# POWER ELECTRONICS EUROPE

ISSUE 7 – Oct/Nov 2010 www.power-mag.com


## POWER MODULES

Wide Temperature Operation of High Isolation HV-IGBT Modules



THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY


**Also inside this issue**

**Editor** Achim Scharf
Tel: +49 (0)892865 9794
Fax: +49 (0)892800 132
Email: achimscharf@aol.com

**Production Editor** Chris Davis
Tel: +44 (0)1732 370340

**Financial** Clare Jackson
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034

**Circulation Manager** Anne Backers
Tel: +44 (0)208 647 3133
Fax: +44 (0)208 669 8013
Email: anne@abdatalog.co.uk

**INTERNATIONAL SALES OFFICES**
Mainland Europe:
Victoria Hufmann, Norbert Hufmann
Tel: +49 911 9397 643 Fax: +49 911 9397 6459
Email: pee@hufmann.info

Armin Wezel
Tel: +49 9568 897 097 Fax: +49 9568 897 096
Email: armin@eurokom-media.de

UK
Steve Regnier, Tim Anstee
Tel: +44 (0)1732 366555
email: Sales@starmediaservices.co.uk

Eastern US
Karen C Smith-Kernc
email: KarenKCS@aol.com
Western US and Canada
Alan A Kernc
Tel: +1 717 397 7100
Fax: +1 717 397 7800
email: AlanKCS@aol.com

Italy
Ferruccio Silvera
Tel: +39 022 846 716 Email: ferruccio@silvera.it
Taiwan
Prisco Ind. Service Corp.
Tel: 886 2 2322 5266 Fax: 886 2 2322 2205

**Publisher** Ian Atkinson
Tel: +44 (0)1732 370340
Fax: +44 (0)1732 360034
Email: ian@dfamedia.co.uk
www.power-mag.com

Circulation and subscription: **Power Electronics Europe** is available for the following subscription charges. **Power Electronics Europe**: annual charge UK/NI £60, overseas $130, EUR 120; single copies UK/NI £10, overseas US$32, EUR 25. Contact: DFA Media, Cape House, 60a Priory Road, Tonbridge, Kent TN9 2BL Great Britain.
Tel: +44 (0)1732 370340. Fax: +44 (0)1732 360034. Refunds on cancelled subscriptions will only be provided at the Publisher's discretion, unless specifically guaranteed within the terms of subscription offer.
Editorial information should be sent to The Editor, **Power Electronics Europe**, PO Box 340131, 80098 Munich, Germany.

Printed by: Garnett Dickinson.
ISSN 1748-3530

# Strong Market Recovery Ahead

The upcoming Electronica 2010 fair is the most important indicator for the electronics and in part for the power electronics industry. All market researchers agree that 2010 and 2011 will be years of strong growth for semiconductors and in particular power semiconductors, which also reflect the growth in the end-user markets.

Global semiconductor sales are expected to amount to $302 billion in 2010, up from $228 billion in 2009. 2010 still will be a year of impressive growth and record-setting revenue for the semiconductor industry. Revenue in 2010 will rise by about $74 billion compared to 2009 and be almost $28 billion higher than 2007, the previous last peak year for semiconductor revenue, according to iSuppli's semiconductor industry analysis. In terms of specific semiconductor products, the hottest items in 2010 will be DRAM, voltage regulators, LEDs, Programmable Logic Devices (PLDs) and data converters. Revenue for each of these products is projected to grow by more than 43 percent in 2010. DRAM will lead the group with 87 percent growth on the strength of the soaring PC market.

Semiconductor Days Of Inventory (DOI) for chip suppliers are estimated to have climbed to 76 days in the third quarter of 2010, up 1.5 days from the second-quarter. DOI in the third quarter also was 4.8 percent higher than the seasonally adjusted average for the period, iSuppli analyzed. Mirroring the rise in DOI, the total dollar value of semiconductor inventory held in by chip suppliers continued to grow as well. Inventory in the third quarter was estimated to amount to $34 billion, up 10.6 percent from the second quarter. The value of inventory was not been this high since the second quarter of 2008, when semiconductor suppliers' stockpiles peaked at $35.4 billion. Should demand decline at a rate faster than initially forecasted, an entirely reasonable assumption given the slower-than-expected pace of economic recovery around the world, semiconductor inventory may go into an over-supply situation.

The consumer electronics market continues to hold tremendous growth potential as it rebounds from the recession, but semiconductor vendors operating in this fragmented space will confront major profitability and competitive challenges in the coming years, iSuppli expects. Well on the way to recovery, revenue for the consumer electronics equipment market in 2010 is projected to reach $259 billion, all but erasing the decline of the previous year when revenue fell by more than 3 percent. And in an ongoing sign of strength, revenue will continue to rise in the coming years, increasing by 6.7 percent in 2011 and by 7 percent in 2012. Consumer-electronics-related semiconductor revenue will rise to $57 billion in 2010, up 27.7 percent from $44.8 billion in 2009. This represents a dramatic reversal from 2009, when revenue declined by 15.7 percent. Revenue will continue to rise during the coming years to reach $69 billion in 2014. The increase in consumer electronics revenue is currently fueled by high-value and high-volume products such as LCD-TVs and Blu-ray players.

Power management will enjoy continued growth around 6 percent in third quarter 2010. Opportunities for the growth will lie in the industrial and regenerative energy markets. Pricing is likely to increase as backlogs ease at the backend, which means that some time will be needed before supply catches up with demand. Full year 2010 will be one of strong growth rates reaching 40 percent due to the rising demand for energy-efficient equipment. According to iSuppli power semiconductors are expected to grow by 15 percent in the next five years. Strongest growth is expected among low- and medium-voltage MOSFETs at 25 and 18 percent respectively as well as switching regulators with roughly 20 percent.

Following a decline of over 14% in 2009, the world market for power management and driver ICs is forecast to recover fully in 2010, growing by 20 percent to over $12 billion, predicts IMS Research. Strong growth is projected to continue into 2011 and for most products through to 2014, driven by strong forecast demand in applications such as lighting, PC notebooks, servers and cellular infrastructure. The market for power discretes & modules is set to regain much of its previous years' losses and will be worth $14 billion in 2010, increasing by more than 24 percent from 2009. Discrete IGBTs, power MOSFETs and power rectifiers are predicted to register the highest growth rates in 2010. The power module market, which fell by 22 percent in 2009, is predicted to grow almost 30 percent in 2010 with standard IGBT modules and IPMs accounting for the lion's share of the expansion. IMS projects that three key applications will drive most demand for power modules over the next five years: industrial motor drives, renewable energy inverters and hybrid and electric vehicles. It is predicted these three sectors will account for 70 percent of power module revenues by 2014.

And these are the application areas where PEE will focus on, as we did in the past and even more in the future.

**Achim Scharf**
**PEE Editor**

# Semiconductor Grow by Five Percent in 2011

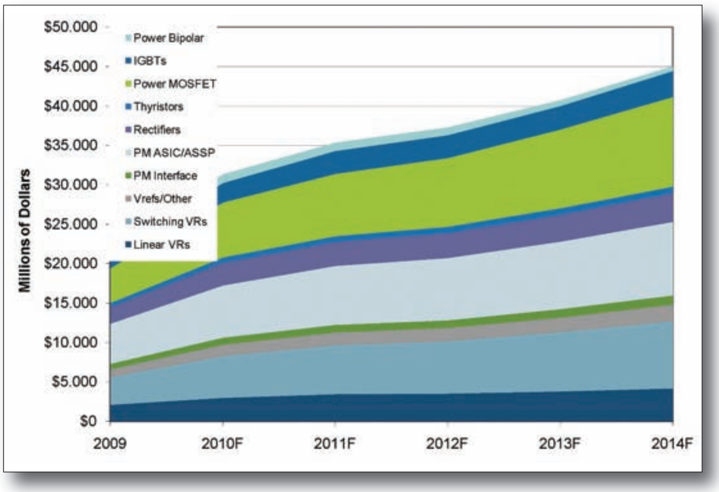
Global semiconductor sales are expected to amount to $302 billion in 2010, up from $228 billion in 2009. 2010 will be a year of impressive growth and record-setting revenue for the semiconductor industry, it will rise by about $74 billion compared to 2009 and be almost $28 billion higher than 2007, the previous last peak year for semiconductor revenue, according to iSuppli's semiconductor industry analysis. This marks are very good outlook for the upcoming Electronica fair in Munich.

Nevertheless, revenue in the fourth quarter will decline by 0.3% compared to the third quarter, the first sequential decrease since the market collapse in the fourth quarter of 2008 and first quarter of 2009. "There has been a significant slowdown in the second half in consumer demand for some electronic devices, including PCs", noted analyst Dale Ford. "Meanwhile, inventories have been building throughout the semiconductor supply chain. These factors will conspire to cause a small sequential decline in semiconductor revenue in the fourth quarter".

The leading electronic equipment market driving demand for semiconductors in 2010 will be the data processing area, a category dominated by PCs. With shipments of mobile PCs (including tablets) continuing to soar in 2010, semiconductor sales to this area will rise by 38%. The second-strongest growth area will be wireless communications, fueled by booming demand for smart phones. Global semiconductor sales to the wireless communications area will rise by 30% in 2010. Even the lowest-growth markets are expected to generate impressive semiconductor consumption in 2010. Wired communications and consumer electronics will drive semiconductor revenue growth by 26% in 2010.

In terms of specific semiconductor products, the hottest items in 2010 will be DRAM, voltage regulators, LEDs, Programmable Logic Devices (PLDs) and data converters. Revenue for each of these products is projected to grow by more than 43% in 2010. DRAM will lead the group with 87% growth on the strength of the soaring PC market.

While the industry outlook remains cloudy and revenue will contract in the fourth quarter, iSuppli does not believe this signals the start of a significant downturn in the global semiconductor market. "Unstable economic conditions and worrisome market reports continue to create an environment of poor visibility and ongoing uncertainty in the electronics industry", Ford said. "This has led to frequently expressed concerns regarding a potential double-dip downturn in both the overall economy and in the electronics and semiconductor industries. However, based on its most recent analysis of the electronics supply chain, iSuppli expects the chip business to experience a soft landing in 2011 and not to suffer the kind of dramatic downturn seen in 2009".




**Power semiconductor long-term forecast (F) Source: iSuppli**

Global semiconductor revenue in 2011 will rise by 5%, iSuppli predicts. Sequential quarterly growth in 2011 is projected to follow a more normal seasonal pattern compared to 2010, with declining revenue in the first quarter followed by improving sales that will reach a peak in the third quarter. The long-term growth expectation is for average annual growth of slightly more than 4% between 2010 and 2014.

### Even more opportunities for power semiconductors

Power management will enjoy continued growth around 6% in third quarter 2010. Opportunities for the growth will lie in the industrial and regenerative energy markets. Pricing is likely to increase as backlogs ease at the backend, which means that some time will be needed before supply catches up with demand, Ford expects. Full 2010 will be one of strong growth rates reaching 40% due to the rising demand for energy-efficient equipment.

According to iSuppli power semiconductors are expected to grow by 15% in the next five years. Strongest growth is expected among low- and medium-voltage MOSFETs at 25% and 18% respectively as well as switching regulators with roughly 20%.

This market forecast is backed by recent IMS Research's figures on the power discrete & module market as well as power management and driver ICs.

Following a decline of over 14% in 2009, the world market for power management and driver ICs is forecast to recover fully in 2010, growing by 20% to over $12 billion. Strong annual growth is projected for the next four years. All sixteen of the power IC markets analyzed in 2010 have outperformed previous growth predictions. Strong growth is projected to continue into 2011 and for most products through to 2014, driven by strong forecast demand in applications such as lighting, PC notebooks, servers and cellular infrastructure. "IMS Research predicts increasing demand in 2011, another year when revenues will increase more than the historical average. Demand for consumer appliances such as notebooks and flat panel TVs remains high; whilst the industrial market continues to recover, driving further demand.10% growth a year is projected for 2012 to 2014", commented analyst Ryan Sanderson.

The market for power discretes & modules is set to regain much of its previous years' losses and will be worth $13.7 billion in 2010, increasing by more than 24% from 2009. The strength and speed of the poer semiconductor market's recovery has surprised many in the industry, following the market's decline of 21.5% in 2009. Discrete IGBTs, power MOSFETs and power rectifiers are predicted to register the highest growth rates in 2010; however, growth levels could have been higher but limited available production capacity has resulted in the majority of power semiconductor suppliers supplying 'on customer allocation' only and shipping less than real demand would suggest..

"Major demand for power discretes returned in 2010, particularly from the consumer and computing sectors as demand for products such as notebooks and LCD TVs returning robustly, at least in the first half of the year. Although a healthy return of demand has been seen so far in 2010 and encouraging outlook for 2011 and onwards is predicted, the market still remains vulnerable to further dips, and inventory re-stocking and double-ordering corrections may take place in late 2010", comments IMS analyst Ash Sharma.

The power module market, which fell by 22% in 2009, is predicted to grow almost 30% in 2010 with standard IGBT modules and IPMs accounting for the lion's share of the expansion. IMS projects that three key applications will drive most demand for power modules over the next five years: industrial motor drives, renewable energy inverters and hybrid and electric vehicles. It is predicted these three sectors will account for 70% of power module revenues by 2014. **AS**

**www.isuppli.com, www.imsresearch.com**

# Smart Power Workshop

**On November 18/19 ECPE will held a workshop entitled 'Smart Power - Technologies and Applications' in Munich.**

**Power ICs are integrated circuits containing at least one power device as their heart and CMOS based intelligence to control and protect its operation for optimum efficiency and reliability. Power ICs are based on a diversity of technologies such as standard BCD (Bipolar CMOS DMOS), Off-line BCD, HVCMOS, BiCMOS, SOI and use advanced high voltage device concepts such as RESURF, trench, Superjunction, LDMOSFET, LIGBT etc.**

**This workshop will give an introduction to the state-of-the-art technologies of Power IC and focus on applications of power ICs to different power systems. Three main targeted areas**

**such as Power supplies and lighting, Consumer and industrial electronics and Smart Power for automotive will be covered.**

**The market analysts forecast a strong growth (more than 10% pa) from 2010-2013, recovering from the downturn in 2009. New applications such as LED lighting and PFCs will complement the more traditional sectors such as automotive and power supplies.**

**The workshop should appeal to power system and IC designers as well as product and application engineers in power management, power supplies, lighting, motor control etc. The content of the workshop is also highly suitable for academics and postgraduate students from universities or power electronics researchers from research institutes.**

**The workshop is chaired by Prof. Dr. Florin Udrea (University of Cambridge) together with Dr. Ulrich Kirchenberger (STMicroelectronics) and Dr. Patrick Leteinturier (Infineon Technologies).**

**www.ecpe.org/download/seminars/Progr_Flyer_SmartPower.pd**

# New EPoSS Chairman

Carmelo Papa, Executive Vice President and General Manager of ST's Industrial and Multisegment Sector, has been appointed Chairman of EPoSS (European Platform on Smart Systems). Smart Systems are miniaturized, networked, energy autonomous and highly reliable electronic devices or systems that can diagnose and describe a situation, and then help the decision-making process in time-critical conditions. They can also mutually address and identify each other and enable a product to interact with the environment. Smart systems integration penetrates several industry sectors, bringing many market opportunities and a broad-based manufacturing infrastructure. They can be used in a myriad of fields ranging from low-cost high-volume automotive applications to high-cost low-volume instrumentation applications, and including areas such as medical, aerospace, and security and communications.

In his introductory speech at the EPoSS Forum, Papa presented the organization's vision for a European platform, including technologies such as analog/RF, passive devices, high-voltage power devices, sensors and actuators, and bio-chips, which are all essential to the development of EPoSS' wide-ranging R&D cooperation. "Companies working on their own will find it difficult and expensive to achieve competitive results. R&D cooperation is vital in Europe and it needs to include large industrial partners, research organizations, small-to-medium enterprises and academia, all complemented and supported by strong relationships with national authorities and the EU. In the future, the boundaries of electronics technology will become increasingly blurred among semiconductor devices, packaging and system technologies. For instance, it will no longer be possible for package design to be done independently of chip and system design - all three aspects will need to be considered simultaneously as part of an overall process. Additionally, this level of integration will also need to provide an interface to the application environment, representing the glue between the world of micro- and nano-electronic technologies and systems with which humans can interact", Papa explains.

