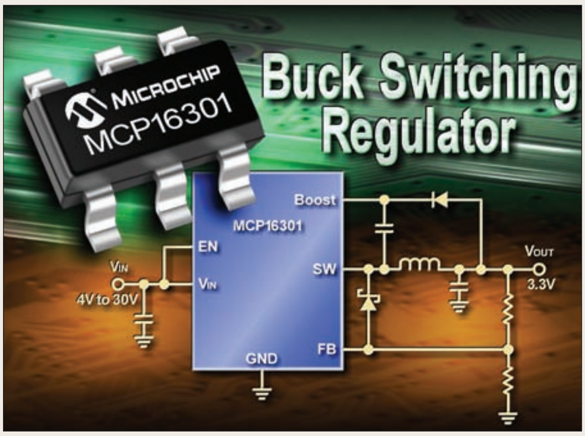
Fairchild Semiconductor expanded the PowerTrench® MOSFET family of 100V and 150V devices to include industrial-type packages such as TO-220, D2PAK, TO247, I2PAK, TO220 Full Pack and D2PAK-7L. These devices are optimized power switches that combine a small gate charge, a small reverse recovery charge and a soft reverse recovery body diode, which allows for fast switching for synchronous rectification in AC/DC power supplies. A shielded-gate structure provides charge balance resulting in improved FOM. A low reverse recovery charge and the soft reverse recovery body diode reduces voltage spikes or oscillation in the system, eliminating the snubber circuit - or replacing a higher voltage rating MOSFET. The first devices available in the industrial-type packages include the FDP083N15A_F102, FDB082N15A and FDP036N10A N-channel PowerTrench MOSFETs.

www.fairchildsemi.com





30V Buck Regulator



Microchip announces its first 30V-input buck switching regulator. The MCP16301 combines a wide input voltage range of 4V to 30V, and a 600mA output across a voltage range of 2V to 15V, with up to 95% efficiency. With a high-side switch integrated into the small 6-pin SOT-23 package, the MCP16301 minimises the number of external components to enable an efficient and compact solution for stepping down 12V to 24V DC power rails. On-board control-loop compensation and slope compensation simplifies the complex task of stabilising the converter control system to provide enhanced reliability. In comparison to low drop-out (LDO) regulators, the MCP16301 offers lower power consumption, heat dissipation and cooling requirements, whilst increasing efficiency and matching the LDO's typical D2PAK footprint. The MCP16301 is supported by two demo boards: the MCP16301 300 mA D2PAK footprint ARD00360 priced at $14.99, and the MCP16301 600 mA Demo Board (ADM00352), priced at $19.99. A component-selection tool and application notes are also available for download.

www.microchip.com/get/TQEG

High-Current Inductors

Three new series of surface mount inductors aimed at high current applications are offered by Murata Power Solutions. The 3700, 3800 and 3900 series are flat coil inductors that provide a wide range of inductance values from 0.15 to 10µH with DC current ratings up to 19.5A. These compact devices, measuring just 14.5mm x 11.5mm x 5.8mm for the 37301C 0.3µH 19.5A part, are available with DC resistance values ranging from 0.9 to a maximum of 20.3mΩ ensuring that any voltage drop is kept to an absolute minimum. The inductors are aimed at DC/DC power conversion applications where a high transient response is required.

