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HIGH-POWER SEMICONDUCTORS

High Power IGCT Switches – State-Of-The-Art and Future

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Also inside this issue

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COVER STORY

High Power IGCT Switches – State-Of-The-Art and Future

Industry standard large IGBT modules have slightly lower ratings than press-pack Bipolar IGCTs (Integrated Gate-Commutated Thyristors). This is basically because of two things. First, they have IGBT chips of a maximum size of 14mm x 14mm parallel coupled to achieve the highest possible current rating. Secondly, the switch has integrated free-wheeling diodes in the package making it a complete switch. The largest switch for a 4.5kV IGBT module is 2kA in a special press-pack design (StakPakTM). Usually, IGBT HiPakTM modules are the preferred choice for traction converters, and when paralleling the HiPak modules it is possible to make power electronics based on IGBT modules for controlling also large AC motor drives for industrial applications. Today, ABB's IGCTs present the best option for medium voltage drives operating at the highest power levels. Combined with optimum switch-off conditions during operation, the switch offers excellent reliability in demanding conditions. Here, we introduce ABB's latest generation of IGCT technology and provide an outlook into product development of IGCTs of the future. Full story on page 30.

Cover supplied by ABB Switzerland Ltd, Semiconductors, Lenzburg, Switzerland

Hot Topics GaN and SiC

In face of the ongoing Japanese nuclear crisis the discussion on enhanced funding for renewable energies is expanding, but also efforts in energy savings. Today 40% of the energy consumed worldwide is electric energy, a figure that is expected to rise to as much as 60% by 2040. Newly designed power semiconductors based on Gallium Nitride and Silicon Carbide will support the requirements of both sides, as PCIM from May 17-19 in general and PEE's Special Session on May 18 in particular will show.

After decades of research efforts Silicon Carbide has gained momentum in power electronics. Wafer quality has significantly improved while 150mm wafers are on the way. Schottky diodes with voltage ratings of typically 600V and 1200V are commercially available and used in different kinds of converters, often together with Silicon transistors reducing switching losses significantly. SiC transistors are currently sampled as JFETs, MOSFETs or BJTs. On the user side, solar inverters have turned out to be a lead application for SiC. At the same time another rising star appears at the horizon, Gallium Nitride allowing hetero-epitaxy on Si wafers. This offers new opportunities regarding costs and co-integration with Si device technology.

Since the advent of the spontaneous AlGaN-GaN based high electron mobility sheet formation, first discovered by M. Asif Khan in 1993, significant efforts have been made to bring the inherent capabilities of this material system to bear in practical semiconductor power devices. The combination of high breakdown field strength due to the wide band gap of the III-nitrides, high electron mobility, as well as, an unusually high channel electron density, yield a remarkably compelling drift resistance. Such devices also benefit from the reduced charge requirements involved in switching the devices on and off. Probably the most exciting attribute of the system involves the easily isolating nature of the inherently lateral devices, permitting unprecedented monolithic integration of power systems. As such GaN based power devices are still relatively early in their development, it is expected that significant improvements in the device performance will rapidly be achieved over the next 5 to 10 years. Gallium Nitride transistors with their higher switching frequency capabilities, lower recovery charge and higher permissible junction temperature are more efficient than Silicon transistors, a saving potential of more than 50% is expected by researchers.

It is predicted that a high percentage of applications for GaN and SiC power transistors - including electric vehicles, solar inverters and high end servers - may choose to use this technology as devices integrated into a module form factor. There are several reasons for SiC in modules including the ability to deliver higher power and functionality. By using a module form rather than multiple discrete devices it is also possible to save both cost and area in the overall system design. Implementing modules also increases performance as gate drivers and control components can be placed close to the active switches, reducing parasitic capacitance and inductances, and allowing faster switching performance. There are further benefits for the SiC device manufacturer because higher power levels can be more easily achieved by paralleling smaller and hence higher yielding devices in a power module rather than using discrete technology. The significant advances in SiC VJFET, MOSFET and BJT technology will inevitably drive the uptake of SiC modules based on the small, high efficiency discrete devices; however, until recently, very few switching characterization reports of these types of modules have been published. So far 1200V SiC JFETs and MOSFETs have been introduced, also 1700V MOSFETs are in samples available. As SiC devices migrate to higher power levels, multi-chip power modules offer a practical and necessary solution for a wide range of applications. However, the high speed transients capable in GaN and SiC devices highlight the need for careful design considerations concerning gate drive, wiring, layout, and module parasitics.

Direct answers on the question how to use new devices made of GaN and SiC will be provided in PEE's Special Session "High Frequency Switching Devices and Applications" on May 18 (10.00 - 12.30, Room Paris). Because of the in-depth content of the five papers to be presented (see our extensive PCIM Preview in this issue) this is an extended session with panel discussion comprising all speakers after the final presentation. You are heartly invited to attend this session as well to stop by at our PCIM booth 544 in hall 12. Hope to see you there!

Achim Scharf
PEE Editor

TI will Acquire National Semiconductor

Texas Instruments Inc. and National Semiconductor announced on April 4 that they have signed a definitive agreement under which TI will acquire National for $25 per share in an all-cash transaction of about $6.5 billion. The acquisition combines two industry leaders in analog and power semiconductors. The market for analog semiconductors was $42 billion in 2010. TI reported 2010 analog revenue of $6.0 billion, or 14% percent of the market, whereas National's revenue in calendar year 2010 was about $1.6 billion, or 3% of the market.

"This acquisition is about strength and growth. Our ability to accelerate National's growth with our much larger sales force is the foundation of our belief that we can produce strong returns on our investment. The combined sales team will be 10 times larger than National's is today, and the portfolio will be exposed to more customers in more markets", commented TI's CEO Rich Templeton. "This merger provides a platform to enhance National's strong and profitable analog capability, power management in particular, leading to meaningful growth", added National's CEO Don Macleod.

Each company has unique strengths. Among them TI's 30,000 analog products, extensive customer reach, and leading manufacturing including the world's first 300-millimeter analog factory. National brings a portfolio of 12,000 analog products, a strong position with customers in the industrial power market, and excellent customer design tools such as Webench. Upon close of the transaction by year end, National becomes part of TI's analog segment, and sales of analog semiconductors will represent almost 50% of TI's revenue. The combined company also will benefit from National's manufacturing operations, located in Maine, Scotland and Malaysia, which TI will continue to operate.

Based on final results from the year 2010, the National acquisition would make TI the world's third largest semiconductor company. This would allow Texas Instruments to rise one place in the rankings from fourth place, supplanting Japan's Toshiba Corp. Within the analog segment, the acquisition will particularly bolster TI's lead in the market for voltage regulators, commented market researcher iSuppli. With $1.7 billion in revenue and a share of 18% TI was the leading voltage regulator supplier in 2010. National was the third largest supplier, with $758 million in revenue. With the acquisition, TI's voltage regulator revenue would amount to $2.4 billion in 2010, giving it a 26.5% share of the market. The global voltage regulator market expanded by 36% in 2010 to reach $9 billion, up from $6.7 billion in 2009. This represented larger growth than the total semiconductor market, which expanded by 32% for the year. The combination of these two titans will represent about 17% of the power management and driver IC market, or $2.2 billion in revenue, whilst their share of the LED IC market will stand at over 25%, added IMS Research.

www.ti.com/acquire

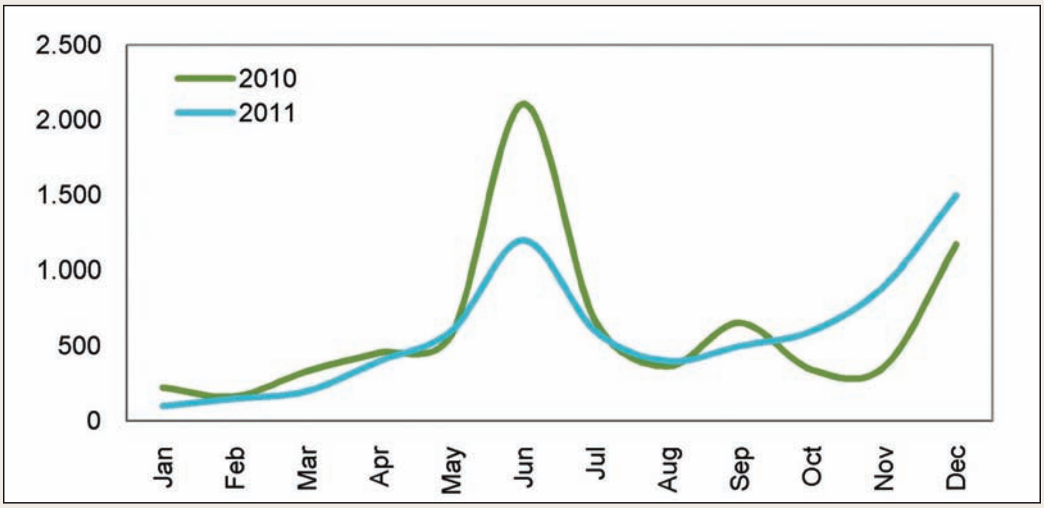
Japan Nuclear Crisis Boosts European Solar Markets

The earthquake-related nuclear disaster in Japan could prove to be a boom to the PV industry in Germany and Italy, the world's two largest solar markets, which have become sensitized to the dangers of a nuclear meltdown, according to new IHS iSuppli research.

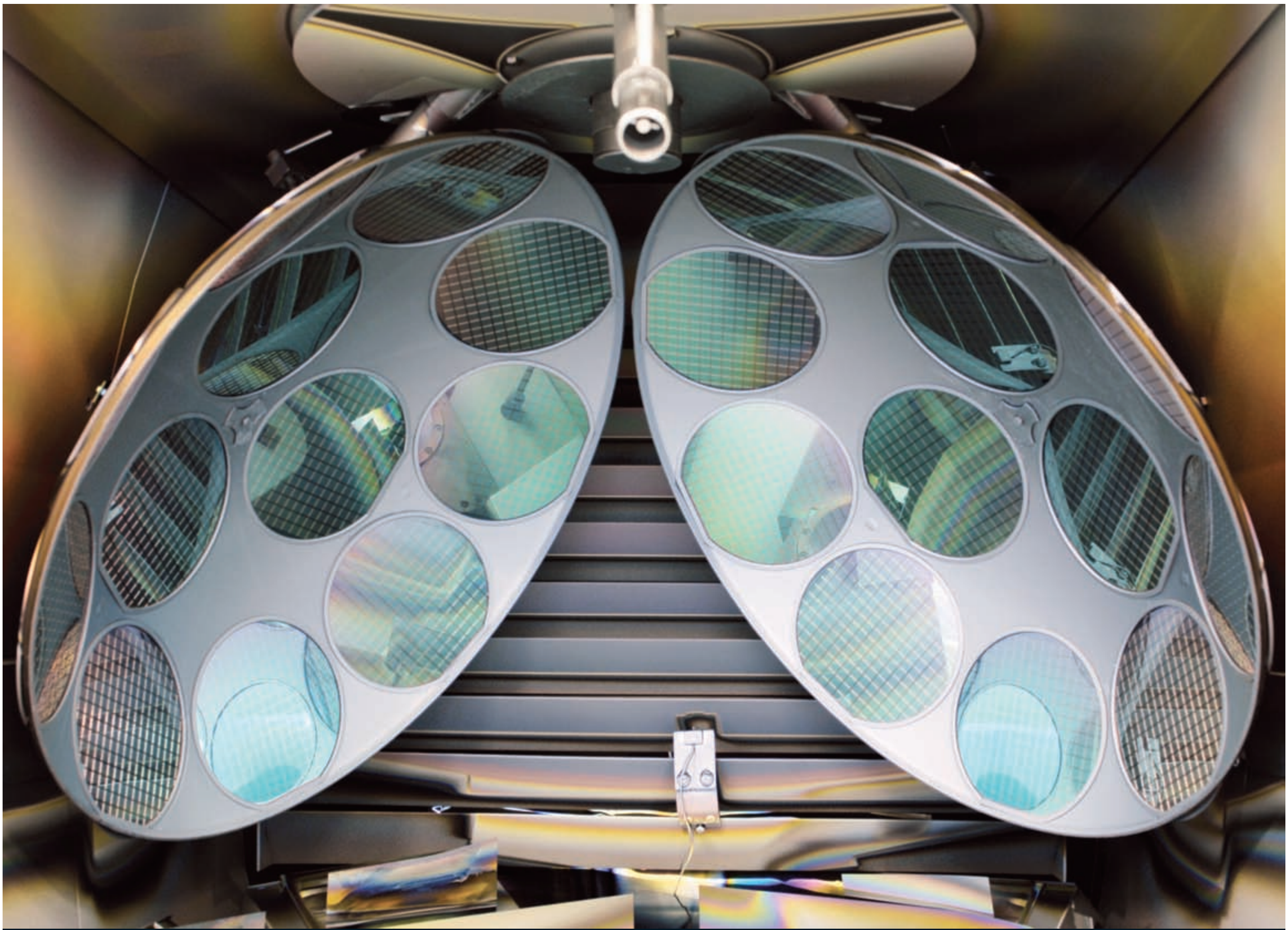
"Reaction to the Fukushima nuclear crisis has been swift in Germany and Italy", said Henning Wicht, IHS analyst for photovoltaic systems. "Germany responded quickly by shutting down seven of its oldest reactors, potentially boosting the prospects for renewable energy in the country. Meanwhile, Italy indicated it might upgrade the role of solar within the country and accept higher volumes of sun-powered energy".

By the third quarter, it will be apparent whether the German government will proceed with a rapid exit path from nuclear power. Assuming that a decision to abandon nuclear energy is reached, renewable energy will be promoted even more strongly, IHS predicts. Wind dominates current public discussions, but solar energy possibly could benefit as well. One possible course of action that could benefit the solar industry would boost the annual PV installation forecast. Germany likely could increase the annual PV installation target for after 2010 to 5 GW, up from 3.5 GW now, increasing the long-term outlook for solar.

www.isuppli.com



German PV installations (in MW)
Source: his iSuppli April 2011



New Ultra-Low-Power Technology for Energy-Efficient Applications

STMicroelectronics has demonstrated a next-generation variation of its smart power technology. The new technology is expected to enable significant reductions in the power consumption of a wide range of electronic systems - from new medical equipment to battery chargers in hybrid electric vehicles.

The new technology is a variation of ST's BCD (Bipolar-CMOS-DMOS) smart power semiconductor technology that combines SOI (Silicon-on-Insulator) substrate technology with 0.16-micron lithography. This will enable chip designers to combine high-density logic circuitry (1.8V and 3.3V CMOS) with full dielectric isolation and a component portfolio including power MOSFET transistors that can operate up to 300V, low noise devices, and high-value resistors, leading to ASICs that cannot be implemented using conventional bulk-silicon substrates.

The development of the technology is one of the results of an advanced European R&D project. In Europe, the EU has stimulated much research and development work in this field through the ENIAC (European Nanoelectronics Initiative Advisory Council) initiative. Within the ENIAC framework, ST and 17 other European partners have formed the SmartPM (Smart Power Management in Home and Health) consortium to answer this growing need for energy efficiency. The SmartPM consortium includes companies and academic institutions from nine countries: Belgium, France, Germany, Ireland, Italy, the Netherlands, Norway, Spain and Sweden. The SmartPM partners are working together to develop innovative semiconductor technologies, circuit designs and system architectures.

"Semiconductor technologies that can drastically reduce electrical energy consumption in consumer and industrial appliances have existed in the labs for many years and their potential contribution to the reduction of worldwide power consumption is significant", said Claudio Diazzi, Group Vice-President, Technology R&D, STMicroelectronics. "However, the cost of these technologies has previously been too high to make them commercially viable. We believe that this new smart power technology will make a significant difference".

www.smartpm.eu

PV Modules 2010 Top Ten Rankings

PV Module Supplier Rankings

2010 Annual MW Shipments (excluding OEM)

	Company Name	09-10 Change
1	Suntech	+1
2	First Solar	-1
3	Sharp	-
4	Yingli	-
5	Trina Solar	-
6	Canadian Solar	+2
7	Kyocera	-
8	Sunpower	-2
9	Hanwha SolarOne	+2
10	Solarworld	-

www.PVMarketResearch.com

Source: IMS Research Apr-11

Suntech was the largest PV module supplier in 2010, growing its shipments by more than 130% over the previous years. First Solar, which held the top spot in 2009, fell to second place, increasing its shipments by less than 50% although the total market more than doubled.

IMS Research's analysis of the global PV supply chain reveals that whilst market conditions meant that all suppliers could grow their shipments, some suppliers were able to benefit more than others: Chinese Tier-1 suppliers Canadian Solar and Hanwha SolarOne (formerly Solarfun) both gained two places in the rankings; in fact, all the suppliers in the top ten gaining rank were Chinese. Conversely, both the suppliers losing rank were Western, headquartered in the US. One Western supplier bucking this trend was REC, which moved quickly up the rankings to become the eleventh largest supplier of PV modules in 2010. Another clear winner in 2010 was JA Solar, another large Chinese supplier, which increased its production by nearly 180%, becoming the largest producer of PV cells, having been only the fifth largest producer in 2009.

"2010 was an outstanding year for everyone in the PV industry. Module suppliers were able to benefit from the strong demand, which lasted all year, and make great increases in their shipments; five of the top ten suppliers more than doubled them, some even increased them by more than 150%," says analyst Sam Wilkinson. IMS Research predicts a slowdown in growth for the PV module market in 2012, as many major European markets cool following amendments to incentive schemes.

www.pvmarketresearch.com

SiC Simulation Software at ITRI

The Industrial Technology Research Institute of Taiwan (ITRI) has adopted Synopsys' TCAD Sentaurus simulation software to support its research and development of Silicon Carbide (SiC) semiconductor devices. TCAD Sentaurus' accurate modeling enables ITRI to speed up the development of SiC power devices with detailed simulations of their electrical and thermal behavior.

Over the past decade, SiC Schottky barrier diodes have become commercially available, resulting in the development of a new generation of SiC devices targeting applications in hybrid and electric vehicles, smart grid and other innovative power systems. ITRI is researching a wide range of power devices to serve emerging market needs for electric vehicles and solar arrays. "The market for SiC devices is growing rapidly because of the need for more energy-efficient power switches in major application segments like automotive and energy distribution", said Dr. Ming-Jer Kao, EOL deputy general director of ITRI. "The Synopsys TCAD Sentaurus software allows us to simulate the electrical and thermal performance of our devices in a very realistic way. This capability is essential for understanding the behaviour of our new devices and is used to optimise the device characteristics to meet market requirements". The TCAD Sentaurus product family comprises 2D and 3D process and device simulation tools for exploring and optimizing silicon and compound semiconductor technologies. The TCAD Sentaurus tools implement models specific to SiC simulation.

www.synopsys.com

RESCAR 2.0 Enhances the Robustness of Electronic Automotive Components

Whether in the powertrain, in central control units or in body and convenience electronics - there is a constant increase in the proportion of electronic components used in the car. This trend is accompanied by growing complexity of the systems installed, meaning that designers are forever faced with new challenges in the fine tuning.

Six partners from all levels of the development chain have now joined forces in a quest to come up with overarching solutions, namely AUDI AG, the BMW AG (associated project partner), ELMOS Semiconductor AG, the Research Center for Information Technology (FZI), Infineon Technologies AG and Robert Bosch GmbH. Support is provided by the Fraunhofer Institute for Reliability and Microintegration (IZM) Berlin, the Fraunhofer Institute for Integrated Circuits (IIS) Dresden, the University of Bremen, the Dresden University of Technology, the University of Hanover and the University of Tuebingen. The project is coordinated by Infineon.

The members of the RESCAR 2.0 research project (RESCAR being the German acronym for the robust design of new electronic components for applications in the field of electromobility) seek to enhance the reliability and robustness of electronic automotive components. The project is receiving support from the German Federal Ministry of Education and Research (BMBF) to the tune of approximately €6.5 million as part of the funding program known as "STROM" (German acronym signifying key technologies for electromobility). Together with the partners, the joint research investment volume is planned at about €13.3 million over the next three years.