Papa will continue in his role at ST, which includes overall responsibility for developing a wide range of products including MEMS sensors, power and analog chips, microcontrollers, application-specific non-volatile memories and smart card ICs.

**www.smart-systems-integration.org**

**ST's Carmelo Papa is new EpoSS chairman**

# Powervation Digital Power from ED-V

The ED-V Gesellschaft für Elektronik + Design In and Powervation signed a distribution agreement for Germany, Austria and Switzerland. Powervation is specialized in digital power management controllers featuring real-time auto-compensation for DC/DC conversion. These very versatile and powerful controllers optimize the performance and energy-efficiency of power-supply systems.

"The digital power ICs from Powervation save 20%-50% power at the system level. Powervation's patented Auto-control technology continuously compensates for load transients, changes in the output impedance and for silicon aging and degradation in components, guaranteeing power-supply stability for the life of the system. The technology also shortens design-time, reduces output components, and improves performance", explained Wolfgang Zang, ED-V's General Manager. Other unique features include Digital Stress Sharing to eliminate hot spots in parallel connection, and fuse-based memory to eliminate long term reliability issues. Powervation's products are designed for networking, computer and communication applications. Their first product is the digital power conversion controller PV3002 for DC/DC conversion control. "Our controllers allow for fast and reliable configuration of smart grid applications. With ED-V we have found a partner who has the required technical expertise and application know-how", added Powervation's CEO Mike McAuliffe.

**www.ed-v.de**

Address:
ED-V Gesellschaft für Elektronik + Design In mbH
Wolfgang Zang
Behringstr. 13
D-63814 Mainaschaff

# 150mm SiC Wafers at Cree

Cree announced that it has achieved a major breakthrough in the development and wide scale commercialization of silicon carbide (SiC) technology with the demonstration of high quality, 150mm SiC substrates with micropipe densities of less than 10/cm_. The current Cree standard for SiC substrates is 100mm diameter material.

SiC is a high-performance semiconductor material used in the production of a broad range of lighting, power and communication components, including light-emitting diodes (LEDs), power switching devices and RF power transistors for wireless communications. "The significant size advancement of single crystal SiC substrates to 150mm can enable cost reduction and increased throughput, while bolstering the continued growth of the SiC industry", commented COO Steve Kelley.

For fiscal year 2010, Cree reported revenue of $867.3 million, which represents a 53% increase compared to revenue of $567.3 million for fiscal 2009.

**www.cree.com**

# SPS/IPC/DRIVES Reflects the Upswing in Automation

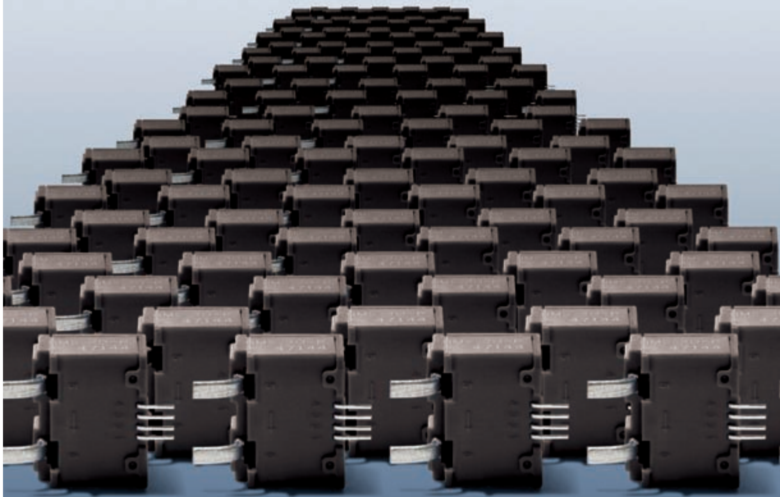
**SPS/IPC/Drives is the dedicated conference/exhibition for electrical drives and automation, it will be held at Nuremberg fairgrounds from 23 – 25 November 2010. With a total of 48,595 visitors in 2009 the event achieved a new record and gave cause for some optimism for the automation branch in difficult economic conditions. About 2/3 of the visitors are active in construction and development, production or management.**

**All the major players have already signed up for this year's event, and more than 1,200 exhibitors are expected. The organizer Mesago foresees an even larger exhibition this year and greater utilization of the 11 halls at the Nuremberg Exhibition Centre. The special topics of the exhibition and its forums are energy efficiency, industrial identification and safety and security. The joint stands "Open source meets industry" and "AMA Center for Sensor, Measuring and Testing Technologies" will offer the visitors a chance to gain an instant overview of each topic. Exhibitors from the power electronics industry include Avago, Infineon, LEM, Mitsubishi Electric (Power Modules) or Semikron.**

**This year's conference will be presenting two Young Engineer Awards for the first time. One goes to each of the best contributions from the Automation and Drives sectors. The official prize reception will take place at a special evening event on 24 November. Factory automation, electric drives and industrial communications are the main topics at the accompanying conference.**

**www.mesago.com/sps**





# The Whole World of Electronics in Munich

Energy efficiency, environmental compatibility, cost reduction and flexibility are just some of the challenges facing the electronics industry today. At electronica 2010, the global electronics industry will demonstrate from November 9-12 on Munich's fairgrounds how it will rise to these challenges. Over a period of four days, the exhibition halls will once again be the place where companies meet at the world's most important trade fair for electronics.
The 2008 event attracted around 2,800 exhibitors and approximately 73.000 trade visitors.

"What lessons have we learnt from the crisis?" will be the title of the podium discussion which will be held from 11.00 to 12.00 on 9 November 2010 during the electronica Forum in Hall A3, Stand 242. The participants in the podium discussion will be Peter Bauer, CEO of Infineon Technologies AG, Rich Beyer, CEO of Freescale Semiconductor, Carlo Bozzotti, CEO of STMicroelectronics, and Rick Clemmer, CEO of NXP Semiconductors, who will answer questions relating to economic developments over the last few years. The discussion will examine the questions of how the crisis in 2008/09 differs from that in 2001, the extent to which relations with suppliers have changed, the role now being played by foundries, the way in which new investments are evaluated and what consequences and risks arise through the, at times, long delivery times and allocations.

Electronica will cover the entire spectrum of technologies, products and solutions of the electronics industry: from semiconductors, sensors, measuring and testing, electronics design, passive components, power supply, PCBs and other non-mounted circuit carriers through to EMS. Automotive with the main theme of electromobility, displays and e-signage or digital signage, embedded systems with hardware and software, medical electronics, MEMS, photovoltaics and renewable energies are just some of the topics that will dominate this year's trade fair.

**Future mobility concepts**

Around 20% of exhibitors at electronica 2010 will show products from the automotive sector and present solutions for future mobility. In addition to the trade fair itself, the 'Automotive conference' and the 'Automotive Forum' will also focus on this topic.

Automobile electronics plays a leading role in the electronics sector as a subsegment. After a drop in turnover to $125 billion in 2009, market researchers such as Strategy Analytics are anticipating an increase to $244 billion up to the year 2017.

The anticipated rise in turnover is due not least to the fact that the industry is tackling the requirements relating to future mobility and is developing innovative solutions. The objective of the project 'Energy Efficient Driving 2014' is to reduce the fuel consumption of vehicles with conventional engines by up to 10% by the year 2014. The participating companies include ELMOS Semiconductor, Flextronics Automotive, Infineon Technologies and Robert Bosch.

Increasing the 'intelligence' of vehicles is one of the most important approaches for reducing fuel consumption. By making full use of all data, for example from the navigation system, driving situations will be predicted in future and the operating strategies of the vehicle will be matched to requirements. This will lead to considerable potential savings. Another way to increase efficiency is to make use of torque generation and transmission. Electronic powertrain systems optimize energy in the vehicle's powertrain. The industry is expecting strong growth of up to 14% for the required components such as 'powertrain ECUs' in the next few years.

The obstacle which all manufacturers of electric vehicles must currently overcome is series production of a battery that is efficient and small and can be quickly recharged. Leading international companies in this field, e.g. Axeon from Scotland and the French battery manufacturer Saft, are also expected to attend electronica 2010. Both companies are developing lithium-ion batteries for industrial applications. The batteries from Axeon are now already being used all over Europe to drive electric cars.

The 'Automotive Forum' will examine the topics of e-mobility, safety and communication during different sessions. The 'Automotive Conference' will be held in the Munich International Congress Center on November 8 and 9, 2010. The first day featuring talks on markets and strategies will be aimed at top managers from automobile manufacturers, automotive component suppliers and electronics companies. The program will include, for example, talks by Brad Maggart, President of Delphi Japan and Sales Director Delphi Electronics & Safety Asia, on the topic of 'Challenges and Opportunities in the Electrification of the China Auto Market' or by Peter Bauer, CEO, Infineon Technologies, who will speak about 'Semiconductors as Innovation Engine for Energy Efficient and Safe Mobility'. Other talks from the program of the first conference day will examine, for example, questions relating to lithium-ion batteries (SB LiMotive) or system architectures for cognitive safety functions (TRW Automotive).

The focal point for the target group on the second day will be technical management technologies. The first session will deal exclusively with electro-mobility. The program will include, for example, talks by Brose Fahrzeugteile entitled 'Energy-Efficient Electromechanical Systems Used in Automotive Applications', or 'Global Standard Charging interface for electric Vehicles' by Volkswagen. The second session will examine communication, driver assistance and lighting. Trade visitors can look forward, for example, to talks by BMW on 'IP & Ethernet as Potential Mainstream Automotive Technologies', by NXP Semiconductor on 'Driving Innovation in a Green Automotive Industry' or by Hella on 'Lighting Based Driver Assistance Systems as an Enabler for Future Safety Functions'.

**Power electronics participation**

Diotec Semiconductor introduces a new low profile SMD bridge rectifier in the popular outline TO-269AA (MiniDIL), called the S40 through S500 SLIM series with nominal 0.8A and forward surge current rating of 40A. Their encapsulation is made by a halogen-free molding compound. Its maximum height of 1.6mm allows designers to put the device on the bottom side of the PCB, where so far only thin passives were placed. The Plasma EPOS chip passivation allows for reverse

voltages from 80V (S40) up to 1000V (S500).
www.diotec.com

**Fairchild's** booth (Hall A4-506) will feature 20 technology demonstrations that enable mobile connectivity and optimize energy usage in power supplies (AC/DC and DC/DC), mobile, LED lighting, motor, solar, computing, consumer and automotive applications.

LED lighting will provide a detailed look at solutions like the FSFR2100, a highly integrated power switch designed for high-efficiency half-bridge resonant converters. One of the many power supply demos will focus on class D audio amplifiers. The FAN6961 is an 8-pin, boundary-mode, PFC controller IC intended for controlling PFC pre-regulators. And the FDMS2504SDC is an N-Channel PowerTrench MOSFET in both silicon and Dual Cool package technologies.
www.fairchildsemi.com

**International Rectifier** will display its power semiconductors in Hall A5-320 including demonstrations of the company's GaN-based power device platform, GaNpowIR, SupIRBuck integrated voltage regulators, MOSFETs and DirectFET MOSFETs, IGBTs and high-voltage ICs for a diverse range of applications including appliances, automotive, lighting, computing and Class D audio. Also DC/DC converters and modules for high reliability applications will be shown.

IR is holding a series of seminars to review the distinct advantages of the company's GaN-on-Si technology platform. The special sessions will feature demonstrations of GaN-based power conversion circuits including motor control and Class D audio designed to enable a new era in high frequency, high density, highly efficient power conversion solutions. Three 90 minute sessions will take place at the Konigshof Hotel, Munich on Wednesday, November 10, 2010 at 9.30 a.m., 2.00 p.m. and 4.30 p.m. Places are limited.
www.irf.com

**Intersil** (A4-207) will introduce a new generation of Li-ion cell monitoring and balancing products that satisfies the requirements of today's electric and hybrid-electric vehicles. The ISL78600 is a Li-ion battery manager IC that supervises 6 to 12 series connected cells. The part performs accurate monitoring, cell balancing and extensive system diagnostics functions. With an integrated 14-bit analog-to-digital converter (ADC) and next-generation input design, the device provides the accuracy needed to squeeze the highest possible performance from state-of-the-art Li-ion batteries. The device's integrated system monitoring and diagnostics functions emphasize safety and reliability while filtering fault-detection inputs to reject false alarms. These safety-related capabilities allow the HEV/EV solution - featuring the Intersil ISL78600 - to approach Automotive Safety Integrity Level (ASIL) C compatibility as a stand-alone part. To check voltage measurement accuracy, the ISL78600 integrates two separate voltage references that can be compared for accuracy. The ISL78600 also works with a backup device, the ISL78601, that provides cell over-voltage and under-voltage detection for redundant monitoring systems.
www.intersil.com

**Linear Technology** (A4-538) introduces within its familiy of µmodules the LTM4628, a dual output 8A regulator operating from input voltages as high as 26.5V. The outputs can be configured to a single 2phase 16A output. Included in the package are the switching controller, power MOSFETs, inductor and supporting components. Output voltage range can be set by a resistor between 0.6V and 5.5V. The device supports frequency synchronization, multi-phase operation, and output voltage tracking for supply rail sequencing. Typical switching frequency is 550kHz. For switching-noise sensitive applications, it can be externally synchronized from 400kHz to 780kHz. A resistor can be used to program a free run frequency on the fSET pin. High efficiency at light loads can be accomplished with selectable Burst Mode operation or pulse-skipping operation. These light load features will accommodate battery operation.
www.linear.com

**Murata Europe** (B5-107) showcases a tiny buck converter

**Automotive (power) electronics are among the most interesting subjects at Electronica 2010**

module to help reduce footprint and a new super-capacitor technology to help provide peak power requirements. The Micro DC/DC converter module (LXDC2HL) is designed to be used with nominal 3.6V input from a Li-ion battery. It uses a newly developed ferrite multilayer substrate which incorporates the power inductor embedded within it. The module features very low noise as the primary noise, the power inductor, is confined within the ferrite substrate. Length of the connection between the controller IC and the inductor is close to zero, also helping reduce noise emissions. Output voltages are 1.2, 1.5, 1.8, 1.85, 3.0 and 3.3V. Output current is between 300 and 600mA, depending on voltage. Switching frequency is 3MHz

Murata, in partnership with Cap-XX, has also announced its first range of super-capacitor products (Supercaps), suited for mobile applications requiring burst power or peak power assists unable to be handled by Li-ion batteries. Parts with peak rated voltage of 5.5V in package size 20.5 x 18.5 x 3.2mm exhibit capacitance between 250 and 450mF. Single Cell types with peak rated voltage of 2.7V feature package size of 20.5 x 18.5 x 1.6mm and exhibit capacitance between 400 and 900mF.

**www.murata.eu**

**Murata Power Solutions** (A5-507) is set to change the shape of 1W isolated surface-mount DC/DC converters. The introduction of its new high performance MTU1 series marks a step-change in the miniaturization of power modules, setting new standards for footprint, load regulation and efficiency. . The MTU1 series' dimensions are 8.2 x 8.4 x 8.5 mm, representing a footprint reduction of 50% compared to the previous generation. Power density is 1.71 W/cm$^3$ and the series features wide temperature performance at full 1W load, between -40 and 85°C. The DC/DC converter also features 56% less power dissipation and lower running temperatures than its predecessor, improving overall efficiency by more than a fifth to 89%. The increase in efficiency and benefit of reduction in power dissipation enables the series' open frame design.

**www.murata-ps.com**

**ON Semiconductor's** A5-225 automotive area will address the company's latest solutions for LED vehicle lighting (front, rear and interior), fuel efficiency and sensing (for gasoline, diesel, hybrid and electric vehicles) and infotainment power delivery and connectivity. The industrial and lighting area will include live interactive motor control demonstrations utilising single chip micro-stepping motor drivers that integrate a position controller and built-in control / diagnostic interface. In the portable consumer area a selection of integrated, small form factor devices that support lighting, audio and power management in the rapidly growing battery powered portable equipment sector will be shown.