www.murata-ps.com

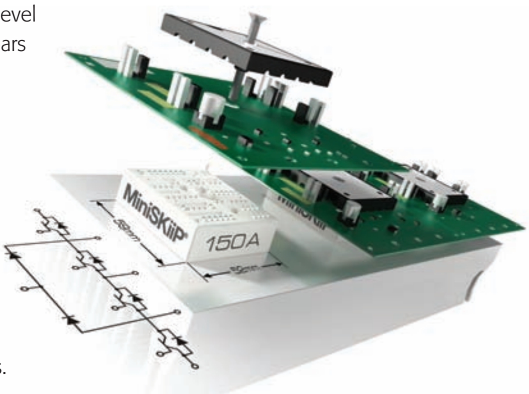
MOSFETs with Usable Body Diode

Rohm Semiconductor has introduced its new PrestoMOS family coming in a variety of package types such as CPT/D-PAK, LPT/D2-PAK and through-hole TO-3PF. With their high speed body diode eliminating the need for an external FRD (Fast Recovery Diode) it only consumes a small mounting area, ideal for miniaturized applications. Compared to conventional 600V/8A products, not only the t_{rr} but also the I_{rr} ratio as well as the loss comparison are significantly improved. For instance, a power conditioner circuit only requires four components without external FRDs. This series of high speed switching MOSFETs is based on high voltage processes to reduce on-resistance by as much as 50% and gate charge by 40% over conventional products while switching speed improves by around 30%. Heat generation is mitigated during switching operation contributing to smaller designs and lower costs.

www.rohm.com/eu

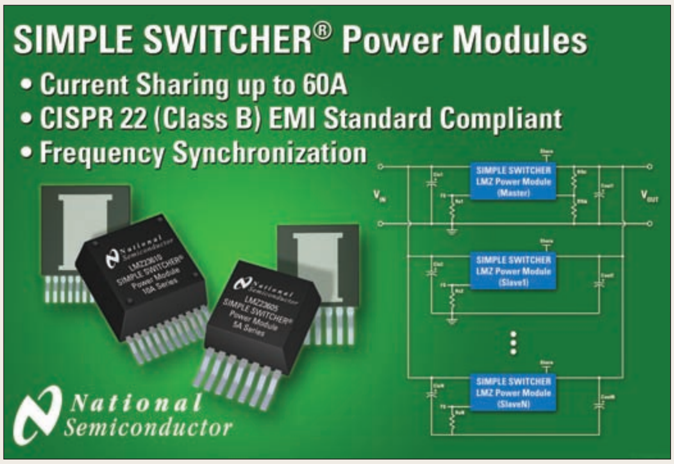
High-Current IGBT Modules

Semikron offers its newest MiniSKiiP IGBT power semiconductor module, which is now also available in 3-level topology, at a rated current density of 4.9 A/cm². The reverse voltage of the IGBTs and diodes used has been increased to 650V to enable DC link voltages of 900V for 480V three-phase power applications typical in commercial or industrial settings in the United States. Each module has a 3-level phase leg with sufficient space for ten power semiconductors each. Thermal and electrical connection between the module and the heat sink and the driver board is established with a single screw or two screws for rated module currents of up to 150A or 200A, respectively. This means that solder equipment and time-consuming soldering processes are done away with in the assembly stage. For solar inverter output power of 60kVA and above, i.e. for rated current of 150A and higher, modules with screw connections were previously used for the busbars. Thanks to MiniSKiiP 200A 3-level modules, the busbars can be replaced with cheaper PCBs in inverters with outputs of up to 85kVA. Former complex 8-screw connections have been reduced to simple 2-screw-assembly solutions.