RESCAR 2.0 aims at optimizing the entire development process of electrical and electronic components of electromobility systems to enable the robustness and reliability of the overall system to be predicted right from the outset. Among the tasks planned is the development of methodology to capture and process the requirements for new components. Moreover, robustness analyses will be designed to investigate the suitability of the components for the application envisaged. The components under study will encompass analog and digital circuits in the low-voltage range as well as high-volt mixed signal ICs and sensor systems.

The company also announced it will invest $160 million this year to expand its production capacity, research & development and to upgrade its manufacturing facilities in Malacca, Malaysia. The investment will mainly increase the capacity to produce power semiconductors for energy efficiency applications and will add 350 jobs in Malacca in 2011.

www.infineon.com

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www.smartpm.eu

Ultracapacitors distributed by Richardson in Europe

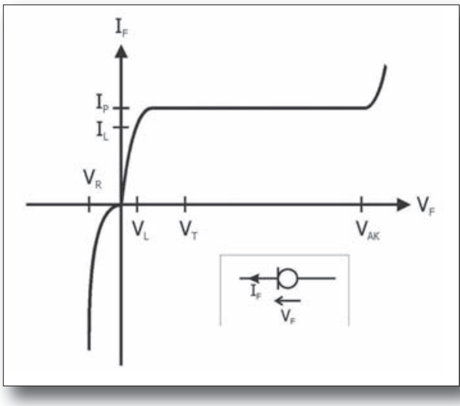
Richardson RFPD and Maxwell Technologies announced the expansion of their mutual business agreement to now include distributing ultracapacitors in the European markets. Richardson RFPD carries a substantial inventory of Maxwell ultracapacitor products, with stocking locations throughout the world.

Richardson RFPD's global field sales engineering team can recommend the proper ultracapacitor considering a customer's specific electrical design requirements and mechanical constraints. The company offers Maxwell's complete line of ultracapacitors from individual cells (1F to 3,000F) to multicell modules (up to 500F) and also has the engineering capabilities to design and build custom ultracapacitor banks and assemblies.

www.richardsonrfpd.com

Driving LEDs Efficiently

Standard LEDs are mainly used for indication purposes, but new designs also show LED array solutions for replacement of neon light tubes. For these applications, Diotec introduces a so called "Current Limiting Diode", which can be used to drive standard LEDs. High Power LEDs, which are more and more replacing halogen and compact fluorescent lamps, require a much higher driving current in the range of 350 to 700mA. Power LEDs are driven usually by means of a flyback converter. Halogen and compact fluorescent lamp retrofits are very space critical, therefore the converter board must be as small as possible to help obtain the necessary compact size.



Typical forward current I_F vs forward voltage V_F curve of a CLD device

New approaches use standard LED arrays to replace fluorescent lights (neon tubes), especially in areas where no high-level lighting is required, e. g. floor lightings, wash and lunch room luminaire, or outdoor lights. Standard LEDs are robust, long-living and available in high volumes at low costs; their power consumption is on a very low level below 100mW. The driving current of such devices is typically 20mA, resulting in a forward voltage drop between 2V and 4V.

Driving LEDs with CLD

Like a Zener diode keeps a voltage constant over a wide range of Zener current, the Current Limiting Diode (CLD) keeps a current constant over a wide range of forward voltage. When applying a positive voltage from anode to the cathode, the current rises until it reaches a constant value I_P. The start of this current limiting area is defined by the limiting voltage V_L, above which I_L = 80% of I_P is reached. IP remains constant, unless a maximum admissible voltage V_{AK} is reached, above which a breakdown happens and the device can be destroyed. In reverse direction, the voltage V_R is quite quickly reached. So operating voltage range is between V_L and V_{AK}, where current is kept to a constant value I_P; the reverse direction is normally not used.

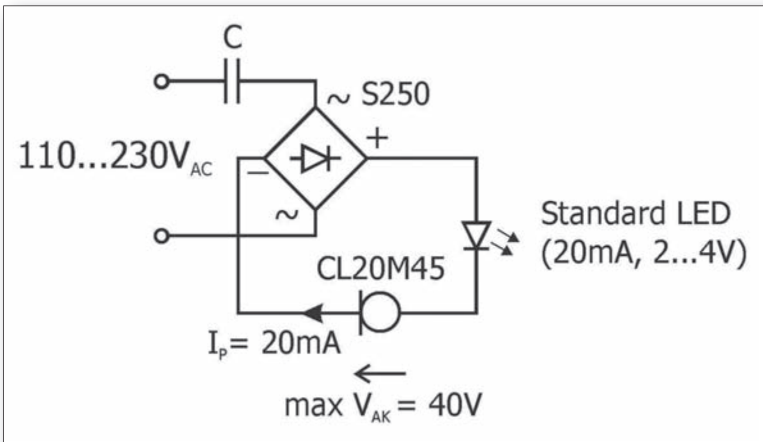
Taking the function of the CLD into account, such device can be used to drive LEDs with a constant current from a variable voltage source V_{IN}. The only condition is to limit the voltage across the CLD to a value less than V_{AK}; that voltage is the difference between VIN and the voltage drop at the LED, $V_{F\text{-}LED}$. The CL20M45 is designed for an I_P of 20mA, V_{AK} is 45V. So in the easiest case, this CLD can be used to drive a single LED from a voltage source ranging from 10VDC up to 45VDC. In order to get higher currents, CLDs can be even operated in parallel; of course the power dissipation / power losses will increase then as well.

However, in most cases there is an AC voltage source, so additionally a (bridge) rectifier device is required. If the circuit is connected directly to the 110V/230VAC mains, V_{IN} can reach quite high levels up to 350V peak. So existing designs require a lot of additional devices, in order to reduce the incoming voltage to an acceptable level; they further require electrolytic capacitors to keep that voltage constant. As a result, such circuits are complex and expensive, and their lifetime is limited mainly by the electrolytic capacitors used.

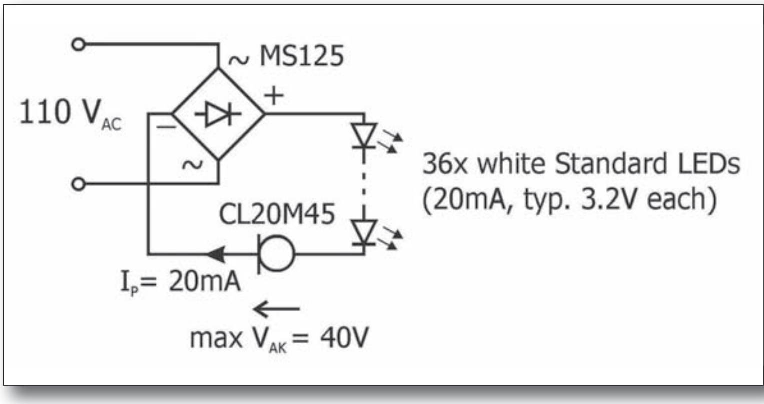
Now by means of just a bridge rectifier, one or two CLDs, either an array of LEDs or an AC capacitor, a circuit for direct operation at 110VAC or 230VAC mains can be build.

This application proposal needs three components to drive one (or more) standard LEDs at a wide input range. The AC capacitor C has got a

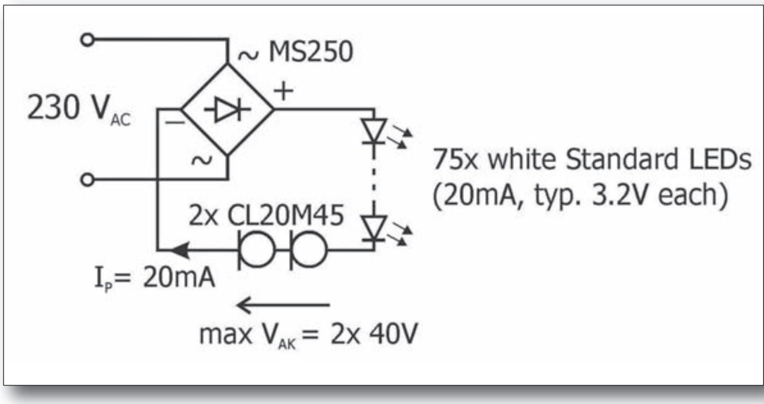
Three component example for LED driving



Two component example for LED driving



Three component example for driving LED arrays at 230VAC



certain dynamic impedance $X_C = 1/(2\pi fC)$. Depending on the output power (and related to that, the input or mains current), there is a voltage drop across this impedance. Capacitor C has to be chosen in such way that the voltage drop is big enough to ensure that V_{AK} of the CLD is not exceeded.

In the application example 2 an array of standard LEDs is used. The resulting voltage drop across the series of LEDs is big enough to ensure V_{AK} is not exceeded. Thus, by only one rectifier bridge and one single CLD a complete LED luminaire operated at 110VAC, can be designed. Since there is no inrush current, the lower cost MS series of bridge rectifiers can be used.

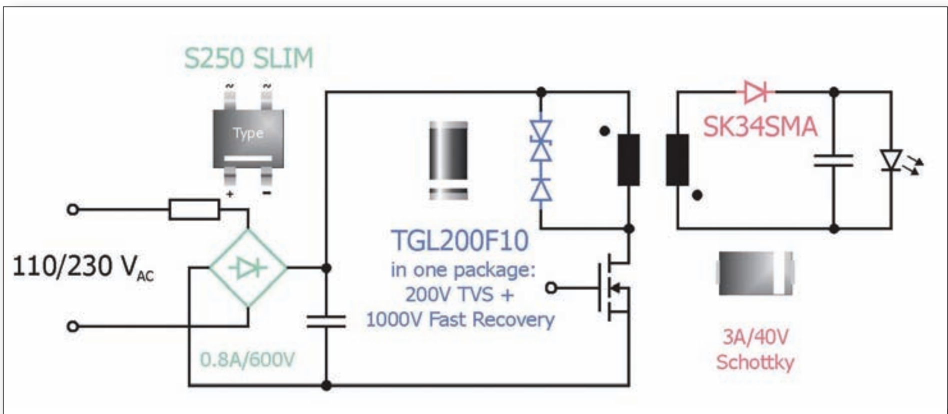
In the application example 3 the same circuit, but operated at 230VAC mains is used. Due to the higher peak voltage, more LEDs have to be connected in series, and also two CLD are used. Anyway, a single rectifier bridge is enough to complete the whole circuit.

In these examples, no electrolytic capacitors are needed nor other complex devices. One may add a simple inductor (coil) in series to the LEDs, in order to reduce the (small) ripple in driving current (occurring during the zero-crossing of mains voltage). Furthermore, a mains fuse can provide circuit protection in case of any unforeseen shorts.

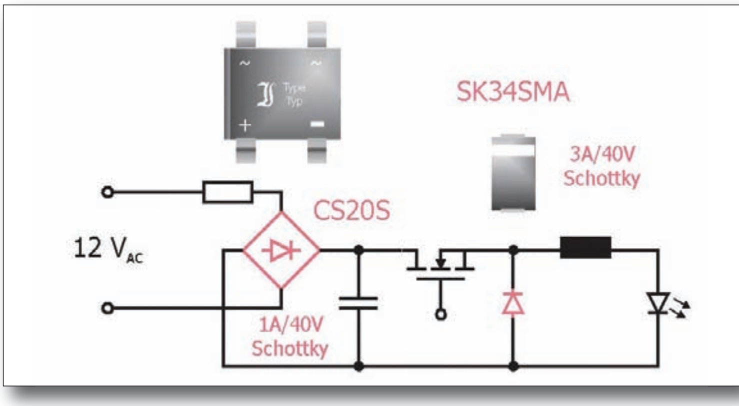
Halogen and CFL retrofits

When replacing halogen light sources, the issues are straightforward. A 4/8W LED lamp has a similar light output as a 30/50W halogen lamp. There are two popular variations - with GU10 or MR16 (GU5.3) connections - depending whether they are operated on the mains or not. LED products used in lighting sources are typically 350mA or 700mA at the moment, in the future they may go up to 1A.

The preferred topology for driving Power LEDs at m 110/230VAC mains at low power levels is the



Flyback converter for driving GU10 LEDs directly at 110/230VAC mains



Buck converter for 12VAC operation of MR16 LEDs

Flyback converter. At 12VAC input a non-isolated topology such as a buck (step-down) converter can be used. The switching stage is available in various integrated versions; main active components to be added are an input bridge, an output or freewheeling rectifier and sometimes a snubber network.

In GU10 designs the input bridge rectifier demands can be easily met from a technical perspective. Space however is always an issue. The S250 SMD input bridge is the optimal component. If lamps are designed for countries where the AC mains is not very well regulated, the 1000V version S500 for extra safety can be considered. The proprietary Plasma EPOS process of Diotec allows production of these small bridges up to 1000V as a standard.

In MR16 designs the bridge can be made out of Schottky rectifiers, giving lower power losses at the (here) higher input currents. It can be made by using four discrete devices such as the SGL1-40 or SK14 (1A/40V), or even the SK34SMA (3A/40V). The SMD Schottky bridge CS20S has an advantage in terms of PCB space savings.

For output Schottky rectifiers normally a 1A Schottky would be sufficient. However the need for a lifetime of up to 50,000 hours necessitates a lower junction temperature in the semiconductors to get a better MTBF, the SK34SMA series is suited for this application. The device offers a 3A/40V rating in the small SMA package. By using them at 350mA or 700mA, designers will increase the lifetime of their design.

Depending on the transistor used for switching, RC, RCD or active snubbers are needed. In the case of active snubbers and low power, Diotec can integrate the diode and the TVS into one package. An existing device is the TGL200F10, a series connection of a 200V TVS and a 1000V Fast Recovery diode in a single Melf package.

The 2012 Drives and Controls exhibition & conference information pack is now available

With just a year to go the next Drives & Controls Show at the Birmingham NEC, a six-page brochure packed full of information for potential exhibitors is now available. The brochure includes data from the previous event in 2010, such as breakdowns of the visitors to the show by job function, company activities, and product interests. There is also a list of some the Blue Chip companies that attended the 2010 event.
For the first time in 2012, there will be direct connection between the halls containing the Drives & Controls show and the MACH show, allowing visitors to move easily between the two shows. The Drives and Controls exhibition will be in one large hall, along with the other shows organised by DFA Media, including Air-Tech, IFPEX and a new show called Plant & Asset Management.
"Due to the success of 2010 and the uptake so far, we have increased our space allocation," says exhibition sales director, Doug Devlin. "Also we will be increasing the seminar programme to reflect current legislation in several key areas." The brochure can be downloaded at **www.drives-expo.com**

"We've been very impressed. We had set a target for the number of enquiries we wanted from the show and had exceeded it by the end of the second day. We look forward to 2012." – Simon Goodwin, General Manager, B&R Automation

"It's been an invaluable show to get our new technology in front of new and existing customers...The leads have been very directed, and a purpose to them…About 80% of the leads are projects or those looking to migrate…You get the footfall at Drives and Controls."
– Mike Loughran, Rockwell Automation

"We're really pleased with the show. In terms of the number and quality of leads, its been up with SPS/IPC/Drives and Hannover. People have been coming with real projects and looking for solutions. We've had some very strong leads"
– Mark Crocker, Marketing Director, Baldor

To receive a free copy of the Exhibition Pack, please contact Doug Devlin on +44 (0)1922 644766 (office), or +44(0)7803 624471 (mobile), or by email at doug@drives.co.uk

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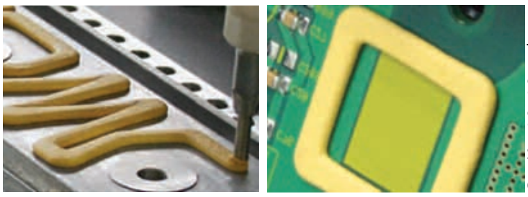

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Advantages of NPC Inverter Topologies

Efficiency is becoming increasingly important in power electronics. Many applications are driven by the initiatives for reduced energy consumption. Inverter applications in the solar market, uninterruptible power supplies and motor drives have new targets for improved efficiency. Vincotech proposes Neutral Point Clamped (NPC) technologies as alternatives for 3~ inverters with 700V DC-link voltage.

The NPC topology offers advantages such as reduced switching losses, smaller output current ripple, and total +/- supply voltage is split. "Only half of the voltage has to be switched, and this also cuts the switching losses in the transistor by half. In the shown NPC topology, it is possible to use 600V components instead of 1200V types. On top of that, in the 600V technology much faster components are available than in 1200V. This will lead to further reduction of the switching losses", outlines Marketing Manager Michael Frisch. The Neutral Point Clamped topology additionally will have lower ripple in the output current and half of the output voltage transient. This will reduce the effort for filtering and isolation in the filter inductor. Also the DC voltage is divided into a positive and negative voltage, which supports the serial connection of DC capacitors without the need for leakage current compensation.

These advantages have to face the drawback of a higher complexity. More components have to be handled (10 instead of 4) and the NPC topology requires 4 independent gate drives instead of 2 in the standard half bridge topology.

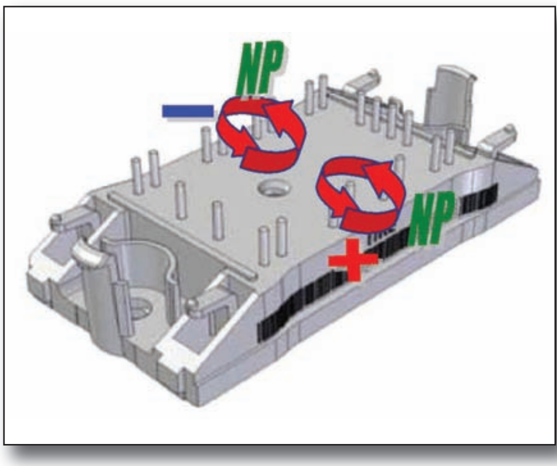
Challenges for NPC power modules

The NPC topology is distinguished with a higher complexity this makes the circuit more sensitive for parasitic effects. To avoid such disadvantages more care for the module design have to be taken.

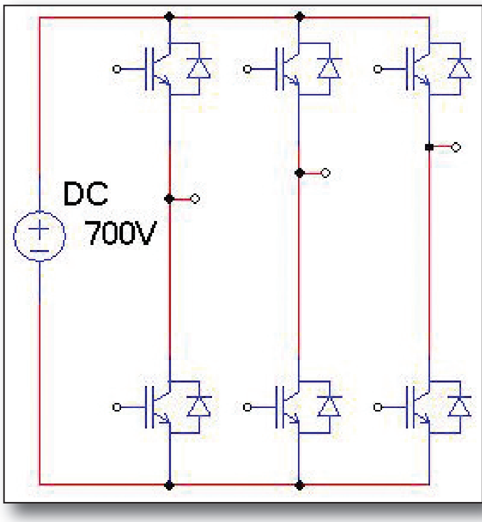
In half bridge topologies is the low inductance between DC+ and DC- decisive. The same is valid for the NPC topology but here is additionally a low inductance between both DC voltages and the neutral point (NP) important. This task is hindered by the fact that more components are included. The inductance of power module based circuits is mainly influenced by the wire bonds of the semiconductors and the external interconnection. The inductive loops inside the power module are largely cancelled by the eddy current inducted into the backside metallization of the module.

Vincotech has made a benchmark of the topologies. In the comparison standard half bridges are compared with the NPC topology and with a mixed voltage 3-level topology under the following conditions:

- 4,6kW Static load (25A) per phase
- 700V DC voltage (2 * 350V for 3-level)
- Output frequency 50Hz
- Modulation frequency 16kHz
- Hard switching environment



Pinning of a low inductive 1200V-75A NPC module



Standard inverter with 3 half bridges

- Sinusoidal output voltage waveform (230VAC)
- Sinusoidal output current waveform
- Cosfi=0,8
- 17,2kVA 3 ~ power

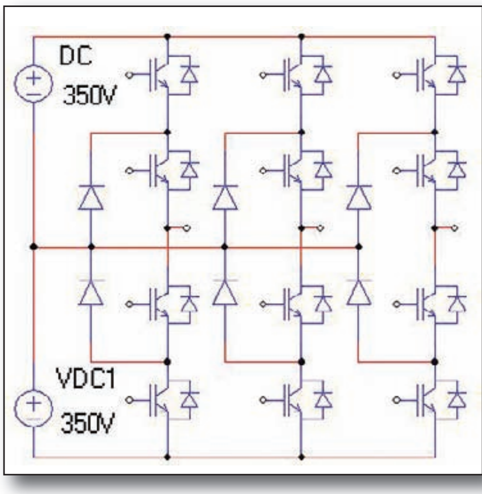
The effort or chip area is given as the product of voltage rating and nominal current of the power semiconductor which is in line with the cost of the semiconductors.