**www.onsemi.com**

**Power Integrations** (A5-507, A4-260) will demonstrate its PI Expert Suite Version 8. The newly released update further improves the productivity of power supply design teams by reducing the time to first prototype and by slashing the number of prototype iterations required to reach a finished product. PI Expert Suite simplifies the design process by generating a complete schematic of the power supply. The new release also features improved power transformer optimization techniques and a more flexible bill of materials selection and report generation feature. New for PI Expert Suite Version 8 is a heatsink calculation and optimization tool which provides the designer with an estimation of the thermal design requirements for a new power supply concept. This may be used to guide layout and mechanical prototyping decisions - avoiding iterations and wasted time. The new version features enhanced PCB layout recommendations based on the device and package chosen, allowing the designer to minimize trace-induced EMI and board area, and also maximize electrical noise immunity and surge tolerance.

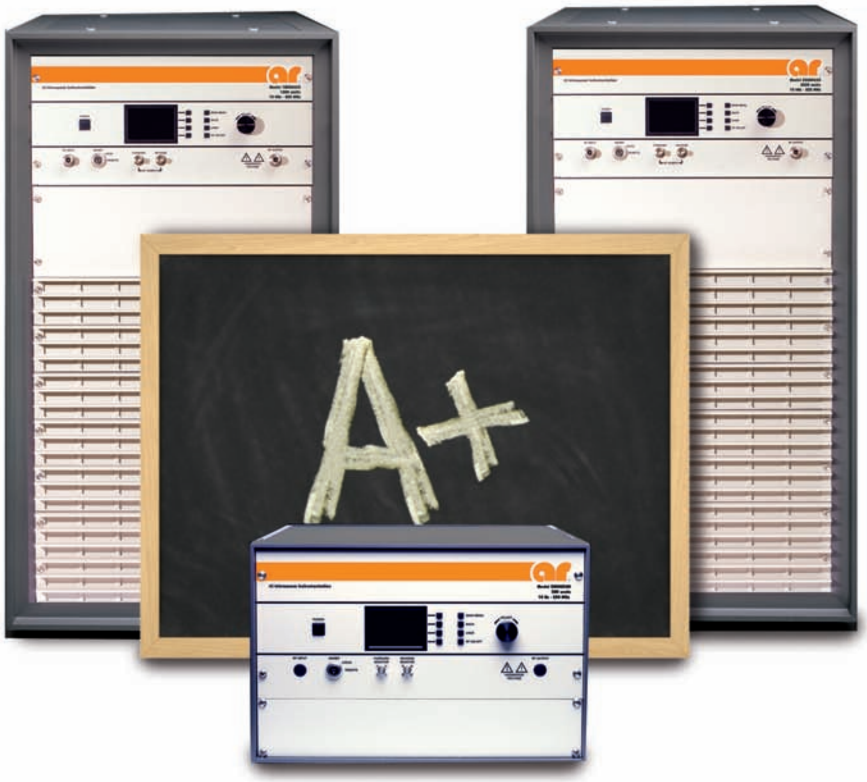
**www.powerint.com/**

**Vishay Intertechnology** will present all its new electronics components at booth A5.143. Special focus is set on the Super12 featured products. The line-up of components features industry-leading specs such as capacitance-voltage, current rating, and on-resistance. In example, the 597D and T97 Multi-Anode Tantalum Capacitors offer a capacitance-voltage of 1500µF at 4V to 15µF at 75V to save PCB space, while ultra-low ESR down to 15mΩ improves design efficiency. The VO3120 and VO3150A IGBT/MOSFET Drivers offer supply voltage range from 15V to 32V, and a wide operating temperature range from -40°C to 110°C.

At the booth Vishay is presenting special sessions pointing out the advantages of the new components in reference to current industrial applications such as diodes; rectifiers and modules; MOSFETs, power ICs; optoelectronics; inductors; resistors; and capacitors. At the Automotive booth A6.A41 Vishay focuses on energy efficiency and presents components which are targeting this market, such as i.e. MOSFETs, MKP film capacitors and Schottky diodes.

**www.vishay.com**

# Maybe We Should Have Called It The A+ Series.




## *Our New "A" Series uses less energy, delivers more power, is lighter, smaller, and delivers a better price performance ratio.*

Our new, redesigned "A" Series amplifiers are so powerful and so efficient that we're able to make them 25% to 50% smaller while maintaining the same output power. They're now lighter, more portable, and able to fit easily in a control room and that translates to one great value for you. Yet they still deliver 500, 1000 and 2500 watts of power, and even more depending on the model you choose.

We're getting more expandable too. Our "A" Series amps now cover the 10 kHz to 250 MHz frequency range. So you can test to virtually any standards.

They feature the latest FET technology, and can be controlled remotely with IEEE, RS-232, USB and Ethernet interfaces. And with all these innovative features, our "A" Series amps use less energy, that's good for you and good for the environment. Our new "A" series also comes with enhanced cooling technology.

At 40 years old, AR is still exceeding the grade, in quality, value, technology, craftsmanship, and service after the sale. And that makes these new "A" Series amplifiers a no-brainer.

To learn more, visit www.ar-worldwide.com or call us at 215-723-8181.

*In Europe www.ar-europe.ie/contact.php*

*Come See Us At Electronica 2010, New Munich Trade Fair, Munich, Germany, October 9-12*

ar®

**ar europe**

National Technology Park, Ashling Building, Limerick, Ireland ¥ 353-61-504300 ¥ *www.ar-europe.ie*

# Wide Temperature Operation of High Isolation HV-IGBT Modules

Mitsubishi Electric has developed new High Voltage Insulated Gate Bipolar Transistor (HV-IGBT) modules called the 'R-Series' with a high isolation package, which can be used with a wide operating temperature range from -50°C up to 150°C. The newly developed chip set achieves stable operation and high SOA capability over a wide temperature range. In addition the new package design is optimized for high isolation. The new HV-IGBT R-series has been developed to meet the requirements of high reliability applications for cold latitudes and to increase the inverter output power without increasing the equipment size. **Kenji Hatori, Shuichi Kitamura, Shigeru Hasegawa, Shinichi Iura, Power Device Works, Mitsubishi Electric Corporation, Japan; Masuo Koga, Fukuryo Semicon Engineering Corporation, Fukuoka, Japan; Eugen Stumpf, Mitsubishi Electric Europe B.V., Germany**

High-voltage IGBT modules are widely installed in high power applications, such as railway and large industrial drives. High reliability of the modules is requested for these applications. Recently, lower temperature operation has been requested for applications in cold latitudes. Also, higher temperature operation is requested for increasing the inverter output power. Therefore, the newly developed high isolation package module of HV-IGBT is able to operate from -50°C to 150°C.

Several issues had to be addressed for achieving the wide temperature operation. At first, a chip set with high SOA capability at $T_j$=150°C was achieved without thermal destruction. It has been already reported that the new planar IGBT structure for 3.3kV IGBT module has a high SOA capability at $T_j$=150°C [1, 2]. The second point was the optimization of package design. The optimization of the layout of the power terminals and chips is done by current sharing analysis in order to satisfy Short Circuit Safe Operating Area (SCSOA) at $T_j$=150°C. The excellent SCSOA robustness at $T_j$=150°C could be achieved by optimizing the current sharing. The third issue is the operation at $T_j$=-50°C. Stable operation is achieved by optimized lifetime control. The last item is the silicone gel for wide temperature operation, which has the same isolation capability as conventional modules even at very low temperatures.

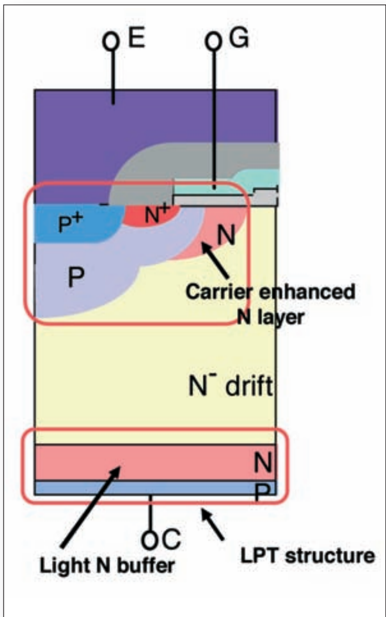



**Figure 1:** The structure of R-Series IGBT

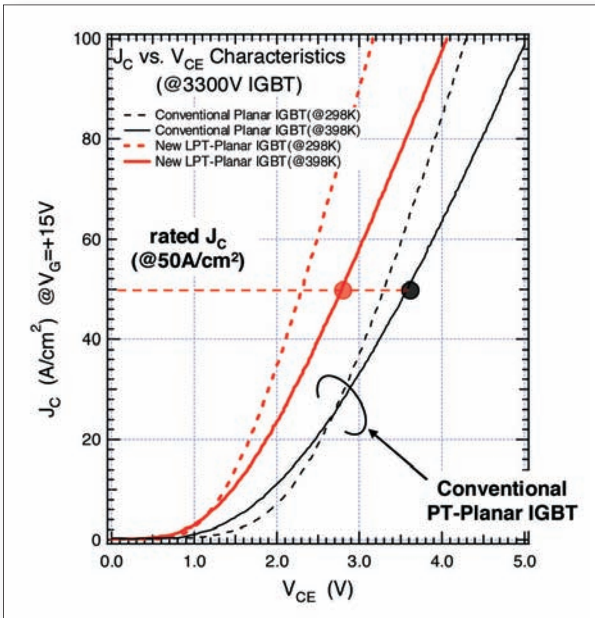



**Figure 2:** Output characteristics (3.3kV class)

## R-Series chip set

The new HV-IGBT module called the R-Series (Figure 1) achieves larger current rating with wide safe operating area (SOA).

Low on-state losses are achieved by three technologies: Carrier enhanced N layer, thinner N- drift layer and LPT (Light Punch Through) structure (as shown in Figure 1). Because of reducing the on-state losses, increased current rating by 25 - 33% is achieved (see Figure 2).

The LPT structure with optimized lifetime control achieves low leakage current and positive temperature

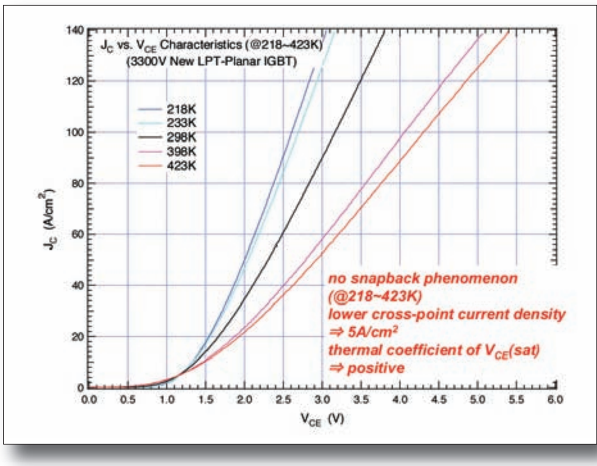



**Figure 3: Output characteristic at $T_j$=-55-150°C (3.3kV class)**

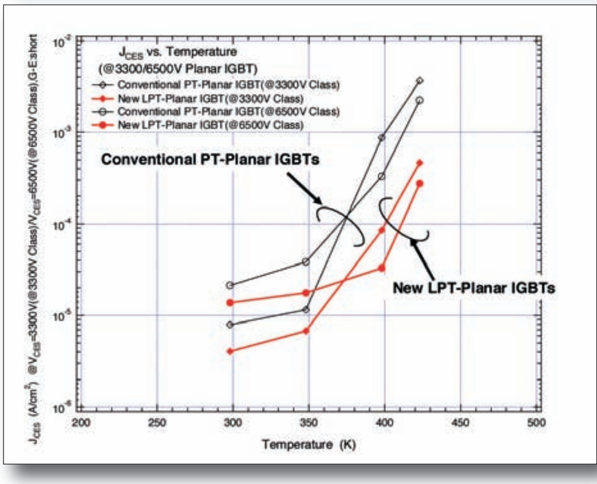



**Figure 4: Leakage current characteristics of IGBT chips as function of temperature (3.3kV and 6.5kV class)**

coefficient of the on-state voltage characteristic. Therefore, this structure is so rugged against thermal runaway and a safe operation at $T_j$=150°C is achieved. The positive temperature coefficient characteristic of on-state voltage has a big advantage in parallel operation. The new HV-IGBT R-series has higher SOA capability at a wider temperature range than the conventional module. The LPT structure also safely avoids the snap-back phenomenon at $T_j$=-50°C and ensures stable operation at $T_j$=-50°C (as shown in Figure 3). Figure 4 shows leakage current characteristics of IGBT chips as function of temperature (3.3kV and 6.5kV class).

The new diode (Figure 5) achieves reduction of reverse recovery current. Reduction of the reverse recovery current is achieved by the following three technologies: light anode by low concentration P layer, thinner N-drift layer and LPT structure, shown in Figure 5. The benefit of reduced reverse recovery current is low peak power during reverse recovery and low turn-on switching energy of the IGBT part. As shown in Figure 6, the reverse recovery current is significantly reduced. The LPT structure with optimized lifetime control achieves a positive temperature coefficient of on-state voltage characteristic and low leakage current, as well as high reverse recovery SOA capability.

### High isolation package

The newly developed package is suitable for a wide temperature operation range. The wide temperature operation at -50°C

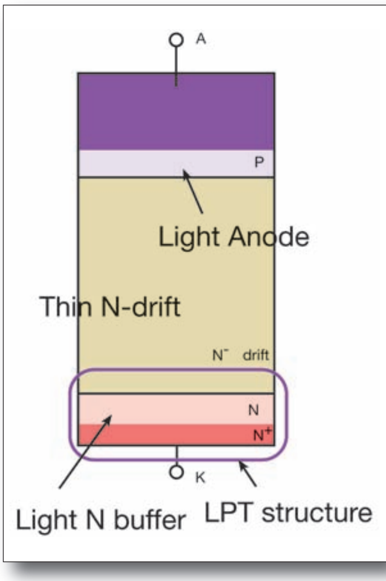



**Figure 5: The structure of R-Series diode**

to 150°C is achieved by adopting the newly designed components, especially the silicone gel material for maintaining high isolation voltage 10.2kVrms at 1 minute in spite of the extended operation temperature. For better utilization of the improved chip performance, the package of HV IGBT R-series is designed to optimize the inside current sharing among parallel chips, especially by newly designed chip layout, gate wiring and electrode structure. Figure 7 shows the new R-series package, which has compatibility of terminals and mounting position with the existing modules.

### Optimized current sharing

Electromagnetic influence on the gate circuit is increased by a large current at

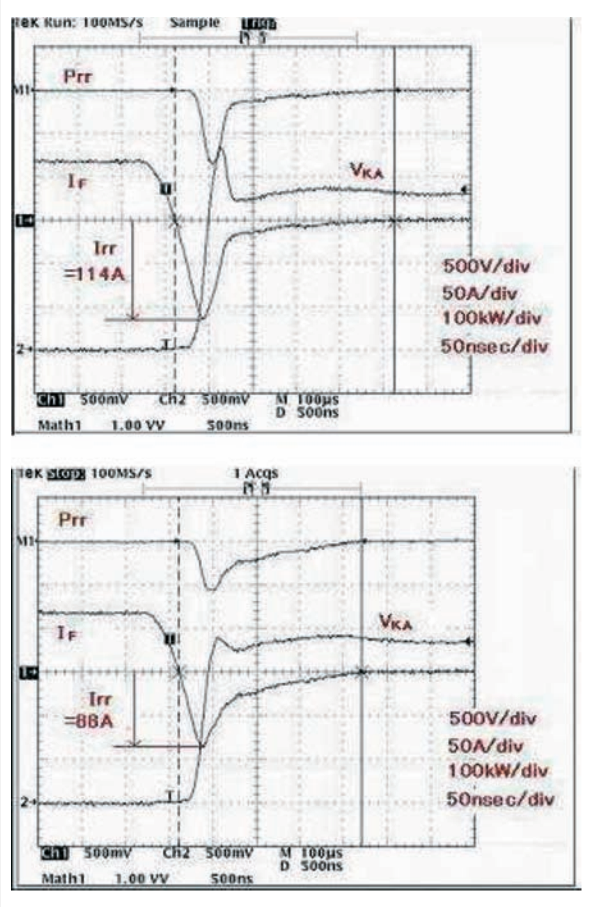



**Figure 6: Reverse recovery waveforms of R-Series 3.3kV-diode (top: conventional chip, bottom: new chip, $V_{CC}$=1800V, $I_F$=67A, di/dt=290A/µs)**

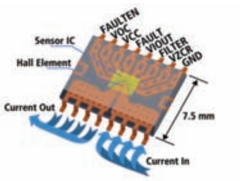
short circuit operation. Therefore, it is important to evaluate the influence of mutual inductance and also design a module to keep the current sharing balanced.