www.semikron.com

10A Simple Switchers

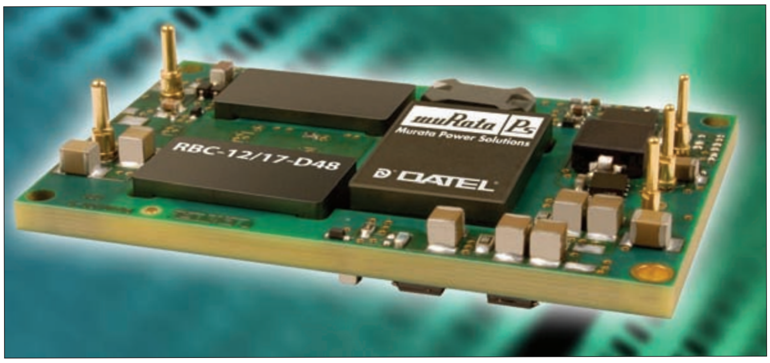


National Semiconductor added 12 power modules to its Simple Switcher family, the first to drive up to 10A of output current and comply with the CISPR 22 (Class B) radiated and conducted electromagnetic interference (EMI) standard in industrial and communications infrastructure applications. The modules include new features for current sharing and frequency synchronization. For high-current intermediate rail and FPGA applications, multiple modules can be placed in parallel to achieve output currents from up to 60A. A synchronization pin enables the modules to operate at the same frequency, controlling switching noise in sensitive systems. With an integrated shielded inductor, the 10A power modules operate at 1MHz switching frequency and up to an ambient temperature of 70°C with zero air flow. Six of the 12 new power modules accept an input voltage rail between 6V and 36V and deliver an adjustable output voltage from 0.8V to 6V. The LMZ13608 and LMZ13610 drive up to 8A and 10A of output current, respectively. Featuring similar output currents, the LMZ23608 and LMZ23610 also include frequency synchronization and current sharing. The LMZ23603 and LMZ23605 drive up to 3A and 5A of output current, respectively, and feature frequency synchronization. The second set have input voltages between 6V and 20V and output voltages from 0.8V to 6V. The LMZ12008 and LMZ12010 drive up to 8A and 10A of output current, respectively. Featuring similar output currents, the LMZ22008 and LMZ22010 also include frequency synchronization and current sharing. The LMZ22003 and LMZ22005 drive up to 3A and 5A of output current, respectively, and feature frequency synchronization.

www.national.com/switcher

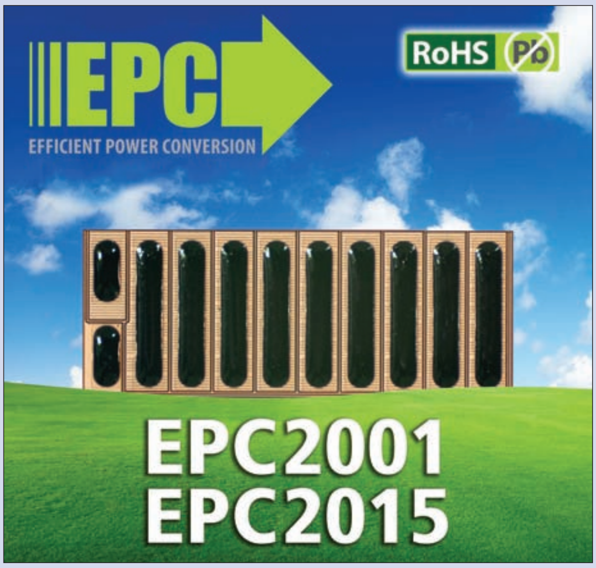
Regulated 210W DC/DC Bus Converter

Murata Power Solutions has introduced a Regulated Bus Converter (RBC) that delivers up to 210W output power at 36-75V input, efficiency of 92.5% at full load output regulation of ±1.5% in a quarter brick open frame package. The fully isolated (2250VDC) RBC-12/17-D48 accepts a wide range 36VDC to 75VDC (48V nominal) input. This is then converted to a 12VDC/17A output. The synchronous-rectifier topology and 225kHz fixed-frequency operation of the RBC results in the high efficiency levels. Protection features include input under-voltage (UV) lockout, output current limiting, short-circuit hiccup, over-temperature shutdown and output over-voltage. Positive or negative polarity remote on/off control is available as an option. A base plate, for mounting to cold surfaces or natural-convection heatsinks, can be specified for applications that do not have forced air cooling or where there is zero airflow. Applications include 48V-powered datacom and telecom installations, base stations, cellular telephone repeaters and embedded systems.



www.murata-ps.com

Enhancement-Mode GaN FETs



Efficient Power Conversion Corporation introduces the EPC2001 and EPC2015, two lead-free, RoHS-compliant enhancement-mode gallium nitride on silicon (eGaN™) FETs.

The EPC2001 FET is a 100V device with a maximum $R_{DS(ON)}$ of 7mΩ with 5V applied to the gate, and the EPC2015 is a 40V with a maximum $R_{DS(ON)}$ of 4mΩ. Both eGaN FETs provide significant performance advantages over similar state-of-the-art silicon-based power MOSFETs. Both devices have low on resistance, are smaller than silicon devices with similar resistance and have many times superior switching performance. Applications that benefit from eGaN FET performance increases include DC-DC power supplies, point-of-load converters, class D audio amplifiers, notebook and netbook computers, LED drive circuits and telecom base stations. In 1k piece quantities, the EPC2001 is priced at $2.80 and the EPC2015 is priced at $2.48. Both products are immediately available through Digi-Key.