The standard configuration for a 3 ~ inverter are 3 half bridges. The components are 2nd generation of 1200V trench field-stop IGBT's with the corresponding freewheeling diodes. The result is:

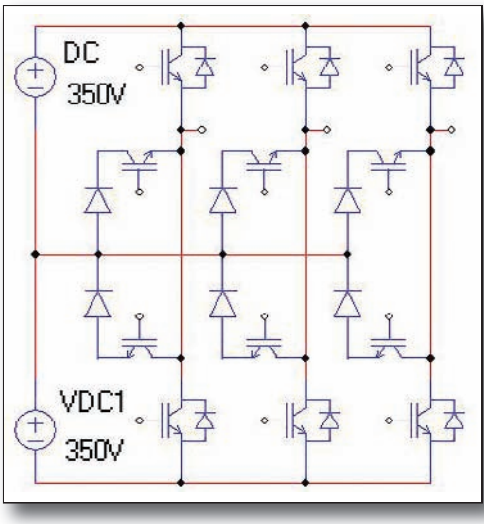
- Conduction losses 36W
- Switching losses 118W
- Total losses 154W
- Efficiency 96,65%
- Total rating of Si 540kVA.

The NPC topology is the next circuit to compare. The components are the first generation of 600V trench field-stop IGBT s with the corresponding freewheeling diodes. Here the results:

- Conduction losses 62W
- Switching losses 28W
- Total losses 90W



NPC topology



Mixed voltage 3-level topology

- Efficiency 98,04%
- Total rating of Si 900kVA.

An additional 3-level topology is the mixed voltage topology. This circuit combines the low conductive losses of the half bridge solution with the advantages of switching only between DC+/- and the NP.

The problem is here that the outside transistors have to be rated with 1200V, this reduces the switching performance to the level provided by 1200V components. The components used in the benchmark are high speed 1200V IGBTs and freewheeling diodes for the outside switches and the first generation of 600V trench field-stop IGBTs with the corresponding freewheeling diodes for the NP-switches. However, here the results:

- Conduction losses 50W
- Switching losses 40W
- Total losses 90W
- Efficiency 98,04%
- Total rating of Si1080kVA.

"The comparison shows that with both 3-level topologies are 98,04% efficiency achievable compared to 96,65% of the standard 3 ~ bridge. The effort in semiconductor cost is 720kVA compared with 900kVA for the NPC", Frisch stated. "The components of the NPC will stay cooler so that a comparison at T_{jmax} will show that the components could be used at higher currents. With a optimization of the chip size to the same T_{jmax} at the same power, the NPC module will be significantly lower in cost than a standard half bridge component. The additional advantages in reduced EMC and increased efficiency are on top. The mixed voltage 3-level topology achieves the same efficiency as the standard NPC but it have to provide a higher effort for the semiconductor of 1080kVA compared with 900kVA of the NPC", Frisch concluded. At PCIM's first day (May 17, 11.00-12.00) Vincotech will introduce a "Mixed Voltage NPC Power Module with SiC for Highest Efficiency Solar Inverter" in the Forum (12-377).

99% efficiency with SiC

Three-phase photovoltaic application becomes new trend. It requires the highest efficiency. Both NPC and mNPC 3-level topologies satisfy this requirement by offering over 98% of system efficiency. By comparing between those two topologies, the mNPC topology shows advantages for photovoltaic application due to lower conduction losses. To overcome the last barrier and reach over 99% of system efficiency, switches based on wide bandgap material must be utilized. Vincotech offers here a new module family with 1200V SiC switches and diodes based on mNPC topology from SemiSouth. These new switches are normally-off SiC JFETs. They show superior conduction and switching performance. Simulation based on characterized values shows the possibility to reach 99% of system efficiency.

Literature

Michael Frisch and Temesi Ernö: Advantages of NPC Inverter Topologies with Power Modules, Power Electronics Europe 6/2009, pages 28 - 30.

PCIM Europe 2011
International Exhibition & Conference for
POWER ELECTRONICS
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POWER QUALITY
17 – 19 May 2011
Exhibition Centre Nuremberg

Power Semiconductors Improve Energy Efficiency

In face of the ongoing Japanese nuclear crisis the discussion on enhanced funding for renewable energies is expanding, but also efforts in energy savings. Newly designed power semiconductors based on Gallium Nitride and Silicon Carbide will support the requirements of both sides, as PCIM from May 17-19 in general and PEE's Special Session on May 18 in particular will show. Having introduced the main facts about PCIM 2011 in our March issue the focus is now on the presentation of new technologies.

Increasing energy costs are not only a burden for private households. In fact, they are becoming an increasingly strong competitive factor among companies. At the same time, ecological targets are driving us to be more responsible in our use of resources. Today, for example, 40% of the energy consumed worldwide is electric energy, a figure that is expected to rise to as much as 60% by 2040. Thus, electricity is the energy of the future, this is consensus within industry and research. As a result, the need for power electronics will grow, too.

Extensive research in power electronics

In power electronic assemblies and systems, besides power semiconductors, passive components such as coils and capacitors are key components. With the major advances achieved in the field of power semiconductors over the past 20 years, at the moment the only things standing in the way of a further reduction in the size of power electronic assemblies is the space needed for the passive components. The reason for this is that the physical boundary conditions relating to the miniaturisation of passive components are far more restrictive than, say, in the area of IT and commutations technology. In communications systems, for example, bits and bytes are being incorporated into increasingly compact systems; in contrast, the electric energy storage systems needed for power electronic processes have to meet a given minimum volume due to the material properties. For this reason, users generally regard passive components as being too large, too heavy and too costly. The focus here should therefore not only be for these components to sustain the developments in the area of power semiconductors. Rather, there should be a call for further improvements in these components as regards higher operating frequencies.

Thus leading passive component manufacturers such as Epcos (**www.Epcos.com**), Sumida (**www.SUMIDA.com**) and Via Elektronik (**www.via-electronic.de**) are joining forces with materials specialists and research institutes such as Treofan (**www.Treofan.com**), FIT Ceramics (**www.FIT-Ceramics.com**), Bosch (**www.Bosch.com**), Semikron (**www.SEMIKRON.com**), Fraunhofer IISB and Fraunhofer IKTS (**www.Fraunhofer.com**) to work on the joint research project "Efficient passive components with maximum energy density for increased temperature range in power electronics - EPa". The aim of the EPa project is to enable the manufacture of far more compact - and hence

PCIM 2011 again will attract more than 6300 visitors and 630 conference delegates. Again PEE's editor (left) and PCIM organizer Udo Weller (right) will hand over the Best Paper Award (2010 to Christian Nöding, University of Kassel) covering €1000.00 plus trip to PCIM Asia 2012

resource-efficient power supply systems - by using innovative passive components. "What makes this cluster different from others is that for the first time component manufacturers and users are working together on improving the technology used in switched-mode power supply systems", explains the cluster co-ordinator Johann Winkler. The total volume is totalling €2.923 million, which is being put into the EPa project as part of the "LES: Power electronics for energy efficiency enhancement" programme, expected to be complete by the end of May 2013.

The main aim of the EPa cluster is to develop a new generation of power electronic passive components based on innovative materials, packaging and cooling solutions - a move that will be instrumental in the increasing miniaturisation of power electronic assemblies. To achieve this, a two-pronged approach is being used: firstly, the energy storage capacity of the materials involved is to be improved and, secondly, the energy content stored in a coil, $1/2\ LI^2$, or in a capacitor, $1/2\ CU^2$, is to be transferred from the input to the output of a electronic circuit as often as possible per second. In real terms, this means a clear increase in operating frequency, which in turn generally means a significant increase in heat losses in the passive components, which then have to be limited by using innovative materials or the heat dissipated by way of suitable cooling measures.

"What makes the EPa cluster different from others is that for the first time component manufacturers and users are working together on improving the technology used in switched-mode power supply systems," explains co-ordinator Johann Winkler

In terms of technology, the research focus will be on the improvement of base materials, the optimization of component design, and the development of a compact prototype. On the economic front, the aim is to slow down the current migration movement in the electronics industry by way of R&D work in the field of "best in class" technologies, in doing so safeguarding existing jobs in this sector. The research findings are to be protected by patents. As part of the EPa project, a component demonstrator is to be developed - a mobile charger for batteries used in electric vehicles - which enables both an increase in efficiency in the power electronics and energy savings in the overall system through mass and weight reductions. From an environmental point of view, this will bring about better overall results - especially in mobile applications - than a solution based solely on the reduction of electric power losses.

An other project within LES is the HiT Module, the objective of this project consists of studying a concept for power electronics components suitable for the very high thermal stresses in aerospace as well as automotive applications. Power electronics modules are responsible for the control of electrical drives in these transport vehicles. At this, they are expected to function reliably for many years under extreme conditions. The components must continue to perform under frequent temperature cycles ranging from minus 60°C in aviation to over 150°C in the automobile. Even up to 175°C and more may occur in some areas inside the components while in operation. At the same time the components' footprint should be as small as possible to save space and weight.

The research project aims at meeting these high demands by employing new materials and innovative assembly technique in the construction of these parts. One of the core elements hereby consists of the production and application of a new substrate structure from aluminum oxide ceramics with an aluminum strip conductor system (Direct Aluminum Bonding, DAB). The new concept to be researched will drastically increase the potential of applying power electronics systems in the areas of aircraft and automotive technology. Positive effects on the energy efficiency of the overall system will result especially from the improved reliability of the power electronics modules as well as the weight reduction. For example, hydraulic systems can be replaced by smaller and lighter electric motor systems in aircrafts or powerful hybrid drives in automobiles. The partners IXYS Semiconductor (**www.ixys.com**) in Lampertheim/Germany, Fraunhofer-Institut für Werkstoffmechanik IWM (Halle), Technische-Universität Chemnitz, Otto-von-Guericke-Universität Magdeburg as well as the associated Liebherr-Elektronik (Lindau) jointly conduct this research. The total project volume is €1.5 million.

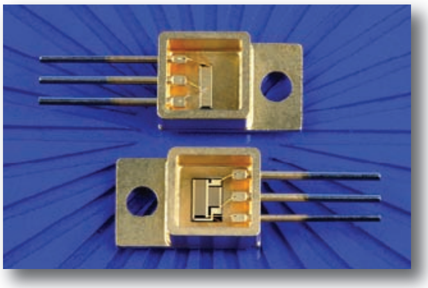
Where electricity is used, power conversion from AC to DC or vice versa and for different voltage levels comes into play, always creating losses. "The DC current supplied by a solar panel must converted to AC for feeding into the grid, and this conversion decreases today the efficiency of the solar energy generation. Here Gallium Nitride transistors with their higher switching frequency capabilities, lower recovery charge and higher permissible junction temperature are more efficient than Silicon transistors, we expect a saving potential of more than 50%", says Prof. Oliver Ambacher from Fraunhofer IAF Institute (**www.iaf.fraunhofer.de**) in Freiburg/Germany. They have designed power transistors for system tests and are working within a research program on demonstrators for an 5kW solar inverter and a battery charger for electrical vehicles based on Gallium Nitride devices. Other partners in this research programme are Bosch, Kaco, IXYS (packaging), and RWTH Aachen.

The impact of wide bandgap power semiconductors on future power electronic systems

That is the motto of a round table discussion on PCIM's first day (May 17, 2.00-4.00 pm, Room Paris) led by ECPE's president Prof. Leo Lorenz.

"After decades of research efforts Silicon Carbide has gained momentum in power electronics. Wafer quality has significantly improved while 150mm wafers are on the way. Schottky diodes with voltage ratings of typically 600V and 1200V are commercially available and used in different kinds of converters, often together with Silicon transistors reducing switching losses significantly. SiC transistors are currently sampled as JFETs, MOSFETs or BJTs. On the user side, solar inverters have turned out to be a lead application for SiC. At the same time another rising star appears at the horizon, Gallium Nitride allowing hetero-epitaxy on Si wafers. This offers new opportunities regarding costs and co-integration with Si device technology", Lorenz stated. Will this new material compete against SiC or will GaN occupy complementary applications in the voltage and frequency range?

"Solar inverters have turned out to be a lead application for SiC. At the same time another rising star appears at the horizon, Gallium Nitride allowing hetero-epitaxy on Si wafers. This offers new opportunities regarding costs and co-integration with Si device technology", Prof. Leo Lorenz states



Gallium Nitride transistors with their higher switching frequency capabilities, lower recovery charge and higher permissible junction temperature are more efficient than Silicon transistors, as has been demonstrated with Fraunhofer IAF test samples

This question will discussed and hopefully answered by the participants Michael A. Briere (ACOO Enterprise/International Rectifier, USA), Peter Friedrichs (Infineon Technologies, D), Oliver Hilt (Ferdinand-Braun-Institute Berlin, D), Prof. Dr. Nando Kaminski (University of Bremen, D), Anders Lindgren (TranSiC, S), Ertugrul Sönmez (MicroGaN, D), Prof. Johann Walter Kolar (ETH Zürich, CH), and Prof. Dr. Bruno Burger (Fraunhofer ISE, D).

Application hints for GaN and SiC

Direct answers on the question how to use new devices made of GaN and SiC will be provided in PEE's Special Session *"High Frequency Switching Devices and Applications"* on May 18 (10.00 - 12.30, Room Paris). Participants are again Michael Briere and Ertugrul Sönmez as well as Bob Callanan (Cree, USA), Jeff Casady (SemiSouth Laboratories, USA), and jointly Gerald Deboy (Infineon Technologies) with Regine Mallwitz (SMA Solar Technology, D). Because of the in-depth content of the papers this is an extended session with panel discussion comprising all speakers after the final presentation.

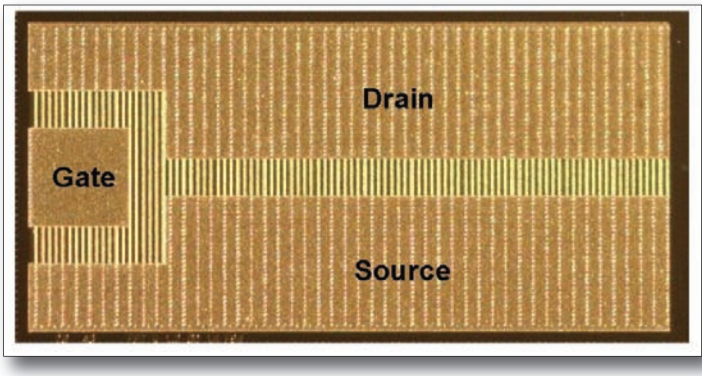
Efficient GaN products for 600V operation

Especially for mains voltage applications, new efficient 600V class devices are required. These devices are within the main product focus of MicroGaN (**www.microgan.de**). Two basic elements are devel oped 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.

Discussed will be the requirements on the semiconductors facing the high voltage level in front of the transformer of a typical mains voltage application for a standard DC down-conversion. Simplified speaking, the core circuit elements are the PFC and the hard switched H-bridge for instance. The next section introduces MicroGaN's approach to address all these demands of a high efficient mains voltage application for a standard DC down-conversion, including low cost solutions.

MicroGaN utilizes a lateral HEMT device technology using 4-inch and 6-inch GaN-on-Silicon wafers for its 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 leading to an output charge of about 10nC with an on-resistance of about 180mΩ. The GaN-HEMT is switched off for control voltage values $V_{GS} < -3V$, whereas the full on-state is reached for values above 0V.



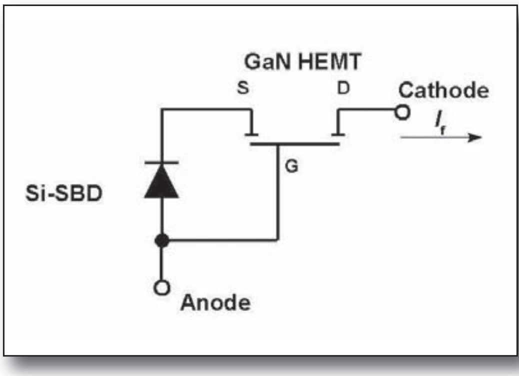
MicroGaN's normally-on 600V 180mΩ GaN-HEMT

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 negligible Gate-Source capacitance of about 1pF and 8pF for the Gate-Drain capacitance allows the transistor to be seen as purely voltage controlled device.

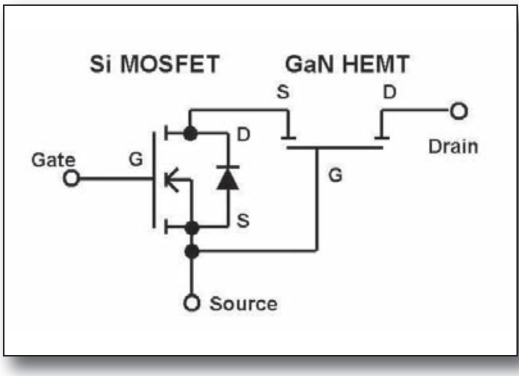
Basic elements suitable for power application circuits are derived from the GaN-HEMT, a low barrier power diode and a normally-off power switch for Cascade or Cascode operation.

The cascade consists of a low voltage (30V) Si-SBD (Schottky Barrier Diode) and a 600V GaNHEMT. The resulting behavior of this 2-port circuit is a 600V SBD with a barrier of a low voltage Si-SBD. This cascade provides a voltage barrier of 0.3V with a differential resistance of about 200mΩ. The Gate-Drain path of the GaN-HEMT defines the 600V behavior of the cascade, whereas the Si-SBD is charged to about 5V. The cascade's charge is roughly the output charge of the transistor (10nC) in addition to the charge of the Si-SBD at only 5V, which is in some single digit nC-value range. With at least comparable charge values to SiC-SBD an unbeatable low on-set voltage can be obtained.

The application benefit of this cascade is manifold: Used as a PFC-Diode, it will pass current starting at 0.3V, which gives an excellent tool for wide efficiency bandwidth solutions. The low cascade 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,



MicroGaN's Cascade of a low voltage Si-SBD with a HV GaN-HEMT



MicroGaN's Cascode made of a low voltage Si-MOSFET with a HV GaN-HEMT

charging of several µC and a harming recovery time of several hundred ns are prevented.

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 GaNHEMT are added to about 200mΩ. In the off-state of the cascode the Si-MOSFET is switching off the GaN-HEMT and is charged to about 5V, analog to the cascade. Here again, the Gate-Drain path of the GaN-HEMT is defining the 600V behavior of the cascode. In the reverse operation mode (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 5V) and these of the GaN-HEMT (high speed, no body diode, lowest possible charge). This cascode is predestinated to be used in hard switched / high switching speed PFCs as well as in H-bridges, maintaining the high peak and wide bandwidth in efficiency.

"As a result, the target to enable design and fabrication of improved high efficient mains voltage down-converters is reached. Furthermore, by combining the presented elements Cascode and Cascade, one may obtain an unprecedented pair of design elements for realization of efficient motor drive applications, too", Ertugrul Sönmez summarizes.

Fast switching GaN based power devices enabling high frequency power conversion

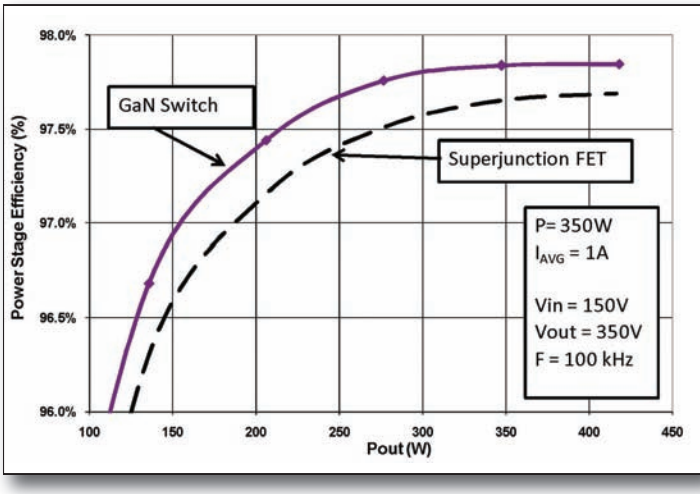
This second GaN paper given by ACOO Enterprise/International Rectifier (**www.irf.com**) will present GaN based power devices in point of load (POL) applications such as VRMs for CPUs and compares them to state-of-the-art alternatives. This paper has been nominated for the Best Paper Award handed over at the PCIM Opening Ceremony.