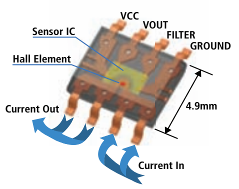
The calculation result of current sharing in new high isolation package under short circuit operation is shown in Figure 8. The electromagnetic influence on the gate circuit is avoided and excellent current sharing is achieved. The waveform of the high isolation package with 3.3kV IGBT is measured under short circuit condition ($V_{CC}$=2800V, $T_j$=150°C, $V_{GE}$=16.5 V), shown in Figure 9. It is confirmed that the new module can turn off at such harsh conditions without destruction.

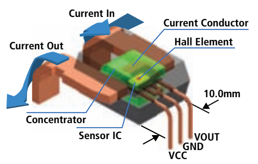
## Silicone gel

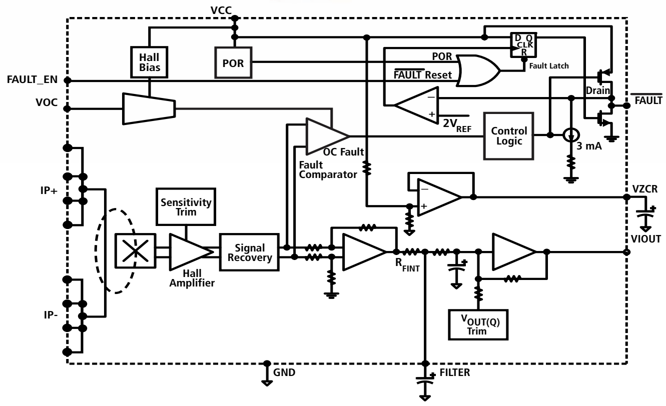
The silicone gel material is one of the key components for insulated modules. The characteristics of new silicone gel are less dependent on the temperature than the conventional one. Therefore, the new silicone gel has tougher characteristics even at the wider temperature range of -50°C up to 150°C. Of course, the new silicone gel has a good adhesive capability that achieves stable isolation at 10.2kVrms for 1 minute and partial

# Innovative Current Sensor ICs with Integrated Conductors and Galvanic Isolation




## Small Form Factor, High Bandwidth Hall-Effect Sensor IC Solutions

### Features - 5 A to 200 A Sensor Family

- Small form factor, low profile packages
- 100 µΩ and 1 mΩ internal conductor resistance
- 3 kVrms, 60 second voltage isolation
- >120 kHz analog output bandwidth
- 2 µs FAULT output for IGBT protection
- Output error typically +/- 1%
- Electrostatic shield provides dV/dt immunity

### Key Applications

- Motor / pump / compressor control
- Power supply control
- Inverters in alternative energy systems
- Hybrid electric vehicle power systems

### Representatives

**ALLREM**
94616 Rungis Cedex
FRANCE
Tel: +33 (0) 1 56 70 03 80
E-mail: info@allrem.com

**SSG Semiconductor Systems GmbH**
D79856 Hinterzarten
GERMANY
Tel: +49 (0) 7652-91060
Website: www.ssg-de.com
E-mail: mail@ssg-de.com

**Consystems s.r.l. – Divisione Cefra**
I-20144 Milano
ITALY
Tel: +39 02 4241471
Website: www.cefra.com
E-mail: info@cefra.it

**MSM Ltd.**
Weybridge
Surrey, KT13 0RZ
United Kingdom
Tel: +44 (0) 1932 341106
E-mail: msm@intonet.co.uk

Allegro®
MicroSystems Europe Ltd.
High Performance Power and Hall-Effect Sensor ICs

www.allegromicro.com/promo938

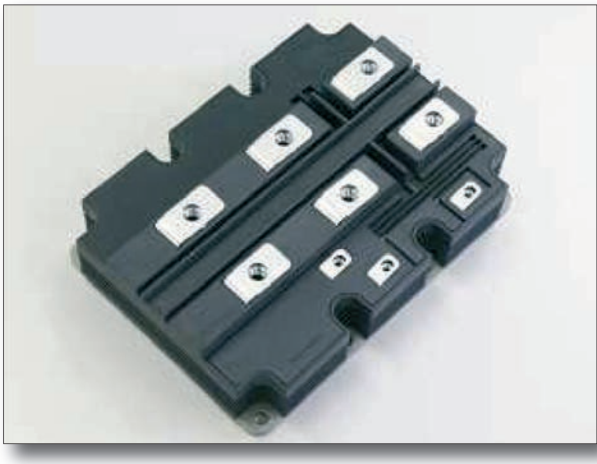


Figure 7: **R-series package (size: 190mm x 140mm x 48mm)**

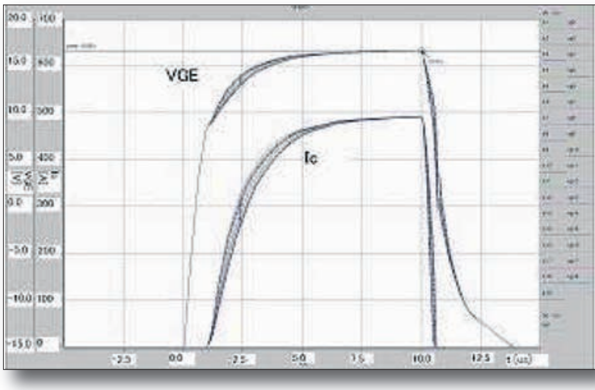



Figure 8: **Calculation result of new high isolation package with 3.3kV IGBT ($V_{CC}$=2800V, $T_j$=150°C, $V_{GE}$=16.5V, $L_s$=80nH)**

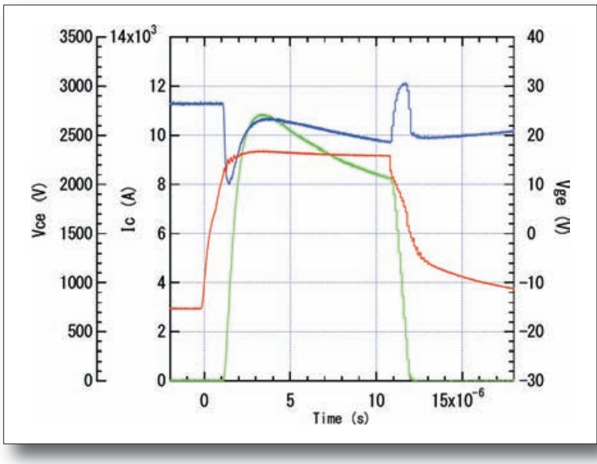



Figure 9: **Measurement of the new high isolation package with 3.3kV IGBT under short circuit condition ($V_{cc}$=2800 V, $T_j$=150°C, $V_{ge}$=16.5V, $L_s$=80 nH)**

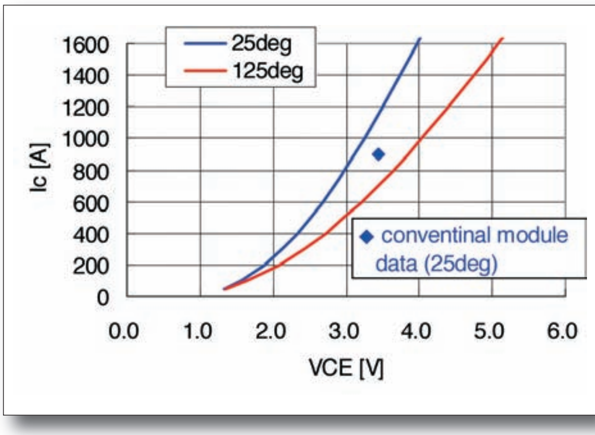



Figure 10: **Output Characteristic of new 4.5kV IGBT ($I_{C(nom)}$=1200A)**

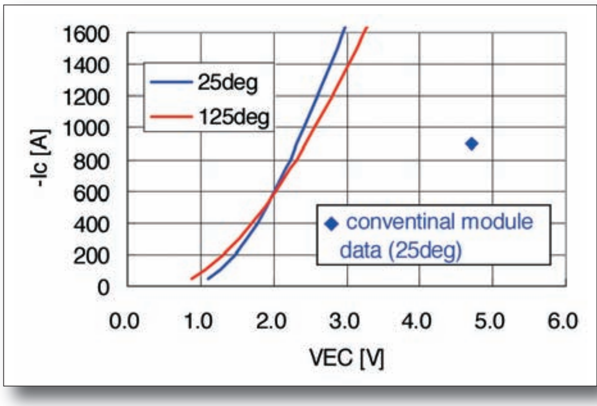



Figure 11: **Output Characteristic of new 4.5kV diode ($I_{C(nom)}$=1200A)**

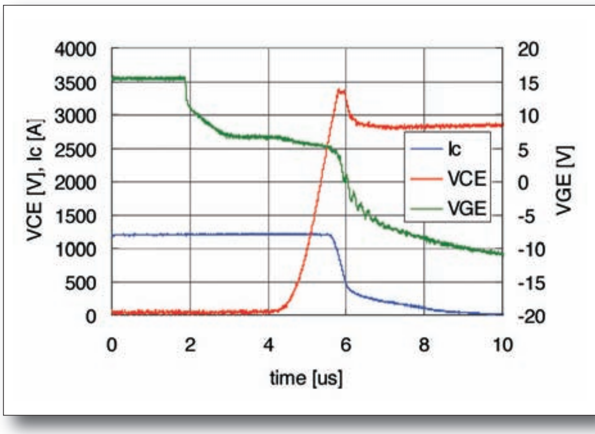



Figure 12: **Turn-off switching waveform of 4.5kV IGBT at nominal condition at $T_j$=125°C**

discharge characteristics according to IEC 61287-1.

The new HV-IGBT R-series has been qualified for the storage temperature test at -55°C and 150°C. In addition, in spite of the expansion of operational temperature, the new module achieves the same lifetime as the conventional module at the same temperature cycling condition.

## Characteristics of HVIGBT

The characteristics for three different voltage classes are shown in Table 1. Figures 10 and 11 show output characteristic of the 4.5kV / 1.2kA modules. It can be seen that both collector-emitter saturation voltage and diode forward voltage at nominal current are reduced. A positive temperature

| | 3.3kV Module | 4.5kV Module | 6.5kV Module |
|---|---|---|---|
| $I_{C(nom)}$ | 1500A | 1200A | 750A |
| $T_{j(op)}$ | -50 to 150°C | -50 to 125°C | -50 to 125°C |
| $V_{CE(sat)}$ | 3.10V | 4.40V | 4.90V |
| $V_{EC}$ ($V_F$) | 2.30V | 2.80V | 3.40V |

Table 1: **Characteristics comparison table of HVIGBT R-Series with high isolation (measured at Tj=125°C and IC(nom))**

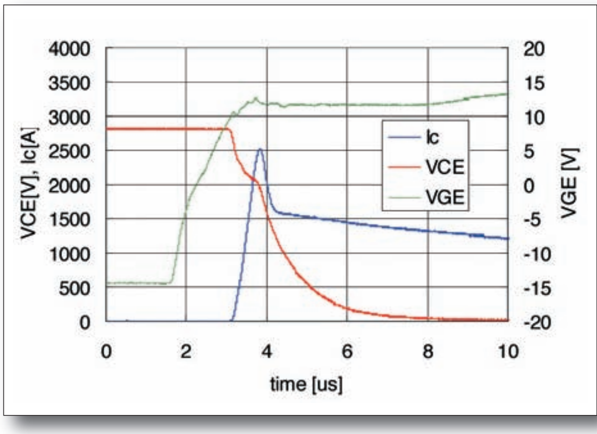



Figure 13: **Turn-on switching waveform of 4.5kV IGBT at nominal condition at $T_j$=125°C**

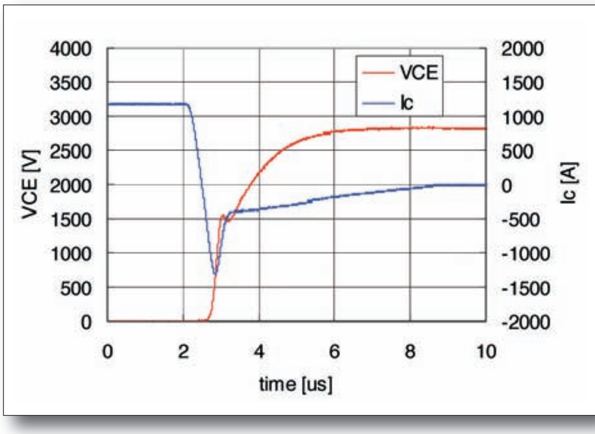



Figure 14: **Reverse recovery waveform of 4.5kV IGBT at nominal condition at $T_j$=125 °C**

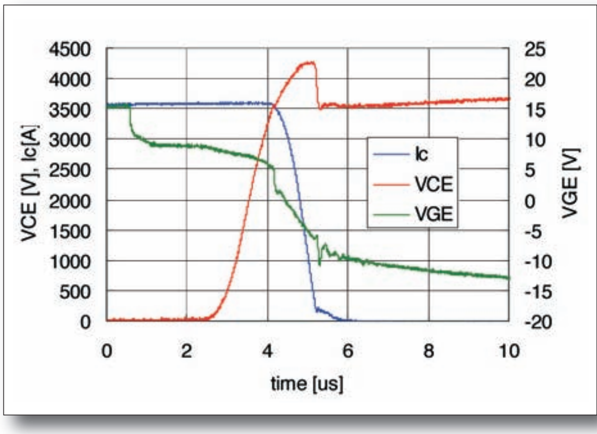



Figure 15: **Turn-off switching waveform at 3 x $I_{c(nom)}$ condition at 125°C.**

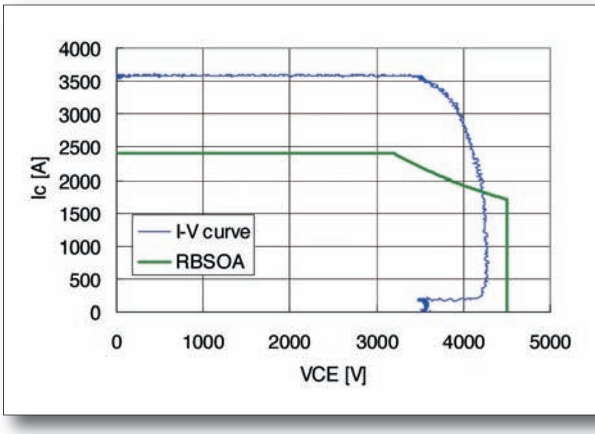



Figure 16: **RBSOA and V-I curve from Figure 15**

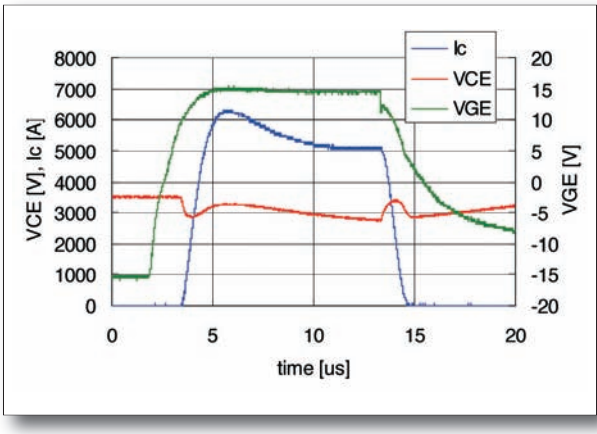



Figure 17: **Short circuit waveform at 125°C**

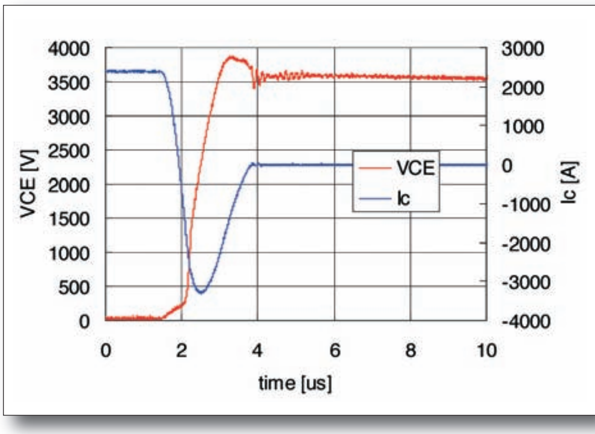



Figure 18: **Reverse recovery waveform at reached $P_{rr}$=9MW at 125°C**

coefficient has been obtained.