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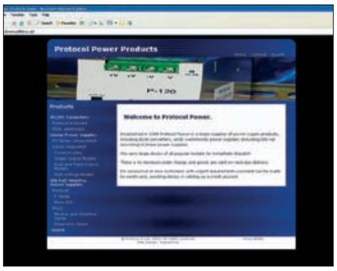

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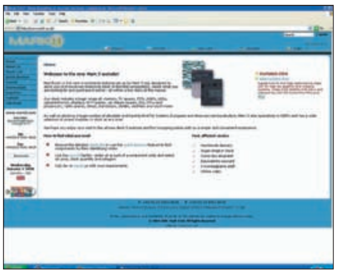

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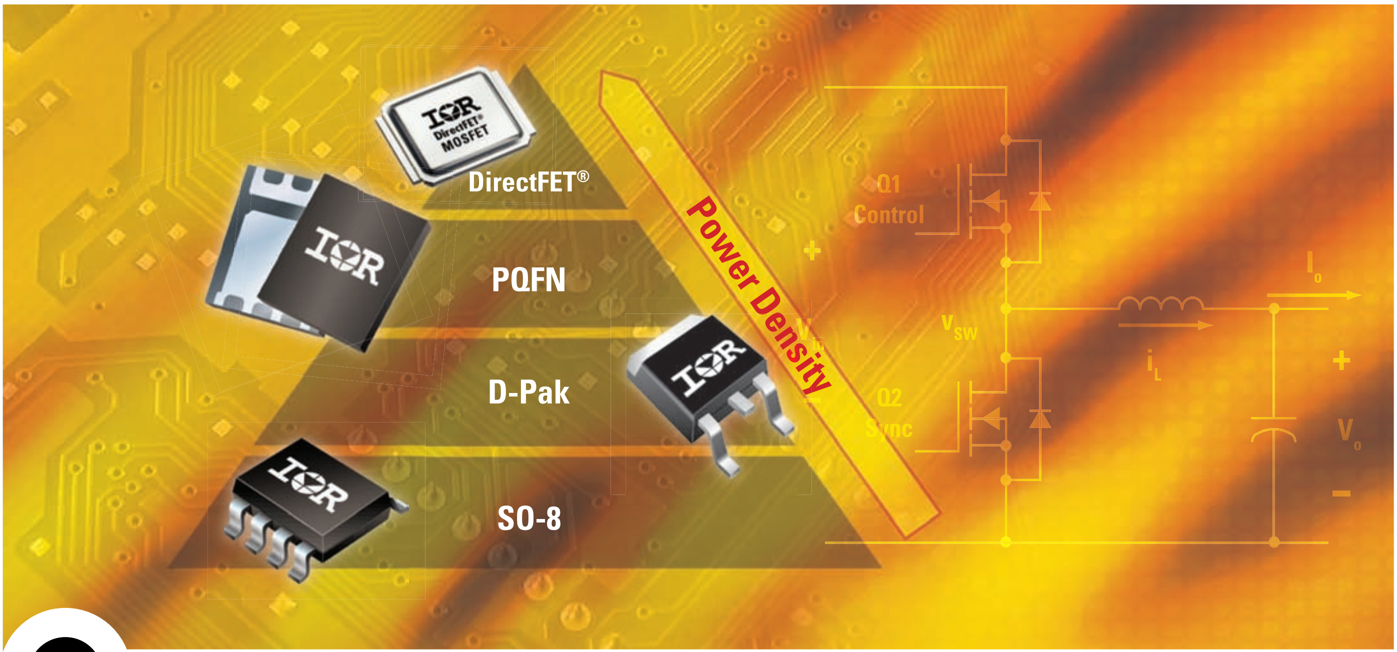

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IRFHM831	30	Control	PQFN 3x3	7.8	7.3
IRFHM830	30	Sync	PQFN 3x3	3.8	15
IRFHM830D	30	Sync	PQFN 3x3	4.3	13
IRFH7911	30	Control	Half-Bridge Asymmetric PQFN 5x6	8.6	8.3
		Sync		3.0	34
IRLR8729	30	Control	D-Pak	8.9	10
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