The prospects for high efficiency, high density conversion to optimally support future multicore processor units will be discussed. In addition, the performance of GaN based 600V rectifiers and switches are discussed in terms of supportive high efficiency and higher frequency power supplies for AC/DC and inverter systems.

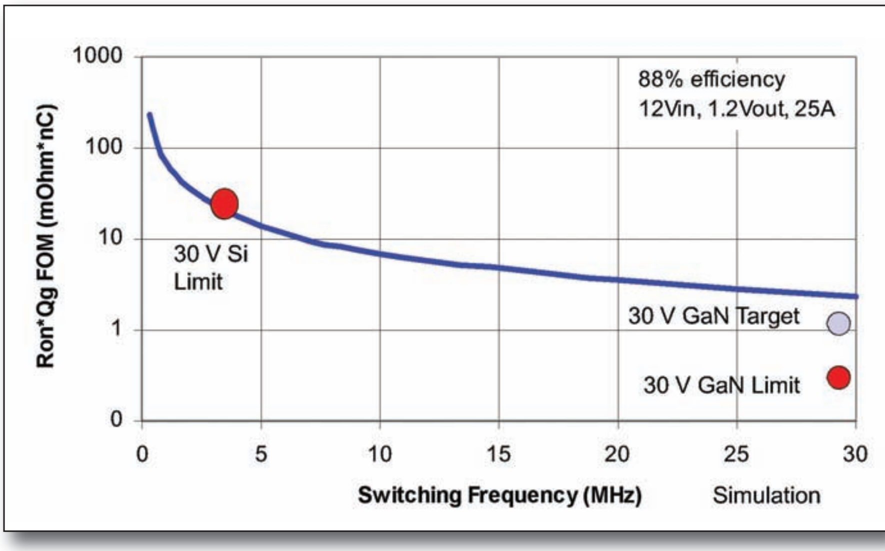
The current state-of-the-art in VRMs consists of a single point of load power supply for each multi-core processor. The processor then regulates the state of each core and divides the incoming power accordingly. Even here there are increasing pressures to decrease power supply size and improve power delivery efficiencies. It has been estimated that some 30-40% of the motherboard PCB area is occupied by power supply circuitry. It is therefore desirable to significantly reduce the PCB area occupied by the power supplies. As Silicon based technology is reaching maturity, a truly revolutionary change in this performance FOM requires that a fundamentally new power device technology platform be introduced.

The trade-off between density and efficiency is largely a question of switching frequency. As the switching frequency increases, losses are compounded in the power converter from three main sources: namely the driving losses, the current x voltage overlap of the power devices and the dissipative capacitive losses of the device output impedance. In addition there are core losses in the magnetic element of the output filter inductance. To achieve improved efficiency, it is therefore imperative that improvements in the power device behavior, particularly the requisite input and output charge levels involved in the device switching between on- and off-states be achieved (Qswitch).

A sufficiently high performing



GaN vs Superjunction MOSFET in HV PFC application



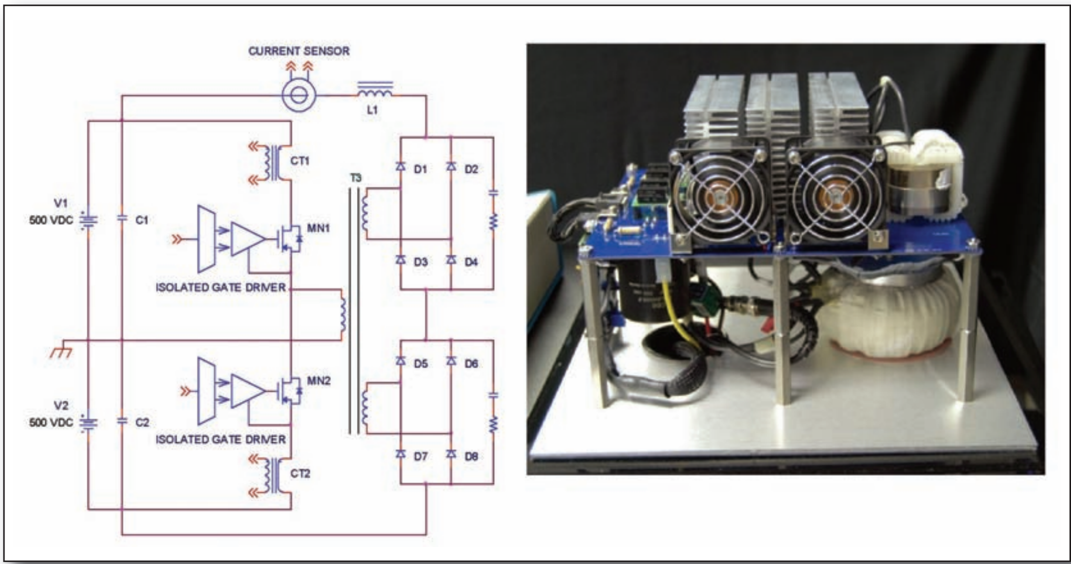
According to ACOO/IR a FOM of 3mΩnC will be achievable with 30V GaN based devices within the next five years

power device technology would allow the direct conversion of 12V (or even 48 V) to POL voltages at high enough frequencies to permit integration of the power stage in the package, or directly bonded to the CPU die, while providing low enough FOM to support efficient power conversion (i.e. > 85 %). Besides reducing the size and improving the overall conversion efficiency, this approach would significantly reduce the current bussing requirement in the CPU package and die. More importantly, a direct bonding approach would allow for each micro-core to control its own power supply, dramatically improving the overall computer energy efficiency. Michael Briere suggests that such a power device technology is possible using GaN-HEMTs. He expects that an R_{on} x Q_g FOM of 3mΩnC will be achievable with 30V GaN based devices within the next five years, supporting a single stage switching frequency of greater than 50MHz and allowing for intimate integration of power stages with the individual cores of many-core processors.

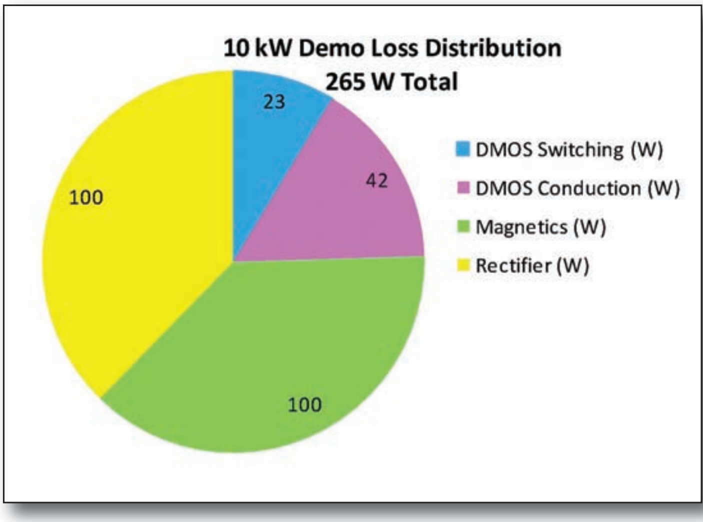
As in the case for low voltage devices, GaN based 600V power devices also exhibit significantly better switching performance than Silicon based alternatives. These switches exhibit significantly less switching losses compared to Superjunction FETs and IGBTs. In fact, the E_{ts} x V_{ceon} performance figure of merit for first generation GaN based 600V switches exceeds that of state-of-the-art Silicon based alternatives by at least a factor of 4. "These improved switching performances make GaN based power devices excellent candidates for such high speed circuits as PFC AC/DC converters, as well as for use with switches in inverter circuits for motor drive or distributed energy generation applications", Michael Briere concludes.

Demonstration of 1.7kV SiC DMOSFETs

After introduction of the first 1200V SiC MOSFET (see PEE 1/2011, pages 21-22), Cree presents (**www.cree.com**) the results of a 10kW transformer isolated DC/DC



LEFT: Schematic and hardware of the 1700V/10kW all-SiC demonstrator designed by Cree



Power loss distribution of the 10kW SiC demonstrator - magnetic and rectifier losses (100W each) dominate the figure

converter design using 1.7kV SiC DMOSFETs. The converter is a half-bridge topology operating at around 30kHz hard-switched with a link voltage of 1kV. An efficiency of 97.5% was achieved without extensive optimization. The characteristics of the 1.7kV SiC DMOSFET, design details of the converter, and measured results are presented.

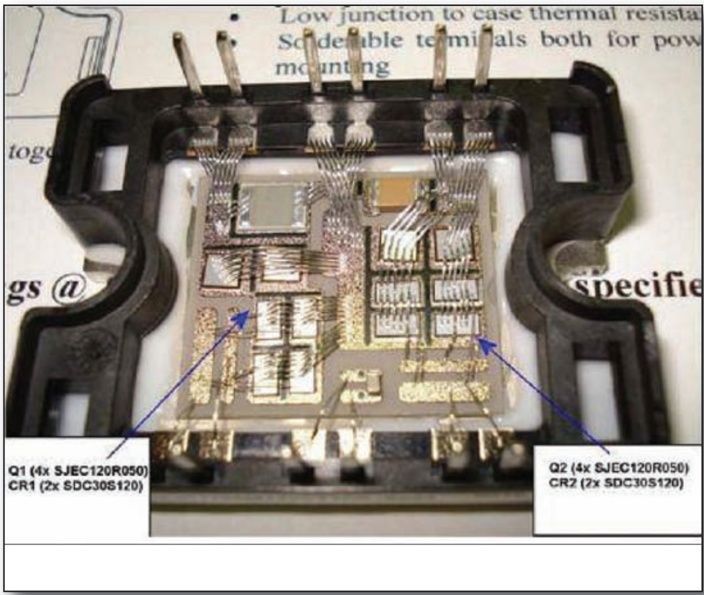
The switch consists of a 1.7kV DMOSFET and a 1.7kV 10A SiC JBS diode co-packed in a TO-258 package. The DMOSFET die size is 4.08 mm x 4.08 mm. The JBS diode die size is 2.70 mm x 3.81 mm. The on resistance of the device is less than 80mΩ with 20V gate drive. Breakdown starts to occur at 2kV and the leakage at zero gate bias is less than 15nA at 1.7kV.

One of the major issues in power testing high voltage power SiC DMOSFETs is that any demonstration circuit to fully exercise the device by definition must be at a very high power level. This requires the use of a high power source and load. The approach taken for this demonstration was to construct a DC/DC converter and feed the output current back to the input of the converter. The converter delivers full power, but the power source need only deliver the circuit77 losses. This approach also gives a direct measurement of the total system power loss. The controls were implemented with a standard Texas Instruments UC3825A pulse to pulse current mode controller. The current mode controller provided pulse to pulse peak current control for the two switches. A Hall effect current sensor is used to sample the current delivered by the converter. An error amplifier compared the value to a reference to regulate the delivered current to a nominal 10ADC. The thermal design employs standard heat sink extrusions for the power semiconductors using forced air. The transformer cooling was accomplished by conduction to base plate.

"The switching losses of the converter are fairly moderate, being about 1/3 of the 265W total device loss. Therefore, higher frequencies are definitely possible. The design was very conservative and no attempt was made to minimize size or optimize efficiency. Nonetheless, the demonstrated efficiency was 97.5%. The efficiency can be improved to over 98% by using a single bridge rectifier with more aggressive voltage overshoot control", Bob Callanan explains.

1200V enhancement-mode SiC VJFET power modules

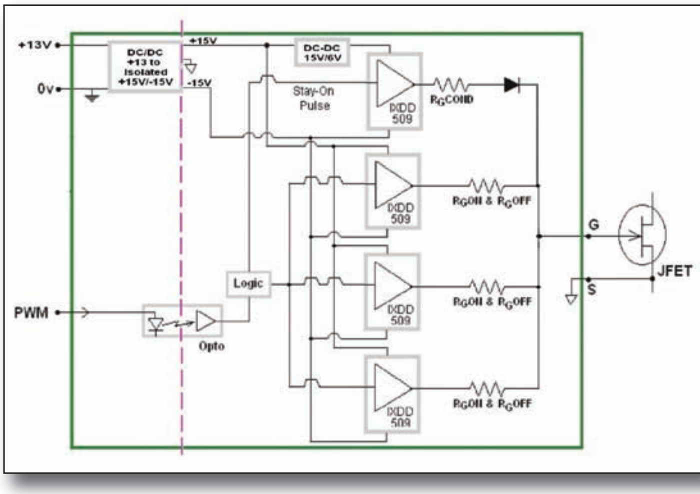
A large portion of applications interested in using SiC power transistors require higher power devices typically packaged in module form factors to save on cost, system area, and cooling requirements. Recent module development work has yielded fast switching, 1200V, 13mΩ, enhancement-mode SiC JFET half-bridge modules packaged in SP1 modules assembled by Microsemi Bordeaux/France. These modules are developed using a parallel combination of 36mm² SiC VJFET die and 23mm² Schottky diodes. A specific on-resistance of 2.7mΩ-cm² was achieved at



Half-bridge, phase-leg configuration using 4 parallel 50mΩ SiC JFET die per switch. Anti-parallel diodes composed of 2 parallel 30A SiC SBDs and internal snubbers included for minimizing oscillations in the SPI package

ID=100A. Switching measurements conducted using a standard double-pulse, inductive load circuit at 600V, 100A, and temperatures of 25°C and 150°C resulted in record low total switching energy losses of 1.25mJ for 100A at 150°C. This paper presented by SemiSouth (**www.semisouth.com**) documents measured switching performance, the gate driver circuit used, and snubbers recommended to achieve these results.

Prior publications introduced an optimized two-stage DC coupled driver specifically designed for SiC JFETs. The first driver stage initially delivers a high peak current pulse at the turn-on transient to quickly charge the devices input capacitance thus achieving very fast turn-on speeds. Once the device has full transitioned to the conduction state the second driver stage reduces the output current to a modest steady state current required to keep the device in the conduction state. The same idea can be used for the SiC JFET modules with a simple adjustment to the output current specs of each driver stage. The driver designed for a single die, 50mΩ SiC JFET delivers a maximum of 9A peak at turn-on. Since the SP1 modules are designed with four paralleled 50mΩ die for each switch



25A peak gate driver schematic for driving SP1 modules

position, the input capacitance will be four times that of the discrete device. Thus the module will require a much higher peak gate current at turn-on for the fastest switching times. The paper will describe in detail the modifications made to the two-stage driver required to make it suitable for driving modules. Also switching characteristics for the single die along with results for the module each driven with the described two-stage gate driver circuit will be presented.

"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 modules. However, in order for users to achieve the 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 parasitics", Jeff Casady states.

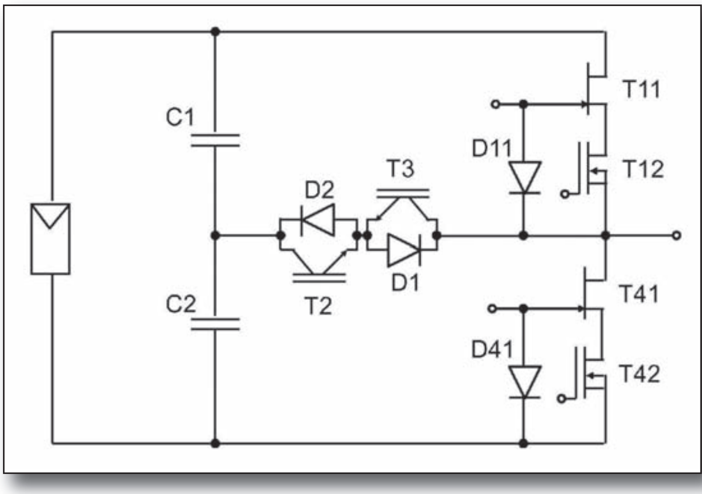
New SiC JFET with integrated body diode boosts performance of photovoltaic systems

This joint paper from Infineon Technologies Austria (**www.infineon.com**) and SMA Solar Technology (**www.sma.de**) proposes a new normally-on SiC JFET device concept with monolithically integrated body diode. Combining ultra fast switching with ohmic forward characteristic and a zero reverse recovery behavior of its body diode allows a significant boost of the performance of photovoltaic 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, compatibility with safety aspects in voltage driven topologies is implemented in combination with a low voltage MOSFET.

The device concept used is a normally-on SiC JFET. "We believe that a JFET structure without a channel being formed below a gate oxide has strategic advantages across a SiC MOSFET", Infineon's presenter Gerald Deboy explains. "First, the reliability aspect - central to applications in photovoltaic converters - is easy to meet in a JFET structure but difficult in a MOS structure due to the still high density of extrinsic failures in the oxide. Second, the still unsatisfying sub-threshold 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 are the structural elements of a SiC JFET 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 a DC/AC output bridge. If this diode is not present in the device structure a full current rated SiC Schottky barrier diode has to be bought additionally for paralleling with the SiC JFET. During hard commutation the body diode of the proposed SiC JFET shows practically a zero reverse recovery charge. This behavior is otherwise known only from SiC Schottky barrier diodes.

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 3. These ultra low switching losses are the natural key to move towards higher switching frequencies needed for the cost reduction of the magnetic components.

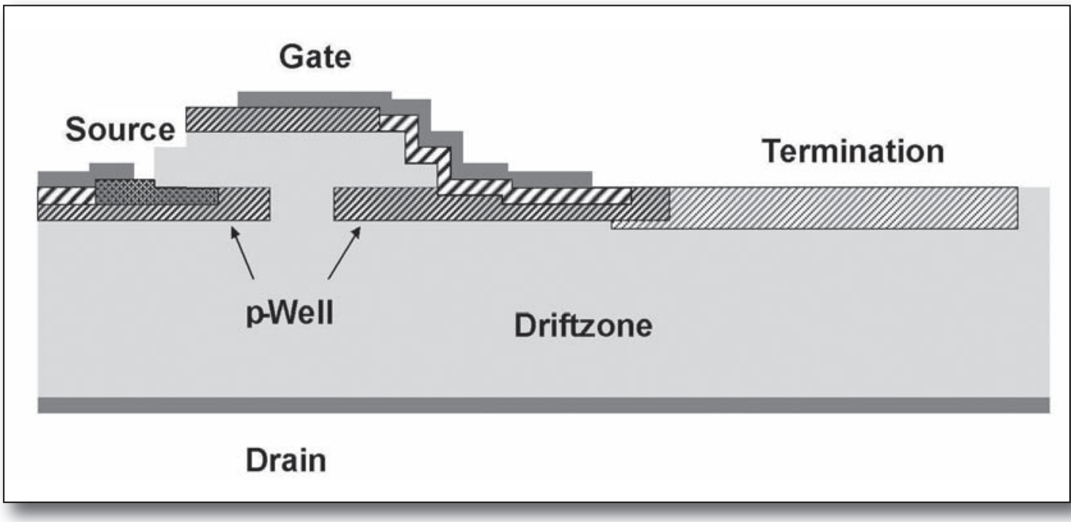


Cascode-light in the SMA's BSNPC topology

"Solar string inverters are characterized by output power between 1kW up to about 20kW, comprise single phase or three phase topologies and show very high efficiencies up to 98%. For increased efficiencies suitable topologies in combination with low-loss power semiconductors are required. SiC power semiconductors promise a high potential achieving this target. Additionally the integrated body diode of the proposed new SiC-JEFT allows a significant boost of the performance of photovoltaic inverters especially in the light of new requirements such as reactive power capability and fault ride through", adds SMA's Regine Mallwitz. The company has designed a so-called Bipolar Switch Neutral Point Clamped (BSNPC) topology combining a SiC-JFET with a low-voltage MOSFET perfoming a normally-off switch in critical situations. This arrangement (Cascode-light) fulfills the safety requirements for solar applications. "The influence of the MOSFET losses on the inverter losses is marginally as demonstrated by calculations. Measurements of losses using normally-on SiC-JFETs in a direct driven arrangement in a real solar inverter are being prepared and will be presented", Mallwitz states.