The waveform during turn-off switching of the 4.5kV module at nominal condition at $T_j$=125°C is shown in Figure 12. It operates smoothly without oscillation. A significantly low switching energy $E_{off}$=4.30J/P is achieved with $R_{g(off)}$=10Ω.

Figure 13 shows the waveform during turn-on switching of the 4.5kV module at nominal condition. The new module can increase di/dt to reduce turn-on switching energy by a smaller $R_{g(on)}$ compared to conventional one. This significant improvement is achieved by installing new diode chips. Turn-on switching energy is $E_{on}$ = 5.50J/P with $R_{g(on)}$ = 2.7Ω and no capacitance between gate and emitter.

The waveform during diode reverse recovery is shown in Figure 14. The behavior is very soft and the reverse recovery current is low resulting in low reverse recovery peak power $P_{rr}$. The reverse recovery energy is $Erec_{=2.50J/P}$ with di/dt = 3.6kA/µs.

It is important to have a wide Safe Operating Area (SOA) for HV-IGBT modules. Figure 15 shows the turn-off switching waveform of 4.5kVIGBT under over-current conditions at $V_{cc}$=3500V and $T_j$=125°C. Three times nominal current ($I_c$ = 3600A) is successfully turned off (Figure 16). Figure 17 shows typical short circuit waveform of 4.5kV IGBT at $V_{cc}$=3500V, $T_j$=125°C and pulse time = 10µs.

A wide Reverse Recovery Safe Operating Area (RRSOA) was the objective for R-series diode design. Figures 18 and 19 are showing the reverse recovery waveform of 4.5kV

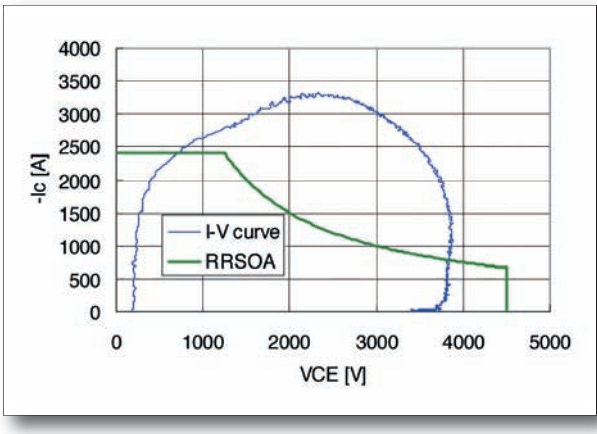



Figure 19: **RRSOA and V-I curve from Figure 18**

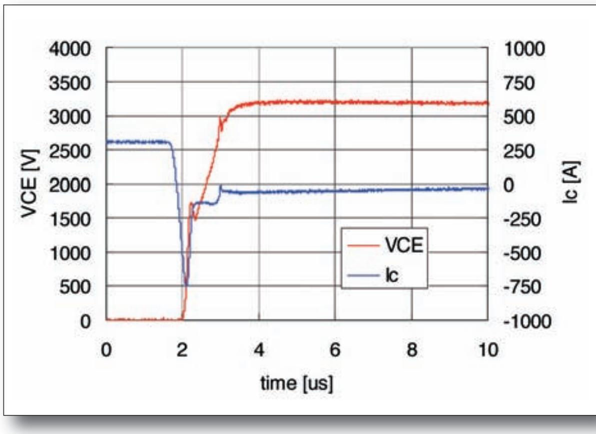



Figure 20: **Reverse recovery waveform at 1/4 nominal current and $T_j$=-40°C.**

diode at $V_{CC}$=3500V, $T_j$=125°C, $I_F$=2400A and di/dt ≥ 6kA/µs. The resulting $P_{rr}$ reached 9MW without destruction. This is 3 times the RRSOA-limit and an indication for very robust diode design.

In general high-voltage diodes have a tendency to oscillation during reverse recovery at low temperature, low current and high DC-link voltage conditions. The new 4.5kV diode has no oscillation as shown in Figure 20 at the critical condition $T_j$=-40°C, $V_{CC}$ = 3200V, $I_C$=300A (1/4 nominal current). A stable reverse recovery operation over the whole temperature range is achieved.

## Conclusions

Mitsubishi has developed the new HV-IGBT R-Series module with high isolation. It has been confirmed that the new module is able to operate safely within a wide temperature range. The new module has an excellent robustness of SOA both for the IGBT and diode part without sacrificing performance. This high performance has been achieved by an optimized design combination of both the chip and the package. The new HV-IGBT R-Series with high isolation completely satisfies the extended needs, such as increasing current rating and operation in cold latitudes.

## Literature

*[1] K. Nakamura, et al. "The Next Generation of HV-IGBTs with Low Loss and High SOA Capability" ISPSD2008*

*[2] S. Iura, et al., "Development of New Generation 3.3kV IGBT module", PCIM 2006*

# Power Module with Additional Low Inductive Current Path

Parasitic inductances are a major problem with power modules, in particular in fast switching applications. The parasitic inductance of the component interconnections causes an over-voltage condition and increases the switch-off losses in the semiconductor. Many initiatives have been investigated to reduce the parasitic inductance in power modules utilizing a complex mechanical construction of overlapping internal bus bars forming the DC path. An alternative to this approach, which is outlined within this article, is a concept using today's standard power module construction but providing an additional ultra low inductive path for the transient current. **Michael Frisch and Temesi Ernö, Vincotech Germany and Hungary**

**Switching-off the IGBT results in a** current change which causes an over voltage spike by the current change in the parasitic inductances according to $V_{CE(peak)} = V_{CE} + L \times di/dt$ [1]. This voltage peak at switch-off endangers the semiconductor itself which than requires a higher voltage rating of the component. Additional increased switch-off losses will be generated in the transistor according to $E_{Off} = \int V_{CE}(t) * I_C(t) * dt$. Both, the increased voltage rating and the losses will lead to higher costs for the application.

The parasitic inductance limits the maximum switching frequency at an acceptable efficiency. The voltage overshot is not only linear with the inductance but also with the switched current. This leads to the requirement of ultra low inductive designs of high power modules. For a low power application, e.g. 100A/700V (1200V component rating), an inductive loop with 10nH is acceptable. To achieve the same switching condition in a high power application, e.g. 500A/700V (1200V component rating), would require a 2nH target for the stray inductance. In contradiction to these requirements are the needs for low resistive tracks, which cause additional stray inductance by the increased mechanical dimensions of bus bars and screw contacts. As a consequence the turn-off speed for high power modules has to be reduced. This reduces the di/dt and the voltage overshot, but in consequence the switching losses are higher and the maximum PWM frequency is limited due to the losses.

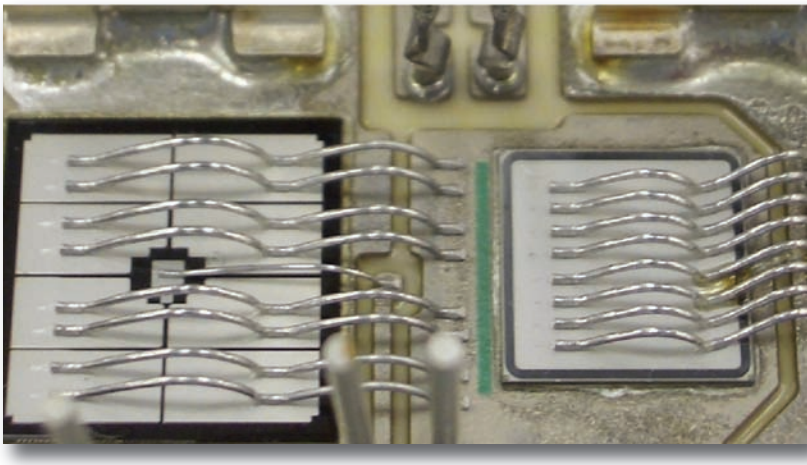


**Figure 2: Wire bonds as a source of stray inductance**

### Paralleling of IGBTs

The paralleling of IGBTs is another critical issue for the design of high power modules. The largest die size of 1200V IGBTs is rated for a nominal current of 150 - 200A. For higher current rating a paralleling of the chips is necessary which produces additional challenges into the module design such as:

- Symmetrical gate drive signal
- Symmetrical static power sharing
- Symmetrical dynamical paralleling

The paralleling during switch-on and off is influenced by the chip tolerances as well as the module inductance. While the semiconductors are switching in a linear mode were the spread in the chip characteristics can cause large asymmetry of the current, this will cause of one of the IGBTs to exceed the RBSOA (Reverse biased safe operating area)[2]. The RBSOA defines the maximum current which can be switched off safely without slowing down the semiconductor or using special circuits such as active clamping, soft turn-off.

The asymmetry in the stray inductance and tolerances of the chip parameters makes it difficult to predict the current sharing during switching, so that a safe turn-off operation becomes to be a complex mission. The higher the switched current the more likely is one of the

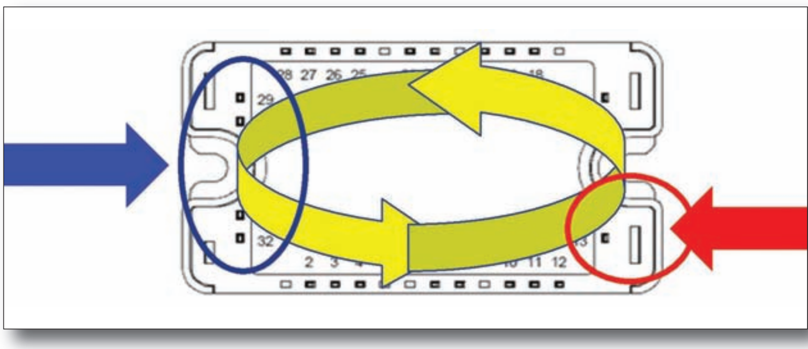


**Figure 1: Inductive loop in power modules**

individual IGBT chips be overloaded at turn-off.

### Sources of parasitic inductance

Parasitic inductance appears when current encircles an area (see Figure 1). In power modules are sources which significantly effect parasitic inductance [3]:

- Wire bond: The loop of the bond wires are add to the inductance (Figure 2). A flat and short bond wire design and the paralleling of wires will reduce the negative influence of this section. A wire bond connection from the substrate to external contacts will increase the problem.
- Substrate: The power tracks on the DBC (direct bonded copper substrate) will also encircle an area but the inductance is not as high as expected. The reason for this is that the back sides of the substrates are usually covered with solid copper of the substrate and the base plate. The inductive loop will now build a transformer which is shorted on the output. The inducted eddy-current in the secondary will compensate the inductance of the primary. The remaining inductance is not that significant.
- Connection elements inside the module: Modules with multiple substrates have the need of bridges to connect the power tracks between the DBCs. The reduction of the inductance of these elements can be achieved with flat construction or with an overlapped sandwich of DC+ and DC- (see Figure 3).

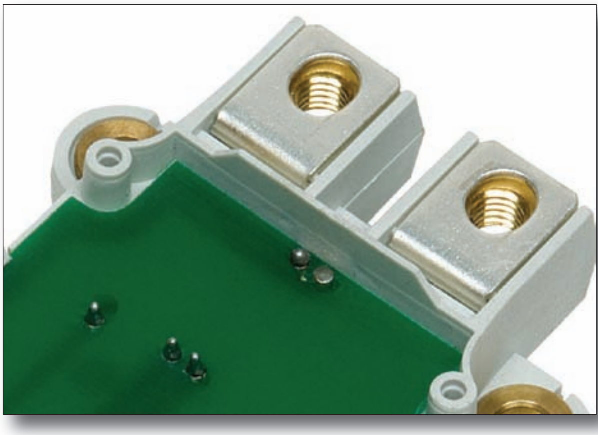


Figure 4: Power module with screw contacts

- External connection: The external connection with screw contacts (Figure 4) has some limitations. The screw system has large dimensions and it is necessary to keep certain distances between the voltage potentials to prevent sparking. With this condition the external DC interconnections have to be as close to each other as possible while still fulfilling the isolation requirements. Additional external effects might be compensated by external capacitors direct assembled on the DC-screw contacts.

The implementation of all the before mentioned actions will lead to an inductive loop between 12nH and 25nH; which is far above the required 2nH target for real fast switching.

### Reduction of the switching frequency

As a consequence of this circumstances with a relative high inductive loop, is to forcing a lower switching speed. The insertion of an increased gate resistor value is the obvious method to slow down the IGBT. But the turn-off characteristic of some IGBT technologies is nearly independent from the gate resistor. The suppliers of IGBTs are answering this problem with special high power components, were the turn-off is slowed down [4]. An additional method to reduce the switching speed is the connection of a negative feedback in the gate drive circuit. The parasitic inductance of the bond wires is used to reduce the effective gate emitter voltage change at the chip (see Figure 5).

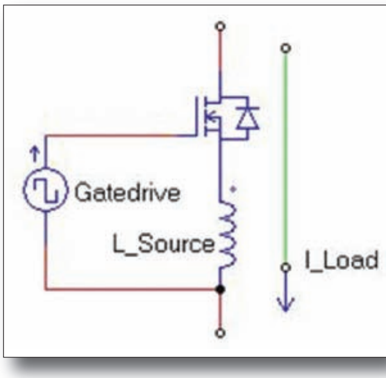



Figure 5: Parasitic inductance as a negative feedback for the gate control

For high power applications this parasitic effect is utilized to slow down the IGBT in order to reduce the overshoot and RBSOA problem. For fast switching applications a Kelvin emitter is used (see Figure 6) to

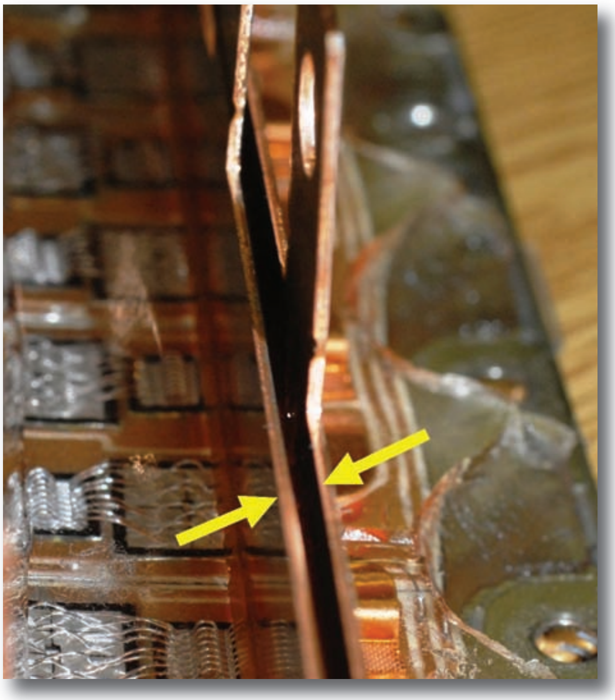


Figure 3: High power module with parallel DC-bus bar

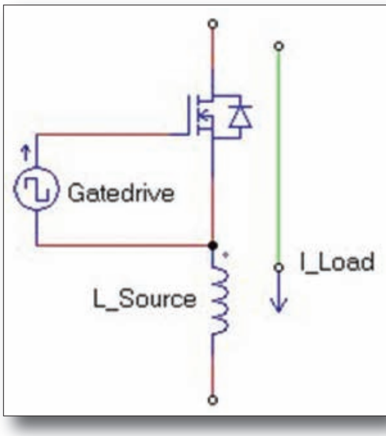
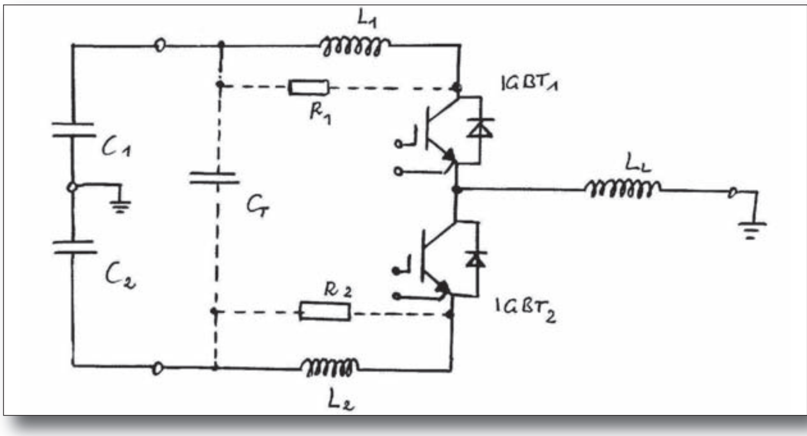



Figure 6: Gate control with current-less Kelvin contact for fast switching applications

Figure 7: **Concept of a power module with separated current path for continuous current (solid) and transient current (dashed)**



eliminate this effect and to reduce the switching losses but here the parasitic inductance helps to keep the IGBT inside its specified conditions.