Thus PEE`s Special Session with its presenters of leading companies in wide bandgap technologies not only presents the latest developments in devices, but also in high-frequency applications. Finally, conference delegates will have the chance to direct their questions to all speakers after the final paper, a chance not possible at other events.

AS



Cross section of Infineon's proposed SiC JFET device concept

99% Efficient AC/DC Converter Topologies

"Hybrid-switching and Storageless-switching methods are overcoming the limitations of the square-wave switching and their resonant and quasi-resonant converter derivatives", Teslaco's president Slobodan Ćuk states **Photo: AS**

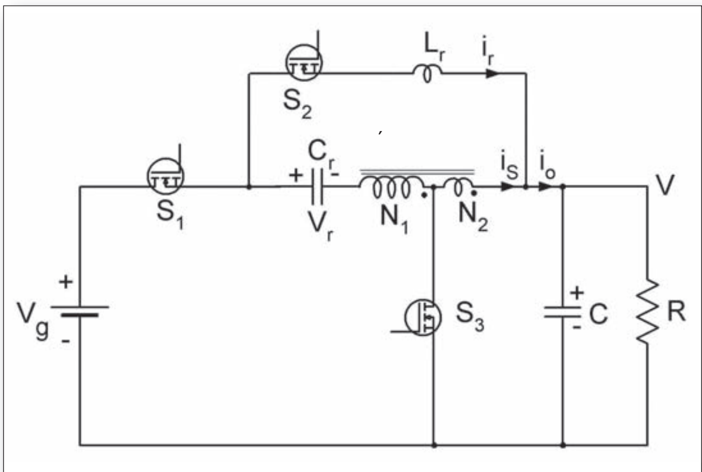
Present switching DC/DC converter topologies are based mainly on inductive energy transfer. Slobodan Ćuk has invented new switching methods and converter topologies, which take advantage of capacitive energy storage and transfer. This is also the subject of his keynote at PCIM 2011 (May 17, 9.45 in Room Paris).

One example is TESLAco's (**www.teslaco.com**) 48V to 1V DC/DC converter shown in the schematic (US patent No. 7,915,874) based on his novel Hybrid-Switching method and the resonance between resonant inductor and resonant capacitor during the OFF-time switching interval only, but still using a PWM transformer, hence Hybrid-Switching name. Despite the presence of the resonant OFF-time interval the DC voltage gain is dependent on duty ratio D only and independent of the load current.

Drastic reduction of switches

In his speech Dr. Ćuk will show how his Hybrid-Switching method also leads to AC/DC converters with PFC and isolation in a single-stage processing, while at the same time eliminate bridge rectifier and operate directly from the AC line. He will also show its unique extension to three-phase rectifier. AC/DC converter topologies based on Hybrid-switching Method result in reduced number of switches (only 4) for Ćuk-rectifier compared to 14 for AC/DC bridge-type converters. The same benefits are also available in a "Single-stage Inverter with High Frequency Isolation Transformer" (Ćuk-inverter).

Dr. Ćuk has also invented a Storageless Switching method applicable to non-isolated as well isolated DC-DC conversion applications. Such a non-isolated step-down storageless converter uses two small resonant inductors and no PWM inductors. Resonant inductors are 10 times smaller then their PWM inductor counterparts in the conventional buck and boost converter. Therefore, the copper and core losses are much reduced and lead in addition to tenfold reduction of size of the converter and efficiencies over 99%. Despite the two distinct resonances, the output



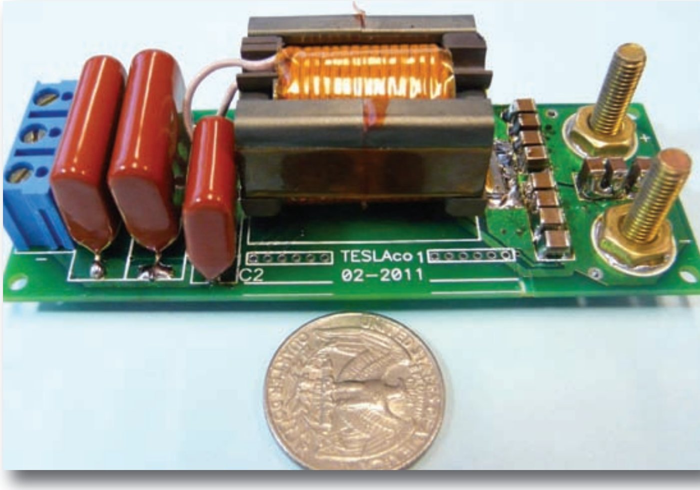
Hybrid-Switching 48V to 1V DC/DC converter schematic

Non-isolated step-down storageless converter, which uses two small resonant inductors and no PWM inductors

voltage is regulated controlled by the duty ratio D providing the output voltage at 48V for input voltage from 100V to 125V with efficiency of over 99% at 750W.

Another example shown has no inductors and a single AC transformer (Ćuk-type), with no DC bias and yet provides very low input and output voltage ripples. Voltage stresses of primary side switches never exceed input voltage while secondary side switches never exceed the output voltage resulting in optimum switch utilization. The transformer is at least four times smaller than the corresponding transformers in present conventional converters based on Square-wave and resonant switching methods. As the converter does not have switching losses and has no losses due to transformer leakage inductance, its efficiency is extremely high and over 98% over the wide input voltage range as seen in the efficiency curve for a 500W, 380V to 24V converter.

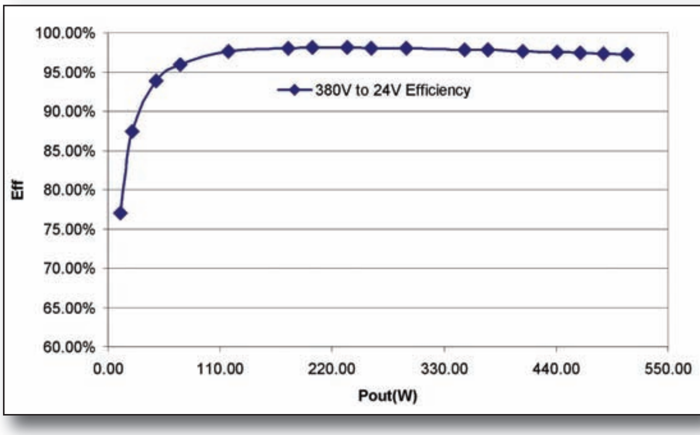
This converter is ideal for the new 380V DC voltage bus being implemented in new data centers.



Converter prototype which has no inductors and a single AC transformer (Ćuk-type)

The converter also regulates the output DC voltage while preserving its no DC storage feature. For high power of 1.5kW three such converters operated in parallel preserve the same over 98% efficiency feature and have much reduced capacitive filtering.

Hybrid-switching and Storageless-switching methods and the corresponding converter topologies are overcoming the limitations of the Square-wave switching and their resonant and quasi-resonant converter derivatives, such as: large number of switches and their poor utilization, large AC fluxes requiring either large magnetic cores or operation at ultra high switching frequencies. The prototypes shown operate at 66kHz and 150kHz respectively, while still having a small size and efficiencies over 99% and 98% respectively.



Efficiency curve for a 500W, 380V to 24V converter

High Power IGCT Switches - State-Of-The-Art and Future

Today, ABB's IGCTs (Integrated Gate-Commutated Thyristors) present the best option for medium voltage drives operating at the highest power levels. Combined with optimum switch-off conditions during operation, the switch offers excellent reliability in demanding conditions. Here, we introduce ABB's latest generation of IGCT technology and provide an outlook into product development of IGCTs of the future.
Thomas Clausen, Björn Backlund, ABB Switzerland Ltd, Semiconductors, Lenzburg, Switzerland

In Figure 1 the maximum average on-state current rating per device vs. blocking voltage for various ABB high power semiconductor devices is shown. Phase controlled thyristors (PCTs) have the highest power rating of any device, making them an excellent choice for power electronics for large LCI drives or large HVDC transmission valves. The PCTs are available in sizes up to 6", thereby supporting much higher current levels. Industry standard large IGBT modules have slightly lower ratings than press-pack Bipolar IGCTs. This is basically because of two things. First, they have IGBT chips of a maximum size of 14mm x 14mm parallel coupled to achieve the highest possible current rating. Secondly, the switch has integrated free-wheeling diodes in the package making it a complete switch. The largest switch for a 4.5kV IGBT module is 2kA in a special press-pack design (StakPak™). Usually, IGBT HiPak™ modules are the preferred choice for traction converters, and when paralleling the HiPak™ modules it is possible to make power electronics based on IGBT modules for controlling also large AC motor drives for industrial applications.

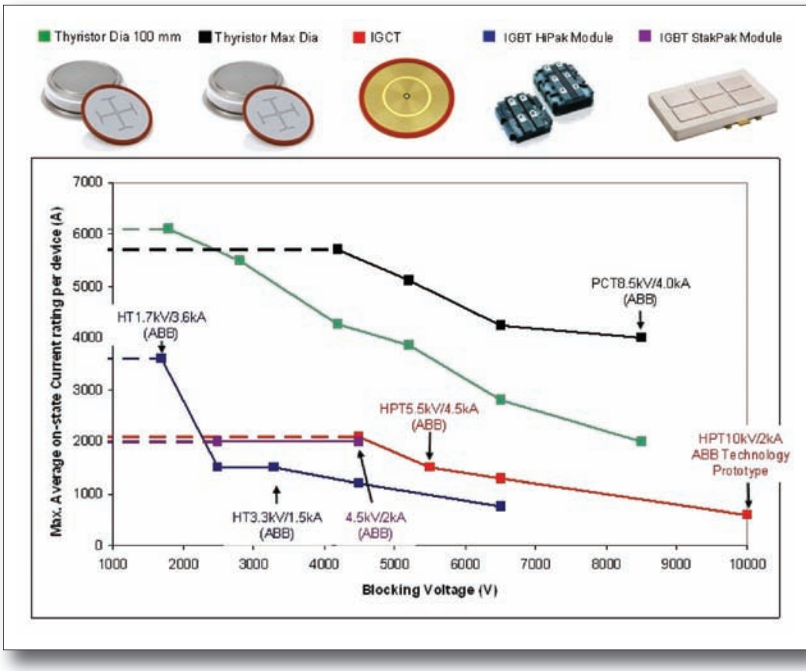


Figure 1: Maximum average on-state current for different device technologies as function of the voltage rating

IGCTs in application

The IGCT is an invention that has made compact and reliable medium voltage drives for the heavy industry possible. Applications range from steel mills and marine drives to trackside power supply systems for traction. For upcoming markets utilizing renewable energy and the need, for instance, to connect generated wind power into the power grid, ABB has developed a flexible medium voltage converter platform called PCS 6000 Wind.

The PCS 6000 Wind, see Figure 2, is designed for wind turbines with conversion of the full generator power, thus decoupling the generator side from the grid side through an intermediate DC link which gives an independent control of the grid side to enable compliance with existing and expected grid codes. The converter consists of two identical 3-level inverter units equipped with large-area asymmetric IGCTs. The selected topology and power semiconductors in the system allow for a power rating of 9MVA without the need of series and/or parallel connection of power semiconductor devices keeping the part count to a minimum. The low part count exhibits a lower estimated failure rate compared with other solutions at this power level. The

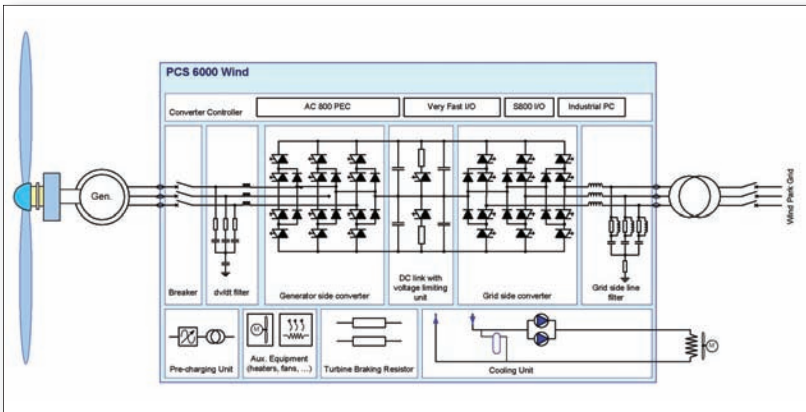


Figure 2: Block diagram for PCS6009 wind, a 3-level converter for wind applications using IGCTs

Figure 3: IGCT 5SHY 55L4500 rated 5000A/4500V

development in the IGCT technology will, in the coming years, allow a further increase in the converter power rating well beyond 10MVA without the need for changed converter footprint. Increased IGCT voltage ratings will also allow an increase in the operating voltage without changes in the basic topology of the converter. The platform has been in operation since the end of 2009 in wind turbines in the offshore test field Alpha-Ventus and additional wind turbines equipped with PCS 6000 Wind will be put into operation in 2011 [1].

Due to the integration of a low inductive gate unit, see Figure 3, the IGCT conducts like a thyristor (i.e. low on-state losses) and turns off like a transistor (i.e. hard switching) which means that it can, as an IGBT (Insulated Gate Bipolar Transistor), operate without a snubber making the circuitry very simple. The IGCT is available with turn-off current ratings between 520 and 5000A and with blocking voltage capabilities of 4500, 5500 and 6500V, all as asymmetric and reverse conducting devices where the latter has a free-wheel diode already integrated on the silicon wafer.

The press pack design of the IGCT, where the wafer is pressed between molybdenum plates, has an advantage in power cycling compared with devices with internal bonding and soldering, which also may impact of the overall reliability of the converter given any mission profile for the application. The field experience we have gathered shows that during a device failure, the IGCT, due to its press pack design, goes into a short circuit without causing much harm to the environment.

Reliability of IGCT units

A concern when comparing ICGTs with IGBTs is the reliability of the fairly large IGCT gate unit. Actually, the circuitry is simple but requires a certain amount of capacitor energy to clear the gate. Especially the electrolytic capacitors on the IGCT gate unit have been designed for reliability and have been selected carefully with considerations made regarding aging. Our experience shows that the gate unit reliability is well within an acceptable range. How competitive this reliability is towards the IGBT gate units is difficult to say, due to the absence of published field data for gate units for devices in a power range close to the IGCT.

When comparing power semiconductor devices such as IGCTs and IGBTs, it must be considered that the IGCT has an integrated gate unit compared with high power IGBT modules that work with a separate gate unit. On the other hand, certain IGCTs need a separate free-wheel diode that most IGBT modules have integrated within the same package. Consequently, to make a good comparison the IGCT with a free-wheel diode must be compared with an IGBT module with its gate drive.

The reliability of a power semiconductor device is determined largely during the design phase of both the device as well as the equipment where it is to be used. Three of the major failure causes are well documented and are considered in the converter design. These concern the selection of the device voltage rating for a given output voltage and the connected stray inductance to ensure that the over-voltage peak during turn-off is within the device capability. Thirdly, the failure rates due to cosmic rays are documented and considered. Most crucial is the thermal design since both the maximum allowed junction temperature of the device must be considered as well as the thermal fatigue through load cycling that can lead to a low life time if not considered in the design. Other failures result from field operation, mainly of transient character, and therefore the estimated field failure rate will be the sum of the probability of the different failure effects at the expected operation conditions.

Despite the uncertainty concerning the above mentioned failures, an estimation of the reliability of a well-designed 8MVA inverter unit can be made according to the selection of the different high power semiconductor devices that come into question for a wind turbine converter and the result is presented in Table 1. For comparison, the 3-level inverter topology such as PCS 6000 Wind is used and compared with a GTO as well as an IGBT solution using standard high power modules with base plate 190*140 mm by ABB referred to as HiPak. The estimation is based on ABB's experience as manufacturer of all three device types, although much of this experience has been gained from applications other than wind turbines.

In calculation, the common reliability term FIT = Failure In Time is used where one FIT corresponds to one failure in 109 hours of operation. This term is only applicable for the steady state failure rate excluding early failures, often referred to as infant mortality failures. To evaluate fatigue failures due to load cycling, detailed knowledge of the load profiles is needed. Since not much data concerning load and mission profiles for wind turbines exists, experience from applications such as rolling stock (traction) and large steel mill drives must be considered, especially because they often have more severe load-cycling stress.

The difference between the IGCT and IGBT mainly comes from the power levels of available high power semiconductors. To reach the same power levels as with IGCTs, the IGBT modules need to be parallel connected, thus increasing the number of devices by a factor of 2. For the same topology with the same number of devices, the difference in expected long-

8 MVA Inverter Type	Switch	FW Diode	Gate Driver	N° of Parallel Devices	Equivalent NPC Diode per position	Equivalent Clamp per position	Inverter Total (12 positions)	FIT Ratio to IGCT
	FIT	FIT	FIT		FIT	FIT	FIT	
IGCT	100	20	200	1	10	50	4'560	1
GTO	100	20	200	1	10	200	6'360	1.4
IGBT	250		150	2	50	0	10'800	2.4

Table 1: Expected long term reliability for an 8MVA, 3-level converter equipped with different device technologies

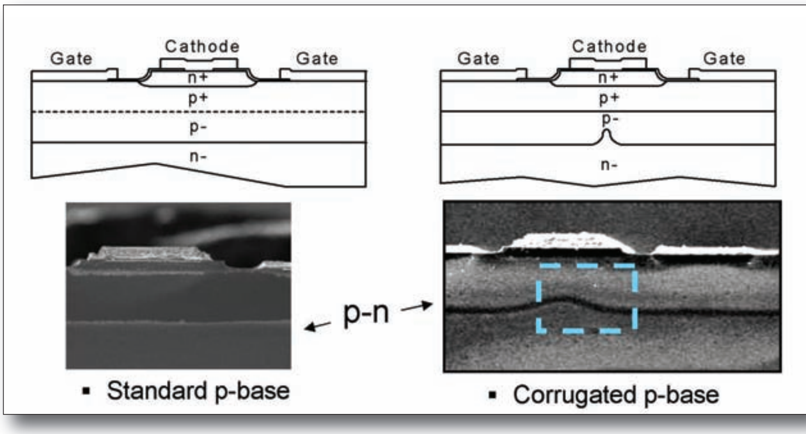


Figure 4: Comparison standard p-base and corrugated p-base

term reliability is, within the accuracy of the estimation, negligible. With no need for parallel or series connected semiconductors as required in some multilevel topologies. the part count of an IGCT converter is very low. The converter power can be increased by using larger IGCT modules, larger reactors and capacitors. The benefit being that the overall number of converter components and its FIT rates remains at the same low level.

Outlook into new IGCT products

Development programs within ABB are on-going to further improve the performance of the IGCT products to enable higher voltages for the common 3-level topology as well as to increase the power rating of existing voltage ratings. Introduction to the market in 2009 of IGCT products with the corrugated p-base technology, see Figure 4, has allowed for a 30% increase of the turn-off current without any mechanical changes to the power semiconductor housing. The corrugated base of the IGCT has been referred to as "High Power Technology" (HPT). ABB has developed a full IGCT range based on this technology for voltage classes between 4.5 kV and 10 kV.

ABB is now ready to introduce the next generation of IGCT with HPT technology. Called HPT+, the IGCTs have been further optimized towards higher SOAs at junction temperatures up to 140°C. In addition to the increased SOA, the turn-off losses have been further reduced and the maximum junction temperature has been increased from 125°C to 140°C. The highlights of the new HPT+ technology will be presented at PCIM [2]. The results of this new product development project give confidence that the rating of the PCS 6000 Wind converter, for instance, can be increased above 10 MVA by utilizing HPT+-IGCT devices without touching the converter footprint.

For future converters rated at 6kV using the basic 3-level topology and without any series connection, a new IGCT has been developed [3]. It uses the HPT technology and will only differ in the height of the ceramic housing, which needs to be higher than for the 4500V version due to creepage and clearance distances. The turn-off switching results show a robust device that can handle turn-off power peaks above 20MW, see Figure 5. The 10 kV IGCT is now in the ABB new product

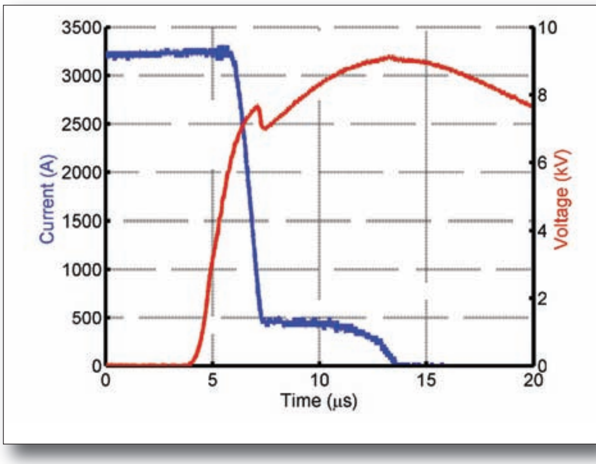


Figure 5: Turn-off waveform for a 91mm 10kV HPT IGCT at V_{DC} = 6 kV, I_T = 3.2kA resulting in a peak power of 20.7MW

Figure 6: **Large area fast recovery diode with 85 mm pole piece**

process phase and results are encouraging. The market echo supports the need for this particular device in new IGCT based converters.

High SOA IGCTs for state-of-the-art voltage source inverters have increased their current handling capability from around 3.5kA to over 5 kA at a 2.8kV DC link voltage with the introduction of the HPT/HPT+ technology. Since the HPT+ IGCTs have the potential to operate above 125°C, the complementary freewheeling and neutral point clamping diodes have to follow this trend, if placed into a common stack. This requires higher turn-off currents at the same di/dt and DC link voltage, and at higher temperatures. The placement of a diode into the common stack with IGCTs requires the same package size with an 85mm pole piece. The size of the accompanying diodes can be then close to 4" (>50 cm_) and the fast recovery diode (FRD) design has to cope with very large area scaling, see Figure 6.

ABB is introducing a new set of fast recovery diodes to the market. Available sizes cover the full range of needs to complement 3-level converter design in a large power range. The large sized diode has been tested at extreme conditions and shows very high RBSOA at elevated temperatures. As an example, rectangular RBSOA up to 7kA and 3.2kV at 140°C have been demonstrated for di/dt values in the range of 0.5 to 1.5kA/_s. The diode also shows sufficiently controlled switching (i.e. softness) for very high di/dt's up to 10kA/_s at a rectangular RBSOA up to 1.5 kA and 3.0 kV at 125°C [4].

The development of a new and proprietary switching element like the 10kV HPT IGCT is of little use if there are no accompanying fast recovery diodes which enable the utilization of the increased switching performance in the converter. In recent years, this has sometimes proven to be a more difficult task than increasing the capability of the switching element itself. A number of requirements, whose standard solution would require contradicting silicon design requirements, are set on the performance on the diode, as low losses and controlled, soft switching without snappiness. New solutions to some of these issues have been recently developed, which do not compromise other features, and they are being implemented into the design of an accompanying 10 kV fast recovery diode. For the earlier mentioned 10kV IGCT, a corresponding 10kV fast recovery diode for dual use as freeheel diode as well as NPC diode (Neutral Point Clamped) in the 3-level converter design is currently in development. A typical switching waveform for this diode can be seen in Figure 7.

Conclusion

ABB is committed to continuously improving and developing their IGCT switching platform. This is in support of existing and new applications featuring energy efficient solutions for industry and applications supporting power quality solutions. High industrial voltages levels up to 6 kV are supported by single switch IGCT solutions, while still being able to switch off large currents in a controllable way under low loss conditions in a single device.

ABB is also committed to improving and developing the fast recovery diodes needed to complement the converter design. The new generation of free recovery diodes will have low losses, high temperature operation and soft switching behaviour so that excessive voltage and current peaks in the device can be avoided during the switching periods of high MVA power.

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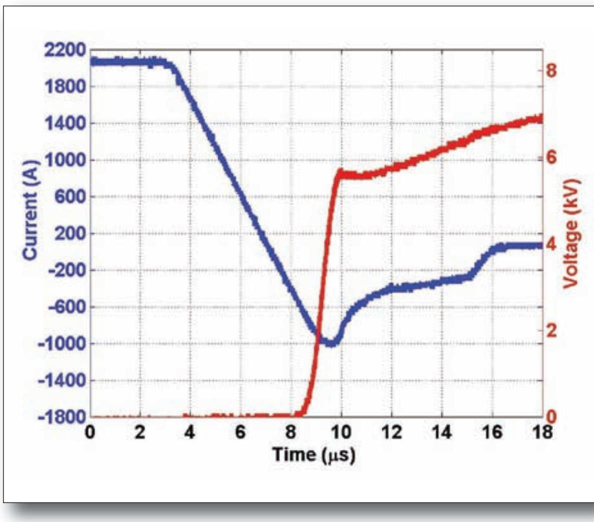


Figure 7 **Soft reverse recovery waveforms for 91 mm FCE 10kV diode in nominal conditions (V_{DC} = 5.5kV, di/dt = 500A/µs, T_j = 125°C)**

Applying Proton Irradiation for Performance Improvement of Power Semiconductors

Control of recombination features in the layers of the semiconductor element is considered to be one of the most effective methods to increase performance and many other characteristics of power semiconductor devices. Some aspects of such technologies based on the accelerated proton irradiation of the silicon elements such as automatically controlled operation line for proton irradiation is being described in the article, which helps selectively introduce the recombination centers and implant hydrogen atoms into the Silicon element at a depth of up to 1000μm. **V. N. Gubarev, A. Y. Semenov, A. M. Surma, Proton-Electrotex JSC, Orel; and V. S. Stolbunov, Institute of Theoretical and Experimental Physics, Moscow, Russia**

Fast thyristors produced with help of proton irradiation technology have remarkably small turn-off time, small recovery charge and peak reverse recovery current. Implanting hydrogen atoms during proton irradiation helps to build local hidden n'-layers with low specific resistance inside the n-layer of the semiconductor element. Using such hidden layers can produce power diode-thyristors (dynistors) and semiconductor voltage suppressors with increased power capacity.

Industrial technological complex of proton irradiation

In collaboration with the Institute of Theoretical and Experimental Physics and All-Russian Electrotechnical Institute, "Proton-Electrotex" has developed a low-cost industrial technology for proton irradiation of semiconductor devices shown in Figure 1. The basis of the technological complex is a 24MeV linear proton accelerator (see Figure 2). The technological complex contains the box for placing cartridges with semiconductor structures before and after irradiation (4), the mechanical system of moving and positioning the irradiating structures (6), equipment for the control of irradiation dose and proton beam characteristics (7, 9) and mobile aluminium screens for control of proton path length in a semiconductor structure (8). The special screen for the beam dissipation (11) in aggregate with the mechanical system of moving and positioning the irradiating structures ensure the irradiation of the wafer with diameter up to 125mm.

The technological complex gives the following possibilities:

- Continuous irradiation of large device lots. It is possible to irradiate correspondingly up to 270 semiconductor elements with diameter of 95-105mm, or up to 360 elements with diameter of 75-80 mm, or up to 450 elements with diameter of 40-60 mm, or up to 900 elements with diameter of 24-32mm in a working cycle.
- A short period of processing time. The duration of one working cycle is 4-5 hours, including the post-irradiating

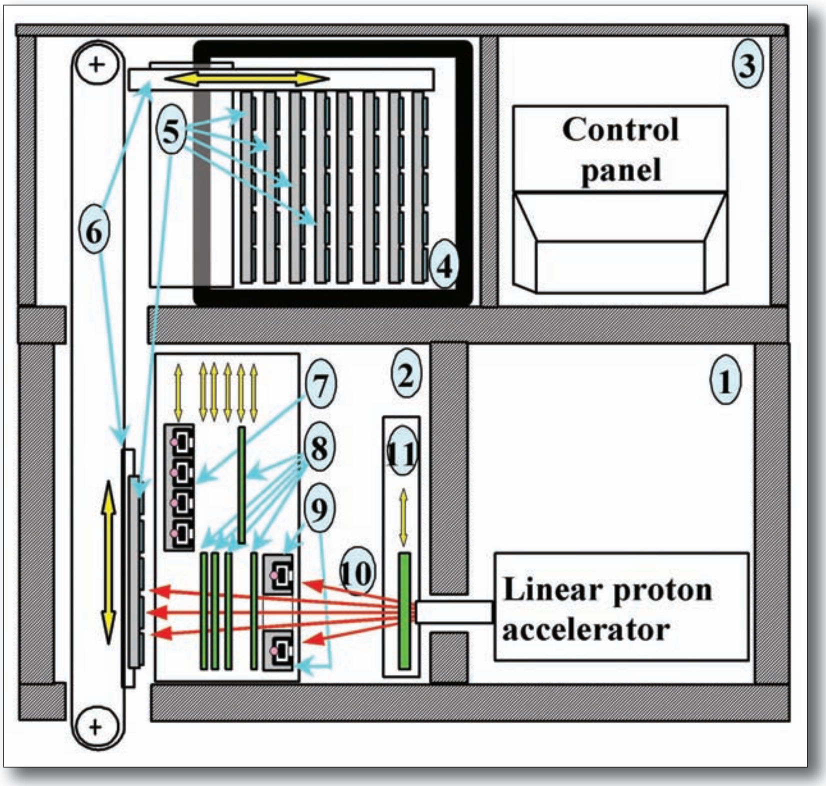


Figure 1: **Industrial technological complex for proton irradiating of semiconductor devices with (1) Proton accelerator room; (2) Irradiation room; (3) Control room; (4) Cartridge box; (5) Cartridges with semiconductor elements; (6) System of moving and positioning cartridges; (7) Matrix of beam current receivers; (8) System of mobile aluminium screens for control of proton path length in semiconductor element; (9) Beam current receivers for the routine control of irradiation dose; (10) Proton beam; (11) Dissipating screen**

LEFT: Figure 2: View of 24MeV linear proton accelerator

storage time necessary for reducing the radioactivity in semiconductor elements and technological cartridges up to the safe level.

- The irradiation occurs in air environment, vacuum is not required in the working zone.
- Control of proton beam characteristics and irradiation dose. It is possible to control the distribution of current density and energy spectrum of protons within the working zone. These measurements are carried out by means of the mosaic current receiver (7) and system of mobile screens (8) at the testing of proton beam before a working cycle. During a cycle the routine control of irradiation dose by means of beam current receivers (9) is carried out.
- Remote control the system of mobile screens (8) to alter proton path length in semiconductor layers of irradiating elements. The control of proton path length in semiconductor structure is achieved by change of the summary thickness of screens, through which proton beam penetrates before reaching the semiconductor surface. The proton path length in a silicon element can be altered within 0-1000µm in steps of 20µm.
- High level of radiation safety.

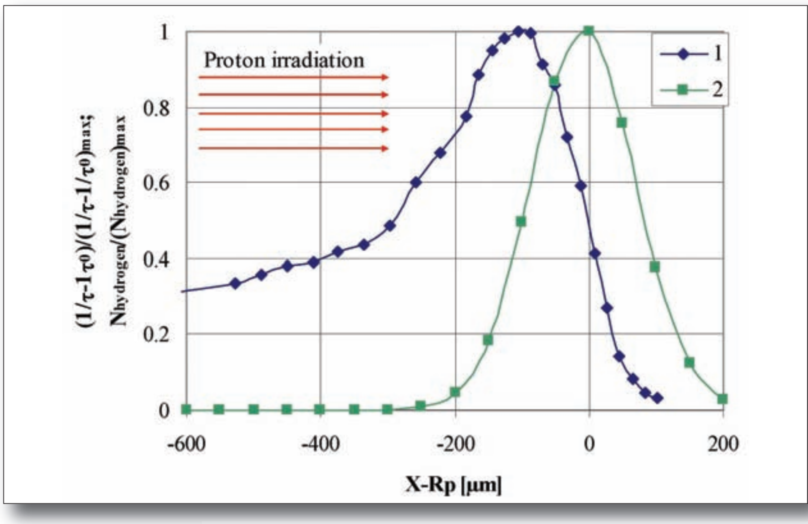
Technology of proton irradiation makes it possible to build hidden layers with reduced carrier lifetime inside the semiconductor element as well as hidden layers with implanted hydrogen atoms. Such technology distributions over the depth of the silicon element are shown in Figure 3. These are according to the following equation

$$1/\tau - 1/\tau_0$$

where τ_0 and τ - carrier lifetime before and after irradiation, and implanted hydrogen concentration as well. Changing proton path length R_p with the help of aluminum screens the needed depth of the layers can be adjusted.

The layers with reduced carrier lifetime are successfully used in many types of power semiconductor devices to optimize their dynamic characteristics [1, 2, 3].

Implanted hydrogen stimulates centers of donor type inside Silicon similar to donor dopants, which helps to build hidden layers with changed specific resistance [4]. Building such layers allows improving the features of high-voltage suppressors and diode-thyristors, and integrating these protective elements inside the structure of other semiconductor devices.



ABOVE Figure 3: Proton distribution over the depth of the silicon element

RIGHT Figure 4: Silicon elements of thyristors which can have diameters 32, 40, 56, 80mm

Fast thyristors with small reverse recovery charge

This technology has allowed production of fast thyristors with reduced reverse recovery charge. Such devices hold a number of the following key features:

- Lifetime control by proton irradiation of cathode side of thyristor element. The region of proton path termination in silicon element is located close to anode p-n junction. The lifetime close to anode p-n junction ($1/100a$) can be in this case 2x to 3x less, than lifetime close to collector p-n junction ((τ/a). Such axial lifetime profile allows optimization of the relationship between V_{TM} and Q_{rr}: the 1.5x to 2x reduction of the Q_{rr} value at the same V_{TM} value is possible by using this axial profile instead of traditional uniform profile.
- The dense grid of cathode short elements. This cathode shorts are distributed within the emitter area, the next elements are located at the distance about 400µm. Such cathode short grid allows obtaining quite short turn-off time at rather large lifetime close to collector p-n junction.
- Distributed amplifying gate (Figure 4). The distributed gate together with rather high values of lifetime close to collector p-n junction and in p base provide fast turn-on of all the thyristor area, reduce turn-on loss energy, increase repetitive

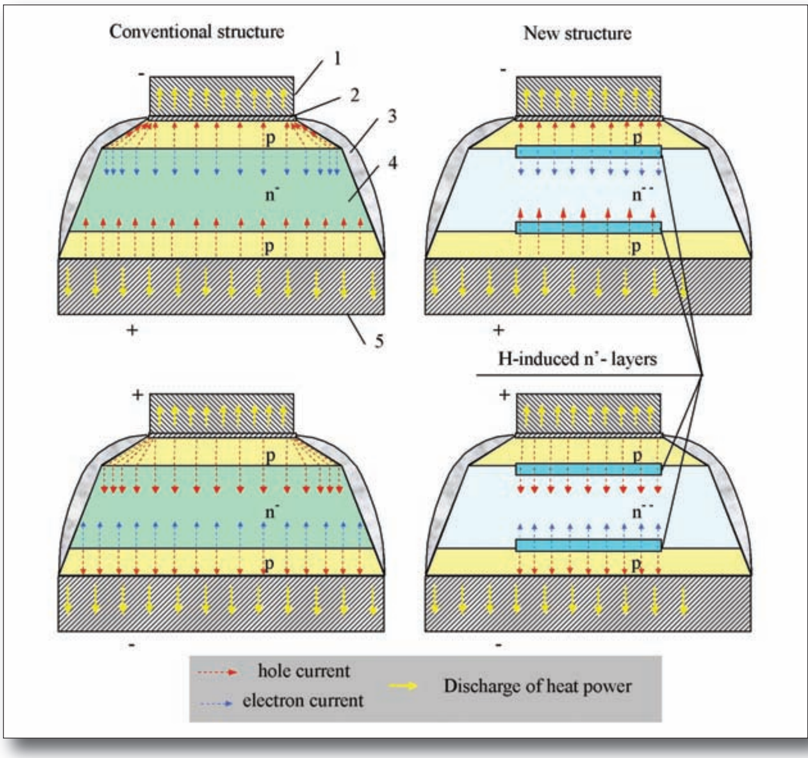


Figure 5: Symmetric avalanche voltage suppressor with "conventional" structure and new device containing hidden n-layers with reduced specific resistance; (1) Copper contact of the package, (2) Contact metallization of semiconductor element, (3) Filler, (4) Semiconductor element, (5) Molybdenum thermal compensator

di/dt-rate and operating frequency.

Owing to the reduced Q_{rr} and t_q values, the new thyristors can operate consequently in the frequency band up to 30kHz for 1000V-1500V blocking voltage range, up to 10kHz for 2200V blocking voltage range and of 2-5kHz for 3400V blocking voltage range. The topology of thyristor element is adapted for high frequencies. New devices can reliably operate at repetitive di/dt's of 800-1250A/µs.

Hidden H-induced layers with reduced resistivity

Symmetric avalanche voltage suppressor with "conventional" structure and new device containing hidden n-layers with reduced specific resistance are shown in Figure 5.

For "conventional" structured devices the problem area limiting peak values of dissipation power and avalanche current as well as maximum admissible energy loss is the periphery area adjacent to bevel. In this area with any polarity voltage applied current density is getting higher, and heat dissipation is very poor because the upper contact size is smaller than thesemiconductor element.

New structured devices doesn't have such problem - there is no avalanche current in the periphery area. This helps to increase peak avalanche current, peak dissipation power and energy loss. Characteristic curves of current and voltage of experiment symmetric avalanche suppressor with the new structure are shown in Figure 6. Diameter of the semiconductor element is 32mm, avalanche breakdown voltage - 1650V.

High-voltage impulse diode-thyristors

Power high-voltage impulse diode-thyristors can be produced on the basis of 4-layer thyristor elements with integrated transistor element - voltage suppressor, shown in Figure 7.