This component will additionally reduce the overshoot problem, but this in consequence leads to high switching losses because of the increased turn-off energy ($E_{OFF}$).

## Low inductive solution for high power modules

The idea is to provide a low inductive path for the transient current during switching, while having a low resistive path for the continuous current. (see Figure 7).

The electrical connections in high power modules have to be designed for the conduction losses of the RMS current. This requirement increases the effort for a low inductive routing of the DC current, as solid copper bars have to be used to avoid over-heating. Unlike the requirements for the continuous current, the transient current path is only active during switching when di/dt is high. This is only for some hundreds of nanoseconds. Thermal issues are a minor problem for the tracks which are used only for the transient current.

The consequence is now to design a new ultra low inductive path for the transient current and use the already existing low resistive path for the continuous current. There are two directions to reduce the inductance in the transient path:

- An ultra low inductive path with overlapped tracks (e.g. on PCB, capacitor foil etc.).
- Paralleling of many connections to achieve the low inductance as a result of a conclusive paralleling (best is a pinning with alternating DC voltage polarity close to each other).

A module concept is developed based on a standard flowSCREW package. The transient current path is defined as PCB-bridges between the DCB-substrates (see Figures 8 and 9).

The DC-tracks in the transient path are routed totally overlapped. This means every DC+ voltage track is overlaid with a DC- track on a second layer. The small adapter PCBs are soldered into the main PCB with PCB fingers into complementary holes. Here, a certain distance is required to keep the clearance and creepage distances between DC+ and DC- fingers. Such a distance would cause parasitic inductance if no action is taken for

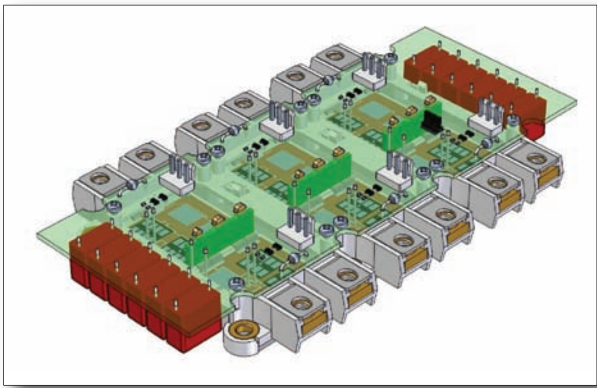
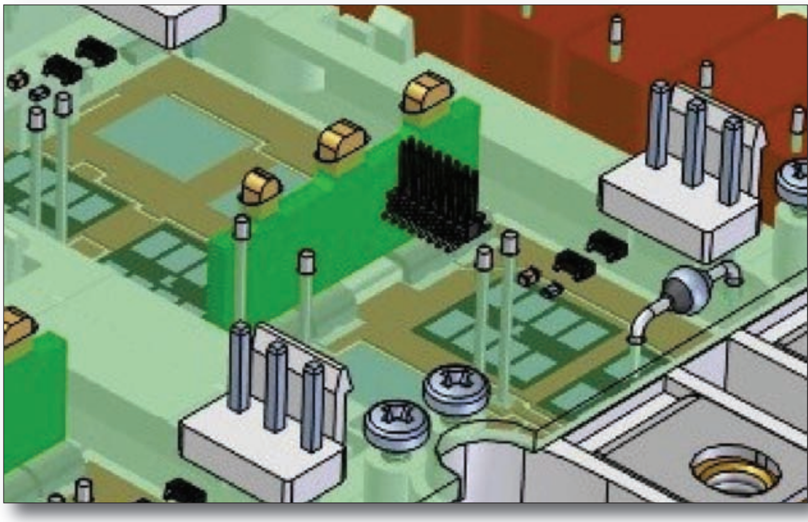


Figure 8: **Module concept based on the flowSCREW2 package with low inductive PCB bridges**

BELOW Figure 9: **PCB bridge in detail**



compensation. The current will take a separate path in the finger, making it impossible to compensate the magnetic field with the working current. But inside of the finger the opposite voltage potential is routed (in the DC- finger there are inside DC+ layers) which ensures the system to store a smaller electrical energy in the connection stray inductances. The transient DC path is routed to foil capacitors with total 1,2_F on the main PCB. For a better utilization of the capacitors all three half bridges are connected to the same DC capacitors.

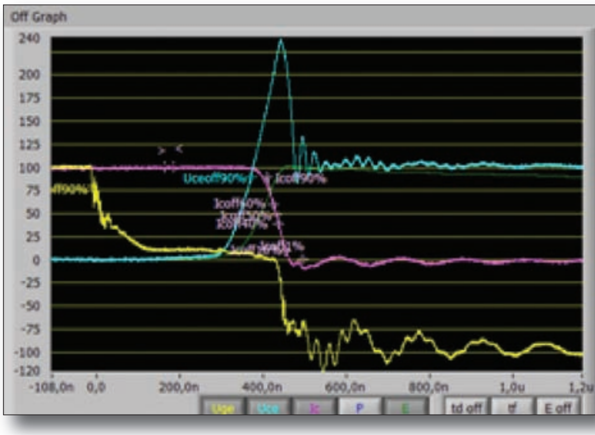
## Measurement and simulation

The investigation starts with the analysis of the performance of actual power modules. It is important to find out how the inductance of the package is limiting the usage of fast components in high power applications. As an example the voltage overshoot of a 600V trench field-stop IGBT in a flowSCREW2 package is shown here (see Figure 10). In this module are two 600V/200A IGBTs paralleled to a 400A half bridge topology.

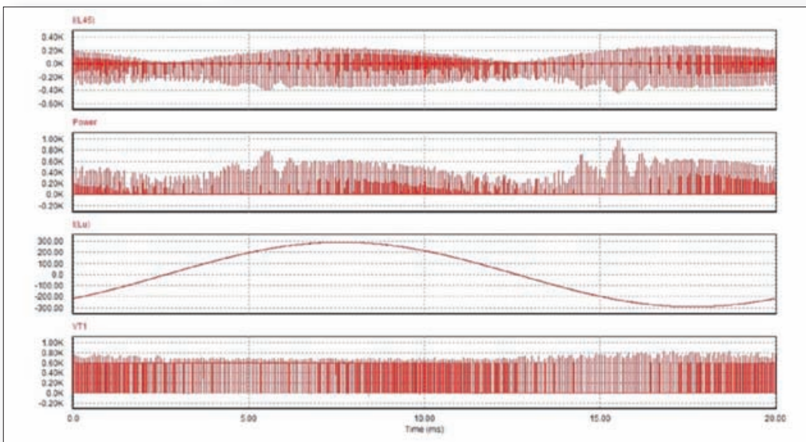
The parasitic inductance results to ca. 22nH. In this value the external DC-bus connection is included. The inductance causes at 700A (25°C) an overshoot of already 370V. The DC-voltage in this test was reduced to 300V but it still exceeded the maximum voltage rating of the IGBT.

The next step is a model with the parasitic inductance of the module (too complex to show here).

Figure 10: **Turn-off characteristics of a fast switching IGBT in the flowSCREW2 package without low inductive feature**




BELOW Figure 11: **Simulation result - module with transient current path**



For a prediction of the improvement of a transient current path we add this design concept feature to the model and perform a simulation of the current, voltage and power values at the semiconductor (Figure 11).

## Verification of low inductive current path

Samples of power modules are built (Figure 12) and equipped with the low inductive PCB bridges. The modules are tested in order to verify the expected behavior with an inductance measurement and the detection of the voltage overshoot of fast switching IGBTs.

The comparison with the standard module will show the effectiveness of the new module concept. Two different tests are defined to verify the effectiveness of the new solution:

- The module with low inductive current path is connected to the DC-link with ca. 9nH inductance in the DC-bus.
- The on-board capacitors on the PCB board are connected to the module.

The IGBT were switched off with 350V and a current of 720A (25°C). The voltage overshoot is 250V. The inductance of the transient current path is 16nH. In this value the 9nH of the external DC-bus connection have been included, the high frequency on-board

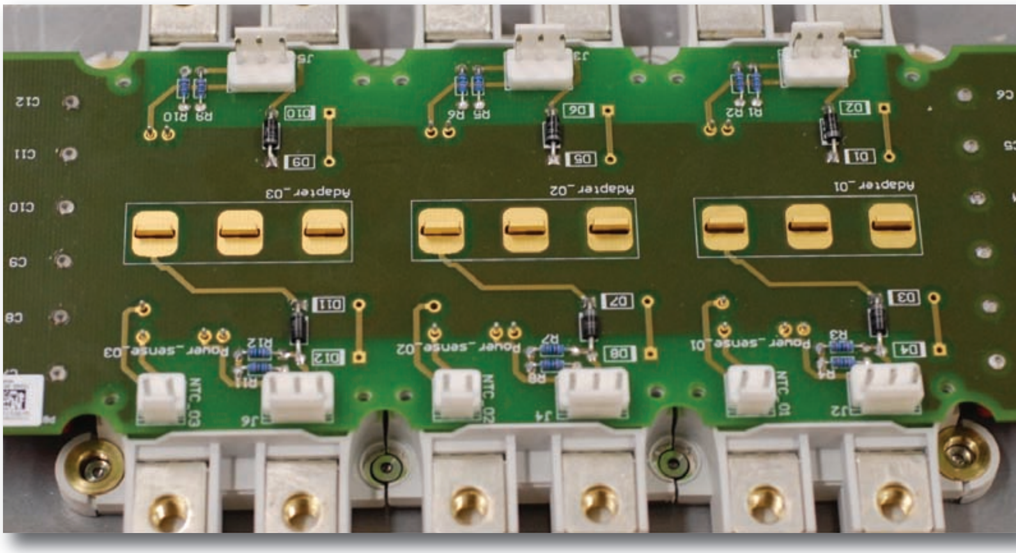


**Figure 12: Three halfbridges are low inductive connected to high frequency DC-capacitors in this test sample**

capacitors were not connected in this test. The comparison between the standard and the new solution are confirming the expectation into the new approach. The low inductive solution reduces the voltage overshoot from 350V (at 700A) to 250V (at 720A). This opens the opportunity to increase the DC-link voltage up to 350V.

With the on-board capacitors implemented, the inductance of the transient path is reduced to 7nH, which does not include the internal inductance of the on-board capacitors. The voltage overshot results to 190V at 720A (25°C) which lead to a maximum DC voltage of >400V (Figure 13). It is possible to reduce the inductance to ca 5nH, when the screw contacts are also connected to fast capacitors in parallel.

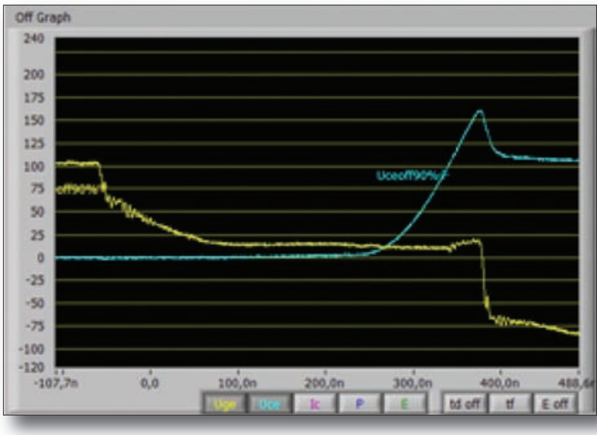



**Figure 13: Turn-off characteristics of a IGBT in the flowSCREW2 package with low inductive current and on-board capacitors**

The next approach is the paralleling of low inductive paths for the transient current. With this technique it is possible to reduce the inductance to a minimum and it offers the possibility to create low inductive paths for each individual IGBT chip. In this case, the current sharing during turn-off is closed to the static value of the paralleled components. This will open the door for new fast switching high-power applications.

## Possible solutions with low inductive current path

The separation of the current paths for a low resistive and low inductive path opens the field for new fast high power module topologies:

- Fast switching high power applications: An increased switching frequency for high power applications is the key for size and weight reduction of such systems.
- High power NPC inverter [5]: The new low inductive approach might be a valuable strategy for neutral point clamped inverters (NPC-Inverters). NPC- or 3-level inverters have three DC voltage potentials. In such applications a low inductance between all DC voltages is required. A high inductance in the DC-loop will kill the reduction of switching losses in this topology.
- Matrix Inverter [6]: At most applications a low inductive connection with the DC voltage will solve the overshoot problems, but in more complex topologies as matrix inverter circuits, there is no DC voltage available and the requirements become more ambitious. Here the low inductive connections between all the switches and all the three inputs and the three output terminals are required.

## Conclusions

Parasitic inductance in power modules is a burden especially for high power applications. It limits the switching frequency and the overvoltage generates problems with reliability (RBSOA) of the inverter system. The first results of the new idea to separate the current paths into a static low resistive screw contact and in a transient low inductive PCB-based connection are promising. The limit for reduction of stray inductance is not yet reached. The new solution is a new milestone for low inductive high power module technology. The 2nH target turns from an imaginary target into a realistic one.

## Literature

*[1] IGBT Fundamentals, Siemens, May 1997*

*[2] Insulated Gate Bipolar Transistor (IGBT) Basics Abdus Sattar, IXYS Corporation*

*[3] Power Modules the Key to Low Inductive System Designs, Michael Frisch, Ernö Temesi, Yu Jinghui, Tyco Electronics / Power Systems*

*[4]1200V IGBT4 -High Power- a new Technology Generation with Optimized Characteristics for High Current Modules, M. Bäßler, P.Kanschat, F.Umbach, C. Schaeffer*

*[5] Advantages of NPC Inverter Topologies with Power Modules, Michael Frisch and Temesi Ernö, Vincotech Germany and Hungary 2009*

*[6] Implementation of Current Commutation Strategies of Matrix Converters in FPGA and Simulations Using Max+PlusII, A. Deihimi1 and F. Khoshnevis, Bu-Ali Sina University, Department of Electrical Engineering, Hamedan, Iran*

# Influence of Stray Inductance on High-Efficiency IGBT Based Inverter Designs

Loss reduction for better energy efficiency is one of the major aspects in advanced inverter designs. Development engineers are striving for technically best performing and cost effective solutions. State of the art power semiconductors, like the Infineon 1200V IGBT4, are one of the key elements to fulfill these requirements. Another important factor for loss reduction and high efficiency designs is the switching speed of power semiconductors which is influenced by the stray inductance of the different inverter solutions.
**Wilhelm Rusche and Marco Bässler, Infineon Technologies, Warstein, Germany**

IGBT technologies can not drop back from these application requirements. As a consequence the latest IGBT chip generation from Infineon is offered in several versions to address specific application needs. Driving force for these different optimizations is the switching speed and the softness requirements related to the application power or respectively to the rated current level in today's existing inverter designs. The versions are the T4 chip with its fast switching behavior, the P4 chip with its soft switching behavior and the E4 chip with a switching speed between T4 and P4. In Table 1, an overview of the three trade-off points of the IGBT4 is given and indicates a hint to the addressed current ranges.

### Dynamic loss consideration of the IGBT and the diode

In order to investigate and to compare the switching losses and the softness of the three different chips at stray inductances from 23nH to 100nH a module type has been chosen which is just close to the limits of being reasonable for using the T4 chip optimization. Hence, a 300A half-bridge configuration in the well known 62mm package has been chosen as a platform and modules have been built with the three IGBT4 versions. The same Emitter Controlled (Emcon) diode is used in all three modules as well as the same gate drive set-up. In Figure 1 the experimental set-up is shown. Figure 2 visualizes the effect of two different stray inductances on the turn-on waveforms of a 300A half-bridge equipped with the IGBT4-T4.

A higher stray inductance ($L_s$) not only increases the inductive voltage drop, $\Delta u = -L^* di/dt$, at the device terminals after onset of the current rise but also affects the current rise speed di/dt itself. Even though the turn-on speed is slowed down by the parasitic inductance, the turn-on losses are significantly reduced.