A thyristor element is the main component of the device, the thyristor in this case plays the role of high peak currents switch. Avalanche current of integrated into device three-layer suppressor switches the thyristor element. If the thyristor has multiphase regeneration control, this element may be located within

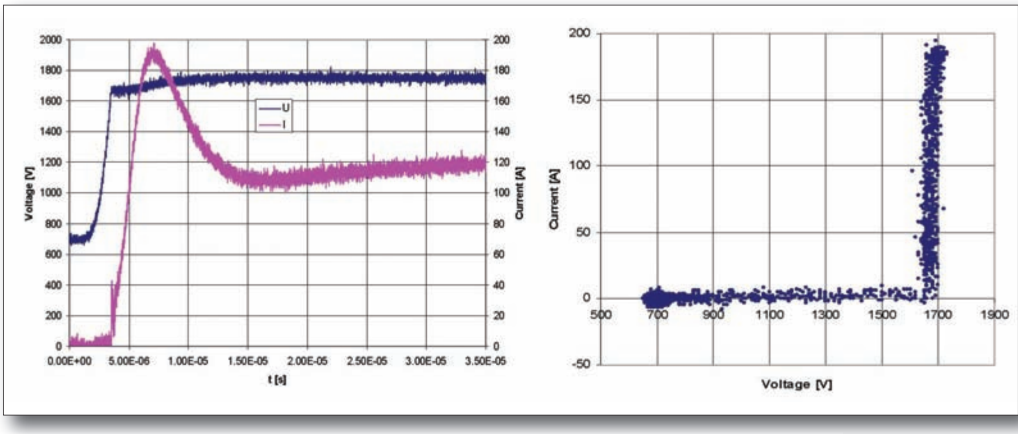


Figure 6: Characteristic curves of current and voltage, temporal variation curves of current and voltage (left) and isothermal dynamic volt-amps diagram (peak impact power 300kW, energy loss up to 150J with single impulses (right)

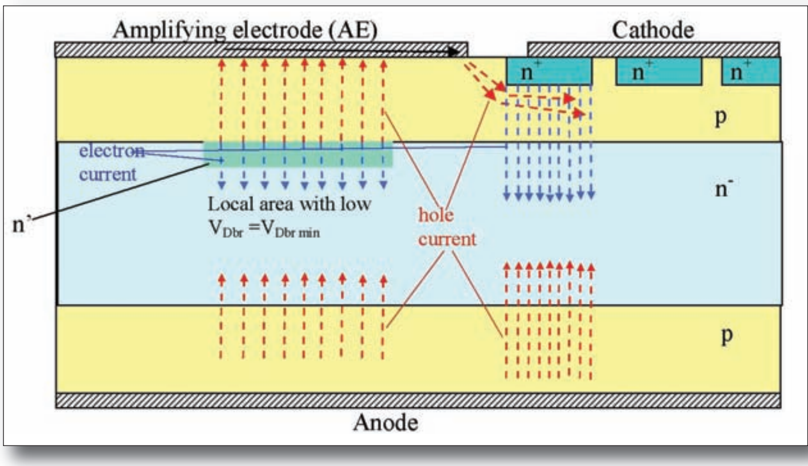


Figure 7: High-voltage impulse diode-thyristors

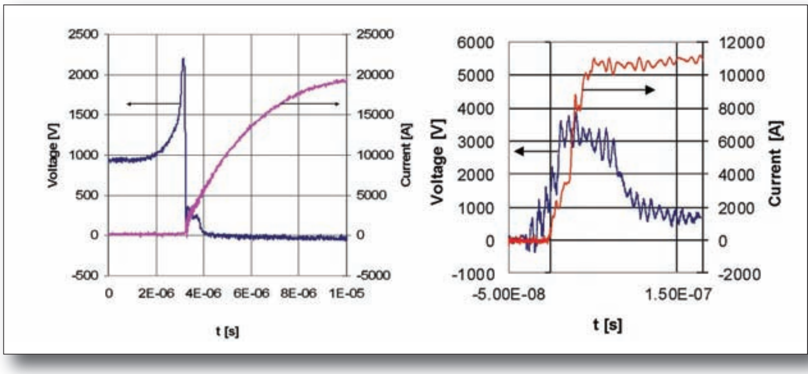


Figure 8: **Impulse current switching with rate of rise about 5 kA/µs (left) and 200kA/µs**

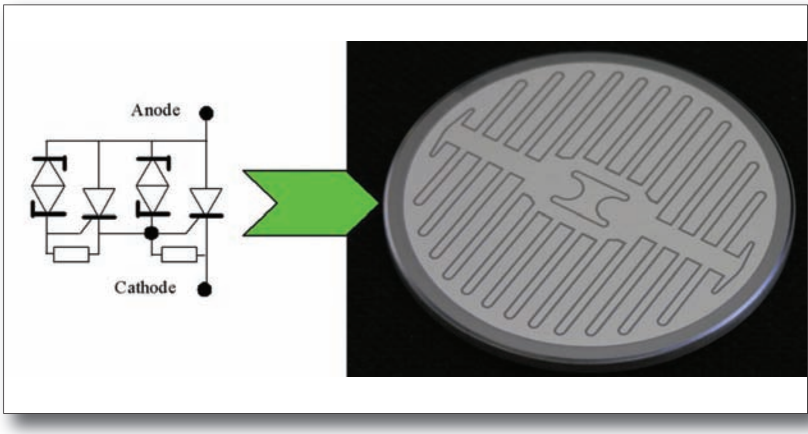


Figure 9: **Diode-thyristor semiconductor element**

any of the amplifying areas or within all of them.

Such device can be used as a fast high-power protective element or current and voltage impulse switch with high rates of rise. Oscillograph traces of current and voltage at switching of experiment diode-thyristor are shown in Figure 8. Semiconductor element of this diode-thyristor is shown in Figure 9.

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Application of Silicon Carbide MOSFETs

The Cree SiC MOSFET has removed the upper voltage limit of silicon MOSFETs. However, there are some differences in characteristics when compared to what is usually expected with high voltage silicon MOSFETs. These differences need to be carefully addressed to get maximum benefit from the SiC MOSFET. In general, although the SiC MOSFET is a superior switch compared to its silicon counterparts, it should not be considered as a direct drop-in replacement in existing applications. **Robert Callanan, Application Engineering, Cree Inc., Durham, USA**

There are two key characteristics that need to be kept in mind when applying the SiC MOSFET (see Figure 1): modest transconductance requires that V_{GS} needs to be 20V to optimize performance. This can be see in the Output and Transfer Characteristics shown in Figures 2-4. The modest transconductance also affects the transition where the device behaves as a voltage controlled resistance to where it behaves as a voltage controlled current source as a funtion of V_{DS}. The result is that the transition occurs over higher values of V_{DS} than are usually experienced with Si MOSFETs and IGBTs. This might affect the operation anti-desaturation circuits, especially if the circuit takes advantage of the device entering the constant current region at low values of forward voltage.

The modest transconductance and short-channel effects are important, the CMF20120D needs to be driven with a higher gate voltage swing than what is customary with SJMOSFETS or IGBTs. Presently, a +20V and -2V to -5V negative bias gate drive is recommended. Care needs to be taken not to exceed -5V in the negative region. The rate of rise of gate voltage will have a greater effect on the rate of rise of the drain current due to the transconductance. Therefore, the gate drive needs to supply a fast rise and fall time gate pulse to maximize switching speed. The device also has a threshold voltage similar to the Si SJMOSFET (2V nominal). Like the SJ MOSFET, considerations need to be made for the lower threshold voltage, especially at high temperatures.

The rather large triode region can have an impact on certain type of fault detection schemes, mainly the active de-saturation circuitry. Some of these designs assume that the switching device enters a fairly high impedance constant current and/or transconductance saturation region during over-current faults. For the CMF20120D, the output impedance is lower and the device does not go into a clean constant current region during this type of over-current fault, especially under moderate over-currents. Therefore, the drain-to-source voltage will not increase as much. These characteristics of the SiC MOSFET need to be carefully considered in fault protection schemes.

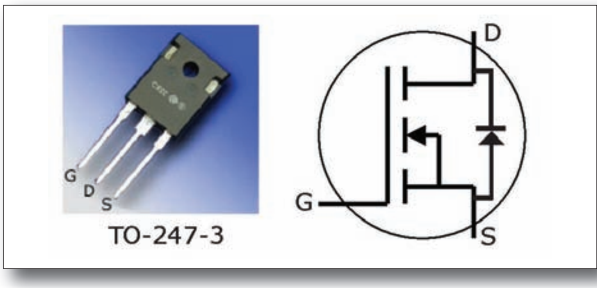


Figure 1: 1200V SiC MOSFET package and schematic

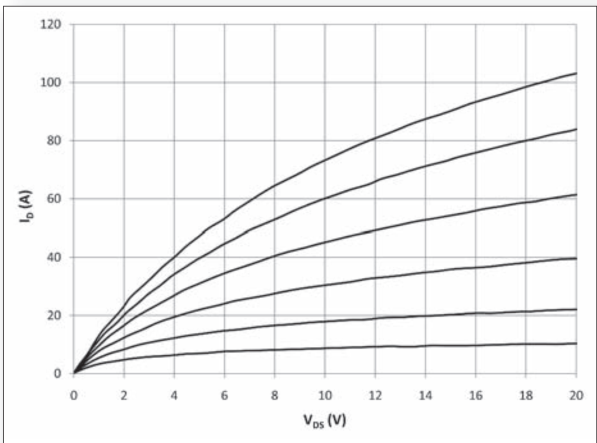


Figure 2: Typical output characteristics at 25°C junction temperature of SiC MOSFET at V_{GS}=20V (upper curve), 18V, 16V, 14V, 12V and 10V (lower curve)

Gate drive requirements

The modest transconductance needs to be carefully considered also in the design of the gate drive circuit. The first obvious requirement is that the gate be capable of a >22V (+20V to -2V) swing. The recommended on state V_{GS} is +20 V and the recommended off state VGS is between -2V to -5V. Please carefully note that although the gate voltage swing is higher than the typical silicon MOSFETs and IGBTs, the total gate charge of the SiC MOSFET is considerably lower. In fact, the product of gate voltage swing and gate charge for the SiC MOSFET is lower than comparable silicon devices. The gate voltage must have a fast dV/dt to achieve fast switching times which indicates that a very low impedance driver is necessary.

Lastly, the fidelity of the gate drive pulse must be carefully controlled.

The nominal threshold voltage is 2.5V and the device is not fully on ($dV_{DS}/dt \approx 0$) until the V_{GS} is above 16V. This is a noticeably wider range than what is typically experienced with silicon MOSFETs and IGBTs. The net result of this is that the SiC MOSFET has a somewhat lower 'noise margin'. Any excessive ringing that is present on the gate drive signal could cause unintentional turn-on or partial turn-off of the device. The gate resistance should be carefully selected to ensure that the gate drive pulse is adequately dampened. To first order, the gate circuit can be approximated as a simple series

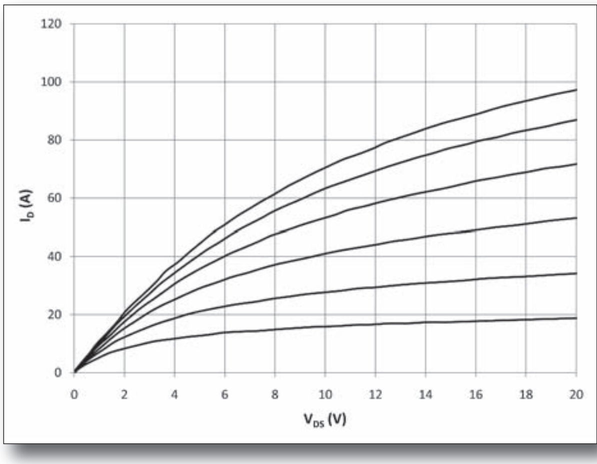


Figure 3: Typical output characteristics at 125°C junction temperature of SiC MOSFET at VGS=20V (upper curve), 18V, 16V, 14V, 12V and 10V (lower curve)

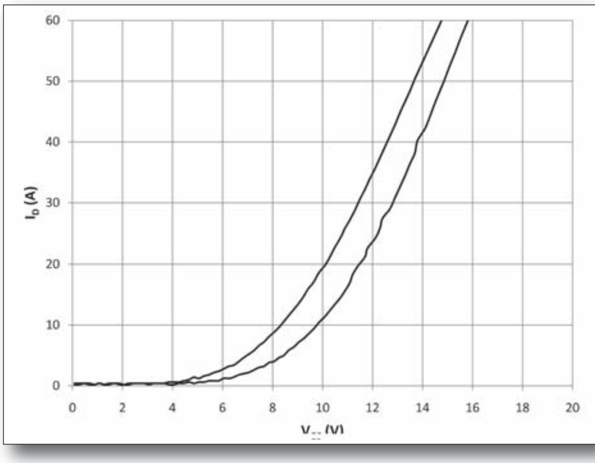
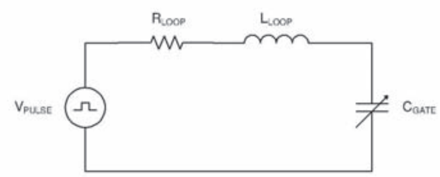


Figure 4: Typical transfer characteristics at 125°C (upper curve) and 25°C junction temperature of SiC MOSFET



$$\zeta = \frac{R_{LOOP}}{2}\sqrt{\frac{C_{GATE}}{L_{LOOP}}} \geqslant 1$$

$$\therefore\ R_{LOOP} \geqslant 2\sqrt{\frac{L_{LOOP}}{C_{GATE}}}$$

Figure 5: Approximated gate circuit

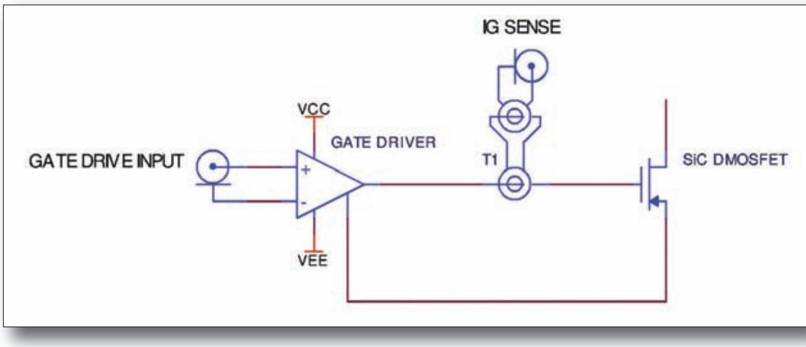


Figure 6: Recommended setup of a 2-stage current transformer for gate driving

RLC circuit driven by a voltage pulse as shown in Figure 5.

As shown, minimizing L_{Loop} minimizes the value of RLoop needed for critical dampening and also minimized the rise/fall time. Therefore, it is strongly recommended that the gate drive is located as close to the SiC MOSFET as possible to minimize L_{Loop}. The internal gate resistance of the SiC MOSFET is 5Ω. An external resistance of 6.8Ω was used to characterize this device. Lower values can be used so long as the gate fidelity is maintained. If no external gate resistor is used, it is suggested that the gate current be checked to indirectly verify that there is no ringing present in the gate circuit. This can be accomplished with a very small current transformer as shown in Figure 6.

The 2-stage current transformer first stage consists of 10 turns AWG30 wire on a small high-permeability core such as Ferroxcube 3E27. The second stage is a small wide-bandwidth current transformer such as the Tektronix CT-2. Lastly, a separate source return should be used for the gate drive.

The used gate driver is an IXYS IXDI414. This device has a 35V output swing, output resistance of 0.6Ω typical, and a peak current capability of 14A. The external gate resistance for characterization of the SiC MOSFET was 6.8Ω. Careful consideration needs to be given to the selection of the gate driver. The typical application error is selection of a gate driver that has adequate swing, but output resistance and current drive capability are not carefully considered. It is critical that the gate driver possess high peak current capability and low output resistance along with adequate voltage swing.

A significant benefit of the SiC MOSFET is the elimination of the tail current observed in silicon IGBTs. However, it is very important to note that the current tail does provide a certain degree of parasitic dampening during turn-off. Additional ringing and overshoot is typically observed when silicon IGBTs are replaced with SiC MOSFETs. The additional voltage overshoot can be high enough to destroy the device. Therefore, it is critical to manage the output interconnection parasitics (and snubbers) to keep the ringing and overshoot from becoming problematic.

Conclusions

The CMF20120D has definite system advantages over competing Si switching devices. However, its unique operating characteristics need to be carefully considered to fully realize these advantages. The gate driver needs to be capable of providing +20V and -2V to -5V negative bias with minimum output impedance and high current capability. The parasitics between the gate driver and the CMF20120D need to be minimized (close location, separate source return, etc.) to assure that the gate pulse has a fast rise and fall time with good fidelity. The fast switching speed of the CMF20120D can result in higher ringing and voltage overshoots. The effects of parasitics in the high current paths need to be carefully assessed.

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Improving PFC Control for Competitive Appliance Designs

The next generation of power-factor control ICs delivers a higher level of integration to help appliance designers cut the cost of PFC circuitry and so deliver new products at more competitive price points.

Helen Ding, International Rectifier Corp., El Segundo, USA

Power-factor correction (PFC) is mandatory in mains-powered equipment of 75W and above. Implementing the necessary circuitry, which is usually based around a boost converter, imposes component costs and design challenges but does not provide a means for designers to differentiate their products. This is not desirable in products such as domestic appliances and some types of industrial or commercial equipment, which must compete in highly price sensitive markets.

A new generation of PFC controllers for applications in the 300W to 3kW range is responding to this challenge by driving up feature integration, simplifying design and reducing overall component count (Figure 1). A key enabler is a simplified control scheme achieving power factor close to unity and well within the EN 61000-3-2 limits for class D and class A equipment types.

Simplified PFC control

In a traditional CCM PFC solution, the control scheme for the boost converter is usually based around an analogue multiplier that generates a current programming signal to control the output voltage. This multiplier multiplies the rectified line voltage input by the output of a voltage error amplifier also integrated in the controller IC. The majority of off-the-shelf boost PFC controller ICs use this scheme, although it is considerably more complex than One Cycle Control™ (OCC).

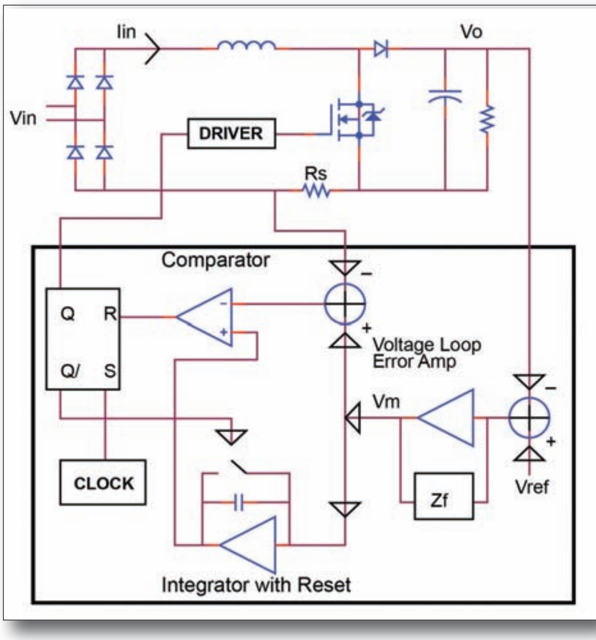


Figure 2: One-Cycle Control (OCC) using a resettable integrator

Figure 1: µPFC controllers are intended for applications in the 300W to 3kW range

OCC, or the integration-reset technique, is a proven method for controlling switching converters. It uses no analogue multiplier, no input voltage sensing, and no fixed oscillator ramp. Instead, the key element is an integrator, which generates a linear ramp from a voltage error signal and is reset at the end of each switching cycle. Comparing the ramp with a voltage reference determines the duty cycle of the boost converter. In addition to eliminating several circuit elements, OCC also bypasses design challenges such as adjusting the analogue multiplier output current and implementing external compensation for the current amplifier, which are intrinsic to achieving average current mode control using a multiplier-based circuit. In contrast, OCC exploits the PFC converter's pulsed, non-linear operation to achieve instantaneous control of the average current value.

Figure 2 illustrates the key functional blocks supporting OCC. Essentially, the OCC algorithm features two control loops;

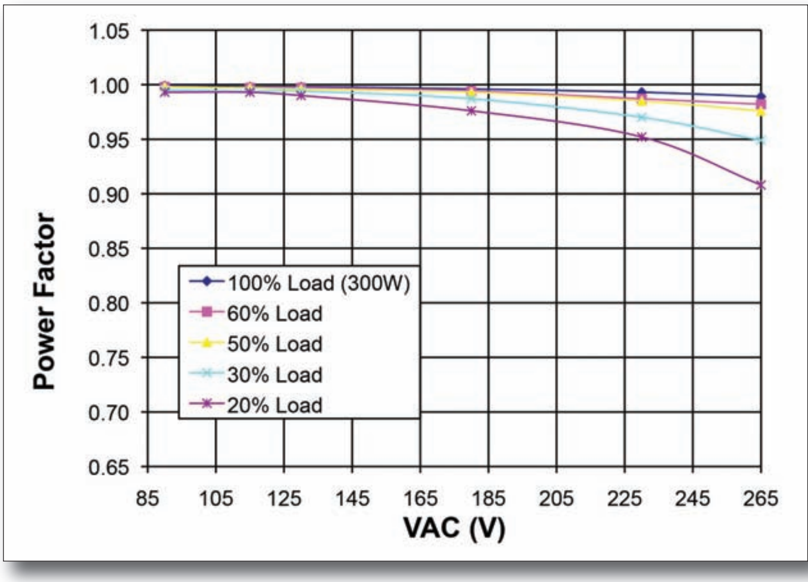


Figure 3: Power factor achieved using OCC

power factor correction is achieved primarily by the fast, inner current loop whose function i s to determine the instantaneous duty cycle every switching cycle. There is also a slow, outer voltage loop, which is responsible for controlling the magnitude of the input current in order to maintain DC bus voltage regulation.

Increasing feature integration

IR has implemented its OCC algorithm in three new ICs within its μPFC™ controller family. These devices are designed to reduce bill of materials costs and simplify the design of PFC circuitry for applications ranging from 75W up to 8kW. Using OCC, they are able to operate the boost converter in Continuous Conduction Mode (CCM), which delivers advantages such as high energy efficiency and small system size compared to Discontinuous Conduction Mode (DCM). By eliminating the complexity and high component count of a multiplier-based control scheme, the μPFC devices featuring OCC deliver the advantages of CCM for high-power applications at a lower cost. Figure 3 shows the power factor achieved using OCC at various line voltage and output power levels.

In addition to implementing a lower-cost control scheme, the ICs also integrate extra features that traditionally require a large number of external components, such as soft-start control and protection features such as open-loop protection, over-voltage protection and brown-out protection. Unlike most controllers for high-power PFC applications, which are usually housed in 16-pin packages, μPFC ICs achieve their high feature integration within smaller and lower-cost 8-pin packages. The devices are fabricated using BiCMOS Silicon technology, which results in low bias currents and hence promotes accuracy and energy efficiency.

By operating in average current mode, using OCC, the ICs enable an economical solution benefiting from extremely low distortion (THD) and improved current shaping. Each IC in the family is designed for fixed-frequency operation. This enables the gate-drive pulses to be generated completely without jitter, which has the advantage of eliminating a significant source of audible noise in the PFC circuit's magnetic components. In addition, fixed-frequency operation has allowed IR to integrate the oscillator on the chip, thereby improving the IC's noise immunity.

One of the devices, the IR1155, allows the operating frequency to be programmed using an external capacitor. This allows the IC to be synchronised with an external clock, if required, and enables the designer to optimise the duty cycle so as to minimise THD while guaranteeing reliable operation. Also, using a capacitor to set the frequency improves oscillator noise immunity.

Soft-start circuitry integrated on the chip allows the designer to optimise the converter start-up time to suit the application's requirements according to the values of components connected to a single external pin; the IC's COMP pin. This programmable soft-start feature controls the increase of input current, thereby reducing stress on system components.

Better protection on-chip

The IR1152, another member of the μPFC controller family, has two Over-Voltage Protection (OVP) comparators integrated on the chip. One monitors the dedicated OVP pin, while the other monitors the voltage feedback (VFB) pin, as shown in Figure 4. Both are identical in operation and have the same trigger and release thresholds.

The two comparators, operating in tandem, lend two important aspects to the controller's OVP capabilities that are not present in other similar devices. Firstly, the

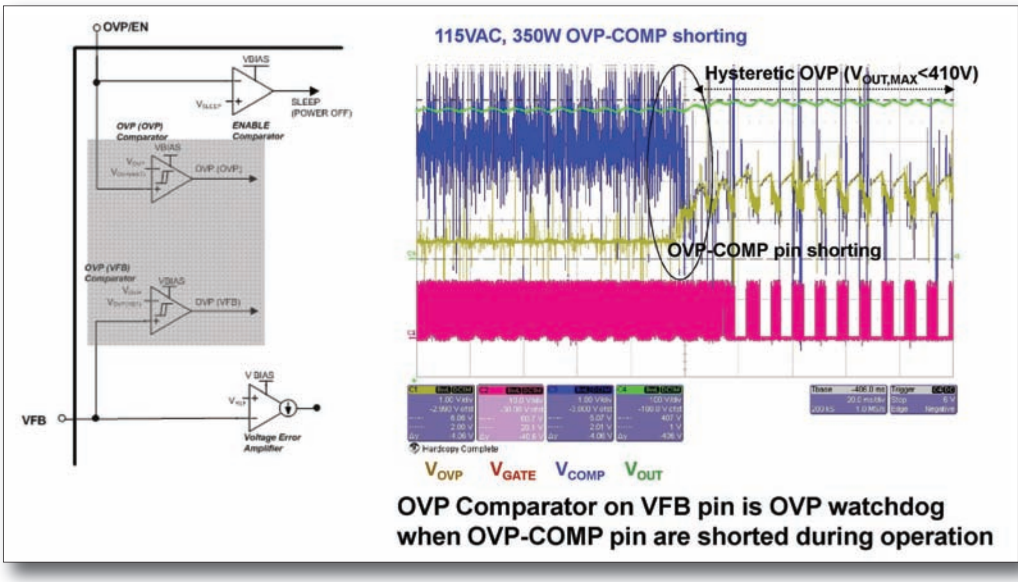


Figure 4: Two OVP comparators operating in tandem ensuring redundancy

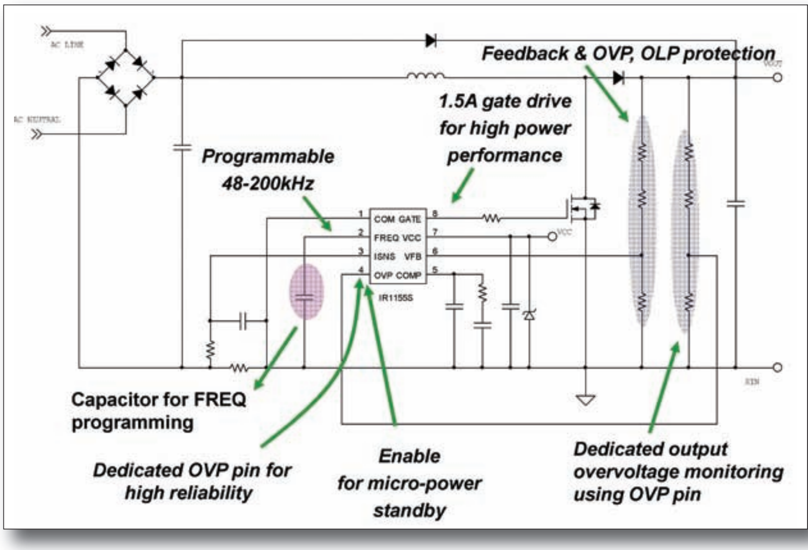


Figure 5: **PFC using the IR1155S featuring one cycle control**

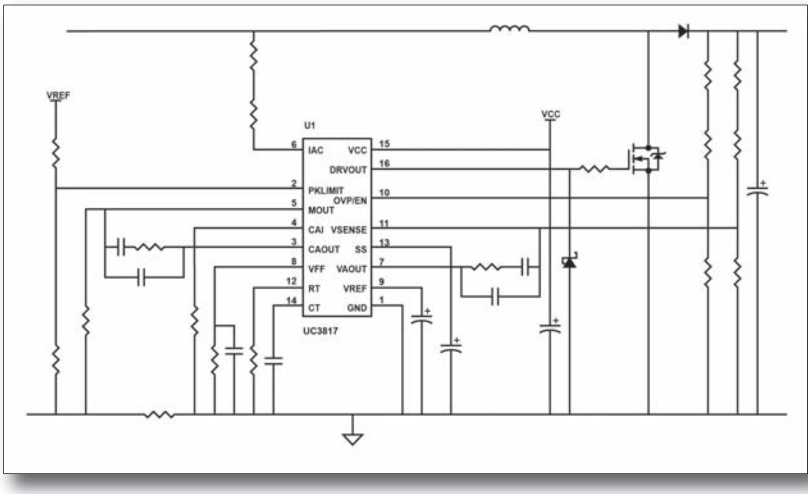


Figure 6: **CCM PFC solution using traditional 16-pin multiplier-based controller**

dedicated OVP pin allows the controller to safeguard the system even if a component failure in an area such as the resistor-divider network causes a break in the VFB feedback loop. In addition, each comparator acts as a watchdog for the other. If a failure such as a pin-to-pin short causes one comparator to give false results, the other comparator will continue to provide over-voltage protection.

Another device in the μPFC family, the IR1153, allows to determine the exact voltage level at which over-voltage protection is triggered by adjusting the values of the resistor divider connected to the OVP pin.

Open-loop protection is an additional integrated protection feature common to all the μPFC controllers. This holds the device in standby mode if an acceptable voltage is not detected at the VFB pin. This prevents the controller from starting up while a fault such as an open circuit in the voltage feedback loop is present, thereby preventing a potential catastrophic failure.

In addition, despite using an economical low pin-count package, all three devices provide an external Enable (EN) pin, which can be actively pulled below a threshold voltage level to force the device into sleep mode. When in sleep mode the current consumption is less than 200μA, even when V_{CC} is above the V_{CC_ON} threshold. The threshold voltage for the EN pin to trigger the sleep mode is very low, and allows system designers to use an external logic-level signal to control the sleep mode.

The schematic of Figure 5 shows how power-factor control is implemented using a μPFC controller; in this case the IR1155S. This contrasts with the more complex circuitry of a traditional PFC controller using a multiplier-based IC in a 16-pin package, shown in Figure 6. The solution based on the μPFC controller, featuring OCC requires only three pin functionalities to obtain the diagnostic signals needed to achieve power factor correction and maintain output voltage regulation. These are the VFB pin, which provides DC bus voltage sensing for voltage regulation, the COMP pin for compensating the voltage feedback loop to set the correct transient response characteristics, and the ISNS pin that provides the sensing of the inductor current needed to determine the PFC switch duty cycle.

Each device integrates internal logic that ensures the voltage at the COMP pin is discharged before the IC enters sleep mode in order to enable soft-start upon resumption of operation. This permits compliance with standby power requirements mandated by regulations such as Energy Star, Green Power and Blue Angel. The IR1152S and IR1153S also feature brown-out protection. Table 1 summarises the power levels and features of the IR1152, IR1153 and IR1155 μPFC controllers.

Conclusion

Power factor correction is a compulsory aspect of mains-connected equipment such as domestic and commercial appliances. Many semiconductor vendors offer ICs capable of satisfying EN 61000-3-2 specifications. As today's appliance markets focus increasingly on aspects such as cost and energy efficiency, new approaches to PFC controller design enable designers to implement this mandatory circuitry more quickly and easily, with greater reliability as well as lower cost and power consumption.

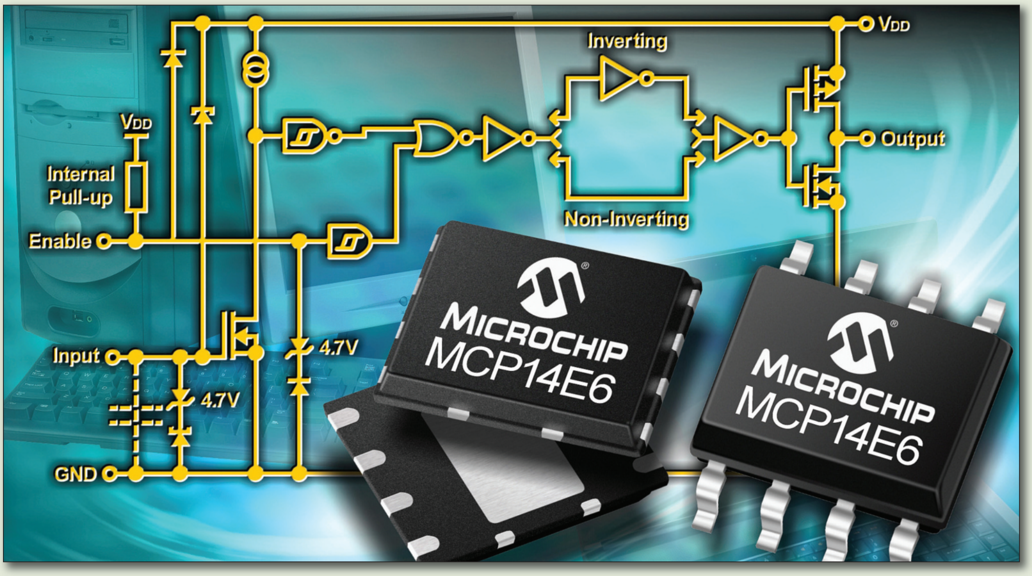
μPFC IC	Operating frequency	Power range and applications	Features
IR1152	66kHz	300W-1kW power level Induction heating, medium-power appliances such as washing machines	Dual OVP, brown-out protection
IR1153	22.2kHz	1kW to 8kW power level High-power appliances (fan, A/C, refrigeration), UPS	Dedicated and programmable OVP, brown-out protection
IR1155	Programmable (48kHz-200kHz)	300W to 3kW power level Induction heating, UPS, medium-power appliances such as washing machines	Dedicated and programmable OVP, programmable frequency

Table 1: **Power levels and features of the IR1152, IR1153 and IR1155 μPFC controllers**

MOSFET Driver Family

Microchip expanded its family of MOSFET drivers with the new MCP14E6/7/8 and MCP14E9/10/11 low-side MOSFET drivers. The new drivers complement Microchip's existing 4.5A MCP14E3/4/5 low-side drivers by offering peak output currents of 2A and 3A respectively. This low-cost family has a wide operating voltage range of 4.5V to 18V and features enable input pins to provide a shutdown capability for conserving power. The drivers are offered in 8-pin SOIC and 8-pin, 6mm x 5mm DFN packages to reduce the board space required to drive power supplies in consumer electronic applications such as servers, personal computers and notebooks. The new MCP14E6/7/8 dual devices are rated for a peak output current of 2A, while the dual MCP14E9/10/11 drivers are rated for a peak output current of 3A. The drivers' wide operating voltage of 4.5V to 18V supports a broad range of input voltages, whilst the small packages lower costs by reducing board space. The MCP14E3/4/5, MCP14E6/7/8 and MCP14E9/10/11 MOSFET drivers are available in 8-pin SOIC or 8-pin, 6mm x 5mm, DFN packages.

www.microchip.com/get/V0WH

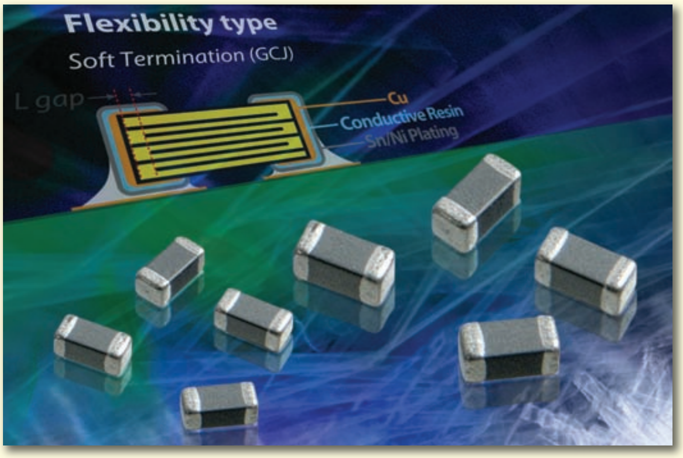


Automotive Capacitors Less Prone to Mechanical Stress

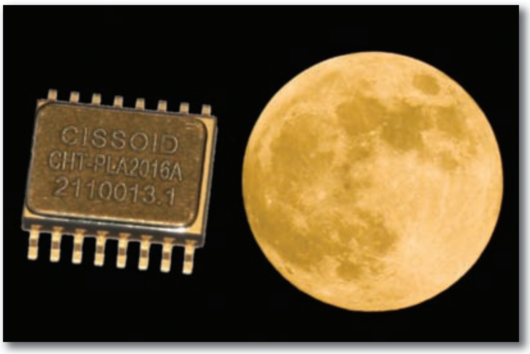
Murata introduced the GCJ series of monolithic ceramic capacitors designed to accommodate the bending, vibration and thermal conditions experienced in under-bonnet automotive applications. Meeting the automotive market requirements by failing-safe against a short circuit, Murata have incorporated a soft termination with the ceramic body.

This approach uses a conductive resin on the outer electrodes to absorb any excessive mechanical stress resulting from board flexing or temperature cycles. Typically, when subjected to undue mechanical bending forces, a ceramic capacitor can crack causing a short circuit. This needs to be avoided in any automotive application, especially when used in power circuits. The GCJ series of X7R capacitors is available in 0603, 0805, 1206 and 1210 packages. All popular capacitance values from 1nF to 10µF are available in 10, 16, 25, 50 and 100V working voltage.

www.murata.eu



High Temperature Dual NMOS Transistor



CISSOID offers a dual high temperature 40V N-channel MOSFET transistor named moon. Available in the small footprint, surface mounting, hermetically sealed ceramic SOIC16 package, this new device can switch currents up to 2A and provides a fully reliable solution for continuous operation over the temperature range from -55°C to +225°C. The tiny CSOIC16 package and its pin-out are optimized to reduce parasitic inductors and capacitors when both N-channel MOSFET's are used in a push-pull stage, such as in DC/DC converters and motor drives. At 225°C, the gate leakage current remains below 100nA, while its drain off current doesn't exceed 3.5µA and its turn-on delay time is only 30ns. The on-resistance and input capacitance are respectively as low as 0.40Ω and 370pF.

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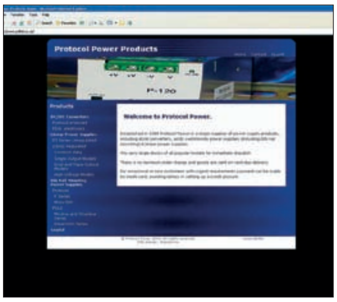

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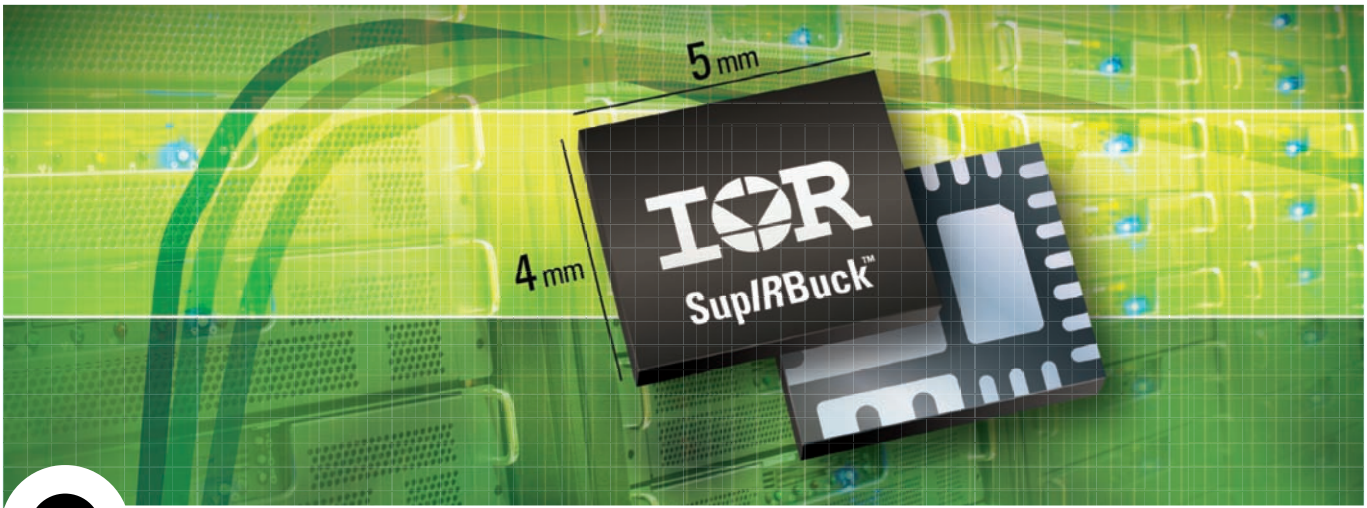

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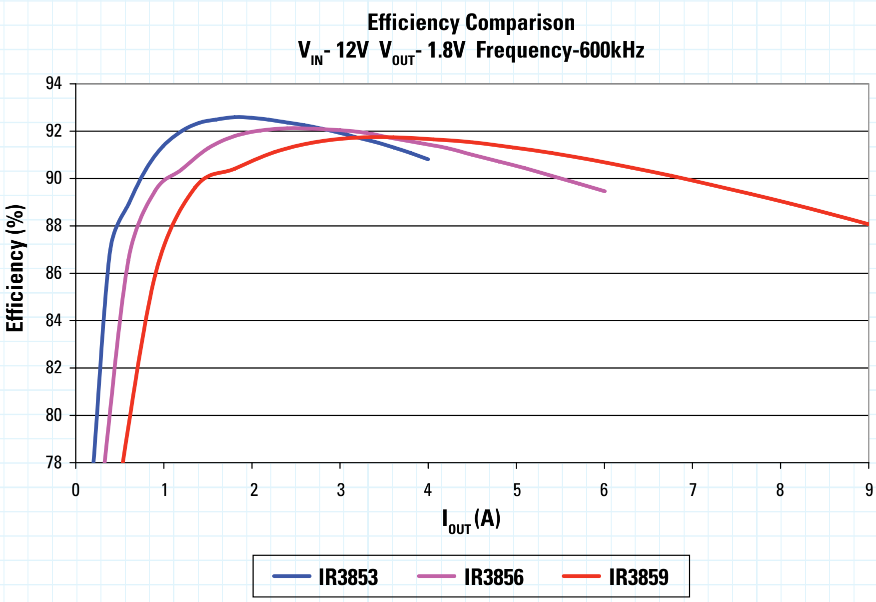

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