In the shown example the losses in this initial switching phase, indicated by the time stamp a in Figure 2, are reduced by the increased stray inductance from 30.4mWs to 12mWs. The second phase of the switching event is characterized by the occurrence of the reverse recovery current peak of the diode and further voltage drop at the IGBT. An increased parasitic inductance leads to a delayed reverse recovery current peak and to increased switching losses during that second phase. Regarding the whole switching event, an increased parasitic inductance therefore may significantly reduce the turn-on losses. In this case the reduction from 40mWs to 23.2mWs.

The di/dt reduces the voltage at the IGBT during turn-on but it increases the over voltage shoot at the IGBT during turn-off. This is well known and therefore a growing of turn-off losses with increased DC link inductance is expected. The turn-off switching event may be divided into two phases as sketched in Figure 3.

At the time stamp b the current waveforms of low and high inductance set-up intersect. In the first switching phase, until the crossing point b is reached the increased over-voltage with the high

| | $IGBT^4$ T4 | $IGBT^4$ E4 | $IGBT^4$ P4 |
|---|---|---|---|
| $V_{CEsat}$ @ $T_{vj}$=125°C | 2.05V | 2.00V | 2.00V |
| $R_{th}$ for a 300A device | 100% | 100% | 100% |
| typical current range | up to 450A | 200A - 1400A | 400A - 3600A |

**Table 1: Infineon 1200V IGBT4 overview**

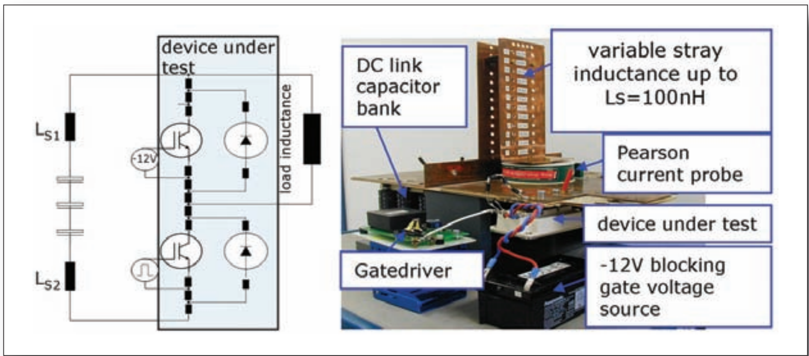



**Figure1: Test set-up, for recovery measurement of the free wheeling diode the high side IGBT was switched and the load inductance was changed to be parallel to the low side diode**

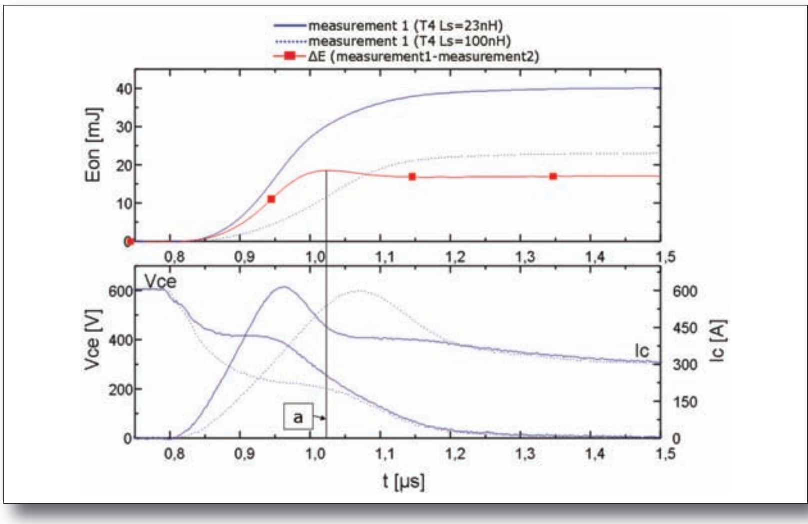



Figure 2: **Turn-on behavior of a T4; the diagram on the top shows the losses versus the time for two inductances, $L_s$=23nH and $L_s$=100nH; the bottom diagram shows the voltage and the current curves**

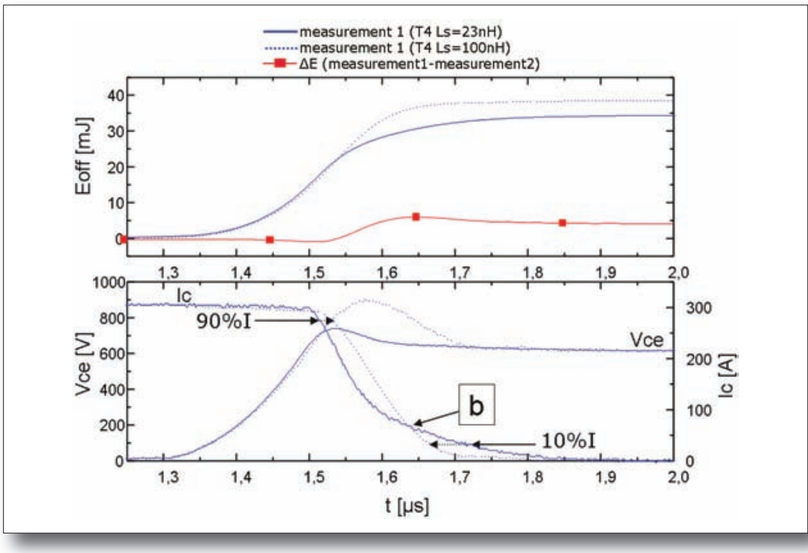



Figure 3: **Turn-off behavior of a Low Power IGBT; the diagram on the top shows the losses versus the time for two inductances (solid: $L_s$=23nH, dotted: $L_s$=100nH); the bottom diagram shows the voltage and the current curves**

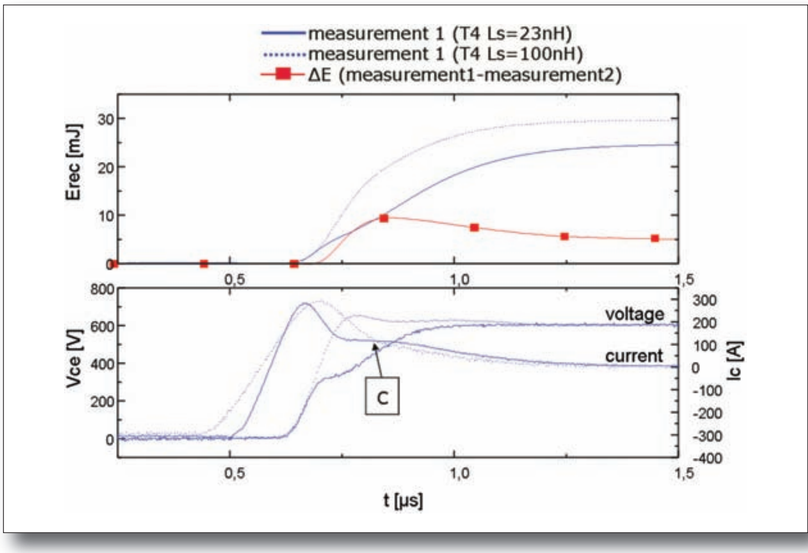



Figure 4: **Recovery of the diode: the diagram on the top shows the losses versus the time for two inductances (solid: $L_s$=23nH, dotted: $L_s$=100nH); the bottom diagram shows the voltage and the current curves**

inductance set-up results in increased losses of 36.3mJ as compared to 30.8mJ in the low inductance set-up. After point b the high inductance setup results in a shorter current tail, however the losses during this phase are about 1.8mJ lower than in case of the low inductance set-up. This result is dominated by the reduction of the current tail, i.e. a faster achievement of the 10% value.

It has been shown that the IGBT turn-on losses decrease with increased stray inductance, the diode losses increase as can be seen in Figure 4. A comparison of the diode recovery at low- and high inductances is also presented in Figure 4.

It becomes clear that the reduced di/dt of the IGBT has hardly any effect on losses at the beginning of the diode commutation since the diode voltage is still about zero. After the reverse recovery peak current the effect of the diode voltage increase by higher stray inductance dominates and induces additional losses. A higher over-voltage results in a loss increase from 10.1mJ to 19.6mJ before point c. As in case of the IGBT an increased dynamic over-voltage results in a reduction of the current tail after point c and the loss balance improves by 4.4mJ in favor of the high inductance setup. In total the first switching phase dominates and the diode losses increase with higher inductance from 24.6mJ to 29.7mJ by 20%.

## Total dynamic loss consideration of the experimental results

The di/dt in combination with the stray inductance reduces the voltage at the IGBT during turn-on but it enlarges the over-voltage shoot at the IGBT during turn-off. A left-right comparison shows that the decrease of turn-on losses at a higher inductance is much more pronounced than the increase of turn-off losses.

This general trend is easily understood if one takes into account that the turn-off di/dt of modern trench field stop IGBT is intrinsically limited by the device dynamics to a value that is at about half of the turn-on di/dt. In Figure 5 IGBT turn-on losses, diode commutation losses and the turn-off losses are plotted against the parasitic DC link stray inductance for all three IGBT versions.

## Softness and snap-off behavior

The preceding chapters have shown that parasitic inductances may be beneficial for the overall loss balance. But stray inductances may also lead to oscillations, e.g. as a consequence of current snap-off, which may limit the use of a device due to EMI or over-voltage limitations. All measurements presented so far have been performed at a junction temperature of $T_{vj}$=150°C which is most crucial for loss

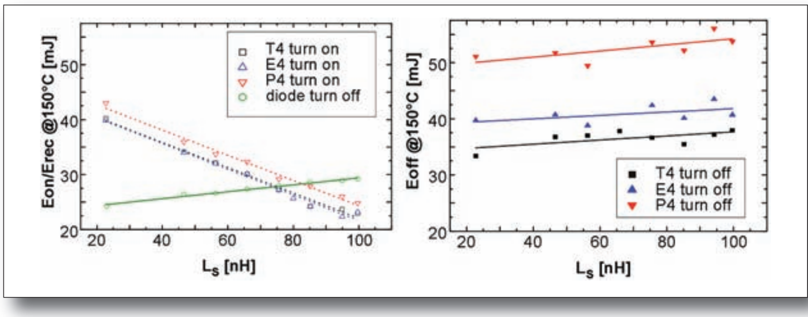



**Figure 5: Switching losses as function of the stray inductance $L_s$, the turn-on losses of the IGBT (left) will be reduced by increasing the inductance and the turn-off losses of the IGBT, right, and the freewheeling diode rise with the inductance**

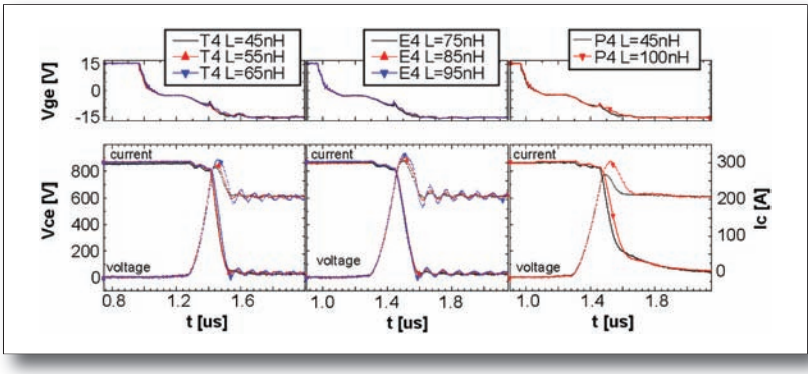



**Figure 6: Switching curves as function of the stray inductance $L_s$ of three IGBT versions; T4 (left), E4 (middle), P4 (right); the diagrams on the top show the gate voltage; the diagrams on the bottom show the current and voltage curves**

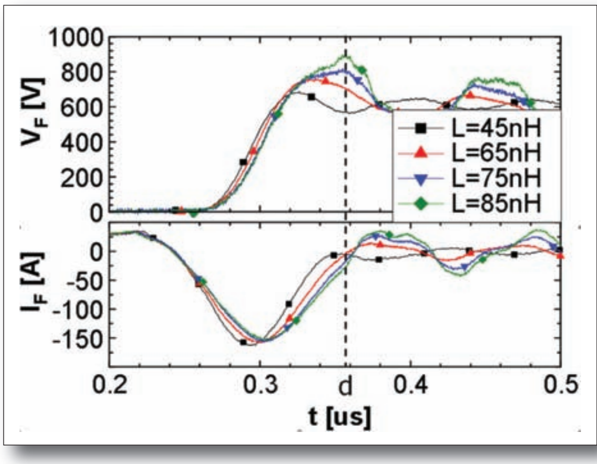



**Figure 7: Diode recovery at room temperature and 1/10 $I_{nominal}$; curves for different stray inductances**

considerations.

Snap-off is more critical at low temperatures since the carrier injection into the device decreases with temperature and pronounces the reduction of charge available for a smooth current tail. Therefore, in Figure 6 IGBT turn-off at rated current is compared between the three chip versions at a temperature of 25°C and a DC link voltage of 600V. As a parameter the DC link inductance is used.

In the given example, the T4 IGBT version gets snappy at a stray inductance of about 55nH and oscillations start to occur. The E4 version stays soft under the same conditions up to a DC link inductance of about 80nH. In case of the high power optimization the P4 chip remains soft in the inductance range observed (20nH...100nH). This observation is not surprising at all since this IGBT is designed to be used in high power modules up to 3600A current rating.

While snap-off tendencies of an IGBT are usually most pronounced at low temperatures and high currents, free wheeling diode softness usually is most critical at low temperature and low current. This is due to a couple of facts. As the diode is a carrier lifetime optimized device, the plasma density is lowest at low currents and therefore the tail charge is reduced with decreasing current level. Furthermore, the switching IGBT forcing the diode to commutate usually switches faster at low current levels. Finally, the diode over-voltage is not related to the switched current but results from the negative slope of the reverse recovery current peak of the diode. This also is steepest at low currents and low temperatures.

As a consequence of fast switching transients, du/dt and reverse recovery di/dt, DC link oscillations may easily be triggered at low current levels even without a diode snap-off. In Figure 7 the diodes reverse recovery at different stray inductances is presented.

Here, low stray inductances lead to higher resonance frequencies and may help to suppress such oscillations. Of course, the situation gets worse if large stray inductances lead to a real snap-off of the diode. This will give limitations for the use of higher stray inductances from EMI considerations.

## Conclusions

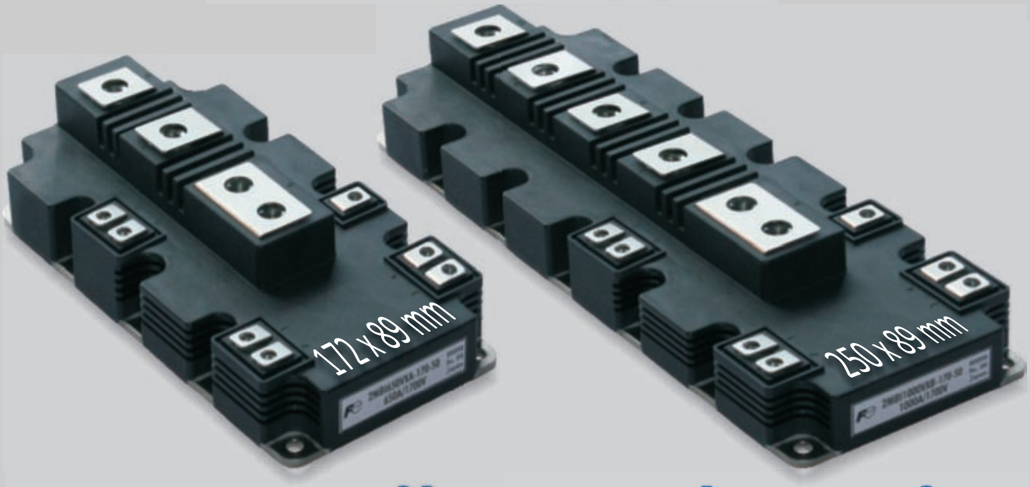
IGBT optimizations designed for enhanced softness requirements pay for this feature by increased switching losses if operated under the same conditions. Besides of the switching losses, the turn-on and turn-off speed, the occurrence of snap-off and oscillation (EMI) are coming more and more into the focus. Parasitic stray inductances play an important role for DC link resonance frequencies and diode snap-off, as well. From EMI considerations at least diode snap-off will draw a simple limit to the reduction of turn-on losses by increased stray inductance or IGBT turn-on speed. Therefore different IGBT optimizations may be expected in future as well. On the other hand, recognizing the DC link inductance as a free parameter of inverter design may create a path for further loss optimizations.

The important aspect is that the further optimization of the DC link design in order to be able to use fast switching devices, i.e. as the T4, must be considered. For the inductance the lower the better is a simple rule for high efficiency designs (see Table 2).

| | IGBT$^4$ T4 | IGBT$^4$ E4 | IGBT$^4$ P4 |
|---|---|---|---|
| $V_{CEsat}$ @ $T_{vj}$=125°C | 2.05V | 2.00V | 2.00V |
| $R_{th}$ for a 300A device | 100% | 100% | 100% |
| typical current range | up to 450A | 200A - 1400A | 400A - 3600A |

**Table 2: Turn-off losses at the same stray inductance and softness**

# High Power IGBT
## Dual & Chopper




***We never sell a product alone***
***It always comes with Quality***

- **High reliability**
  by innovative solder material and ultrasonic welding
- **Improved thermal behaviour**
  by reduced thermal cross coupling and uniform temperature distribution
- **Low internal inductance**
  by parallel and closely arranged bus-bars

| **Package** 2-Pack & Chopper | $I_C$ | 1200V | | 1700V | |
|---|---|---|---|---|---|
| | | E-type | Soft turn-off P-type | E-type | Soft turn-off P-type |
|  89 x 172 mm | 600A | ● | | | |
| | 650A | | | ● | |
| | 900A | ● | ● | | |
|  89 x 250 mm | 1000A | | | ● | |
| | 1400A | | ● | ● | ● |

$T_{j,op}$ = 150°C    $T_{j,max}$ = 175°C    $V_{iso, 1min}$ = 4.0kv    CTI > 600

FUJI ELECTRIC EUROPE
e-Front runners


**Fuji Electric Europe GmbH**
Goethering 58 · 63067 Offenbach am Main · Germany
Fon +49 (0)69 - 66 90 29 0 · Fax +49 (0)69 - 66 90 29 56
semi-info@fujielectric.de . www.fujielectric.de

ONLY £4.99 EACH

# PRACTICAL ENGINEER'S HANDBOOKS

**There are now 6 handy reference books available at only £4.99 each from the publishers of *Drives & Controls* and *Hydraulics & Pneumatics* magazines.**

**Published in an easily readable style and designed to help answer basic questions and everyday problems without the need to refer to weighty textbooks, we believe you'll find them invaluable items to have within arms reach.**

If you would like to obtain additional copies of the handbooks, please complete the form below and either fax it on 01732 360034 or post your order to:
Engineer's Handbook, DFA MEDIA LTD,
Cape House, 60a Priory Road, Tonbridge, Kent TN9 2BL.

You may also telephone your order on 01732 370340

Cheques should be made payable to DFA MEDIA LTD and crossed A/C Payee.

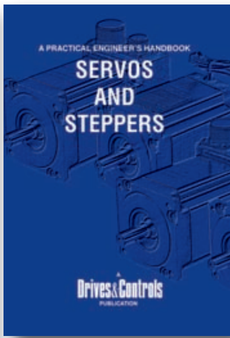
Discounts are available for multiple copies.
2-5 copies £4.30, 6-20 copies £4.10, 20+ copies £3.75.

Postage and Packaging: 1-3 copies £2.49, 4 copies and over £3.49

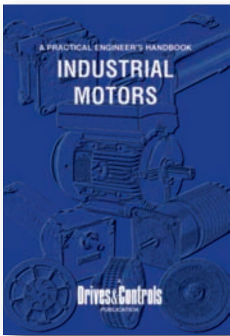
From the publishers of

Drives&Controls Hydraulics & Pneumatics


HYDRAULICS

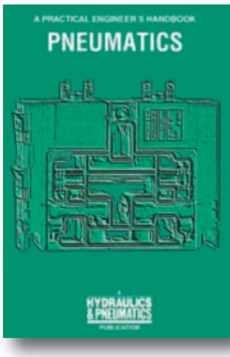



SERVOS AND STEPPERS

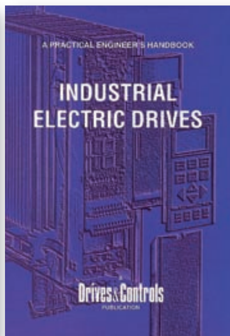



INDUSTRIAL MOTORS


COMPRESSED AIR




PNEUMATICS




INDUSTRIAL ELECTRIC DRIVES

---

**Name:** ______________________________

**Company Name:** ______________________________

**Address:** ______________________________

______________________________

**Postcode:** ____________________ **Email:** ____________________

**Tel:** ____________________ **Total Number of Copies** [ ] @ £________ p+p________ **Total £**________

| **Drives H/B** | QUANTITY | **S & S H/B** | QUANTITY | **Hyd H/B** | QUANTITY | **Pne H/B** | QUANTITY | **Ind Mot** | QUANTITY | **Comp Air** | QUANTITY |
|---|---|---|---|---|---|---|---|---|---|---|---|

# DC/DC Converters Meet Most Demanding Applications

Many small lightweight DC/DC converters for military, civil aviation and other applications requiring greater reliability, combine technical features such as high power density, hybrid thick film technology, hermetic package, full military temperature range, multiple input and output voltage ranges, built-in front end EMI filter and power ratings up to 120W. The devices withstand input surges and transients and meet environmental specifications for temperature extremes, shock, vibration, altitude, salt spray, fog and other key parameters. **Abhijit D. Pathak, HiRel Division, International Rectifier, San Jose, USA**


**LEFT Figure 1: High-reliable DC/DC converters for avionic applications**

Such DC/DC converters are produced in fully qualified facilities to MIL-PRF-38534 and are available in four screening grades such as MIL-STD-883 to satisfy a wide range of requirements. This article describes the features and technical specifications of the AHP series of DC/DC Converters in relation to requirements in targeted applications. Typical measurement data is presented. Other topics such as regulation, efficiency, ripple, synchronization, soft start, parallel operation, input and output protection; thermal, electrical stress, immunity to conducted noise and reliability considerations such as MTBF are also explained.

## A holistic approach

The current and future trends towards aircraft with more electric content and all-electric aircraft require a holistic approach for maintaining extremely high long term reliability, highest possible MTBF and lowest possible MTTR. With the migration to electric aircraft, there is a growing need for DC/DC converters to feed power at the right voltage and power level with all desired features and specifications to each electrical and electronic subsystem that replaces equivalent mechanical and hydraulic subsystems. The long term reliability and optimum availability and operation of such electrical and electronic subsystems depend heavily upon the clean regulated power from such DC/DC converters. This is due to the aircraft having standard electrical buses while every electronic subsystem throughout the aircraft characteristically may require a different voltage and current level, which the DC/DC converter provides when fed by standard electrical bus voltage. It also provides local isolation, filtering and regulation (Figure 1).

Figure 2 shows the block diagra ms of two isolated DC/DC converters rated at 120W using a forward converter topology with built-in EMI filter. The AHP27005S (A) converts raw 270VDC into regulated

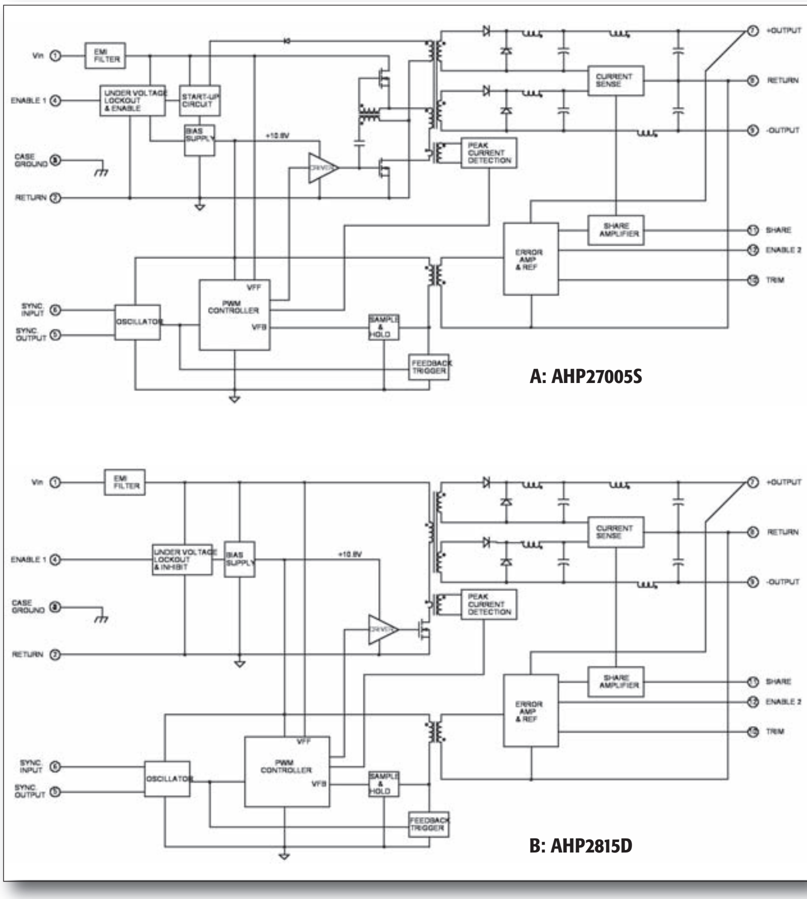



**Figure 2: Block diagram of two isolated DC/DC converters (A: AHP27005S, B: AHP2815D)**

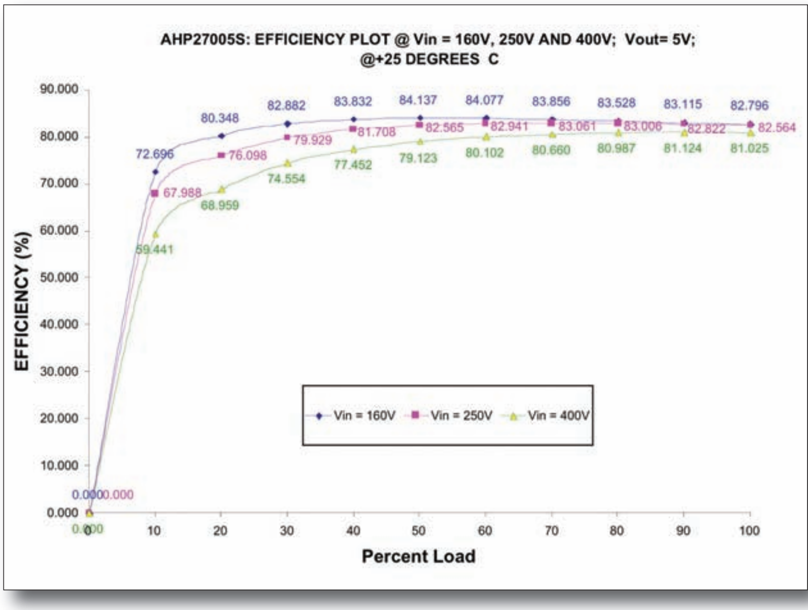



Figure 3: **AHP27005S efficiency vs output load**

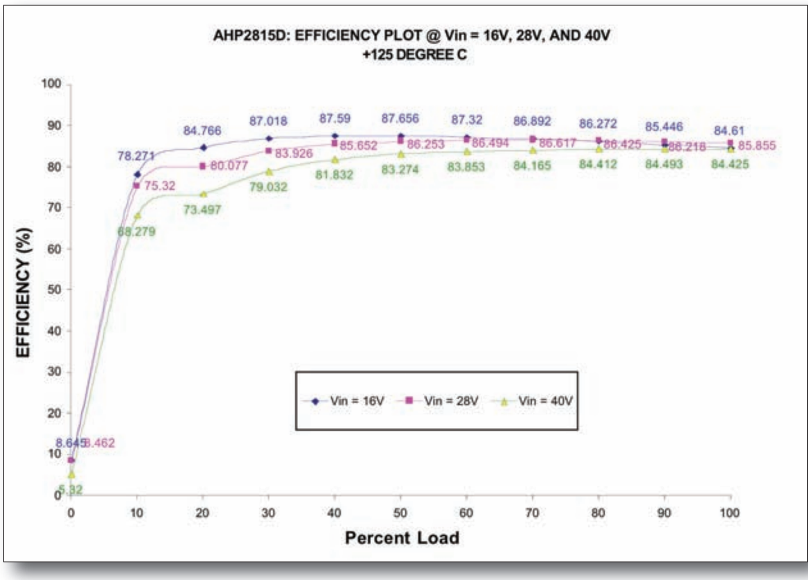



Figure 4: **AHP2815D efficiency vs output load**

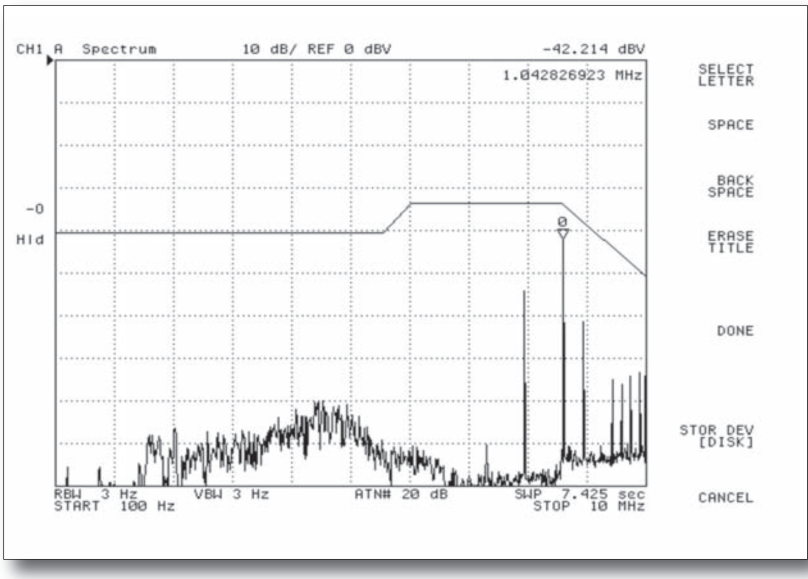



Figure 5: **AHP27005S internally generated noise**

5VDC. Note the use of two MOSFETs in series for withstanding higher line input voltage. The AHP2815D (B) converts 28VDC into regulated ±15VDC. The output regulation uses PWM techniques with controls for output regulation, over-load protection, UV detection and protection, soft start and input over-voltage protection.

The AHP series incorporates proprietary magnetic pulse feedback technology, providing optimum dynamic line and load regulation. This feedback system samples the output voltage at the pulse width modulator fixed clock frequency; nominally 550kHz. A primary and secondary referenced ENABLE circuit affords convenience and control to turn the converter ON and OFF at will, using an event or signal. The driver circuit boosts output from PWM to provide adequate di/dt to turn MOSFETs ON or OFF. A small gate drive transformer affords isolation for driving upper MOSFET in AHP270XX converters. The whole unit works in closed loop, ensuring fast dynamic response and stable performance.

## Meeting or exceeding specifications

Technical specifications are the backbone of every DC/DC Converter. IR's converters are all measured at three temperatures viz -55°C, +25°C and +125°C to ensure they meet or exceed the specifications.

Very good voltage regulation under all dynamic line and load changes is a must. It is expressed in percentage versus line and/or load changes and should be ±1% or better. Dynamic behavior is of utmost importance; meaning that extremely steady output voltage under fast changing load is required for all critical loads. More often than not, line input voltages do not change so abruptly; but immunity towards line transients is a must.

Another important consideration is efficiency. Higher efficiency results in less dissipation of heat in the converter, requiring a smaller heat sink and less power demand on the generator. As the number of such DC/DC converters increase, the impact of efficiency becomes all the more important. Typical efficiency curves for different input voltages and at different loads for AHP27005S are shown in Figure 3. Figure 4 shows efficiency curves of AHP2815D at +125°C.

Many sensitive electronic loads are susceptible to ripple, noise and spikes on the regulated DC bus. Ripple is specified as in mV and is weighted as a percentage of the output DC voltage. Internally generated noise must meet limits set in Figure 5 at full load.

When operating multiple series of DC/DC converters, system requirements

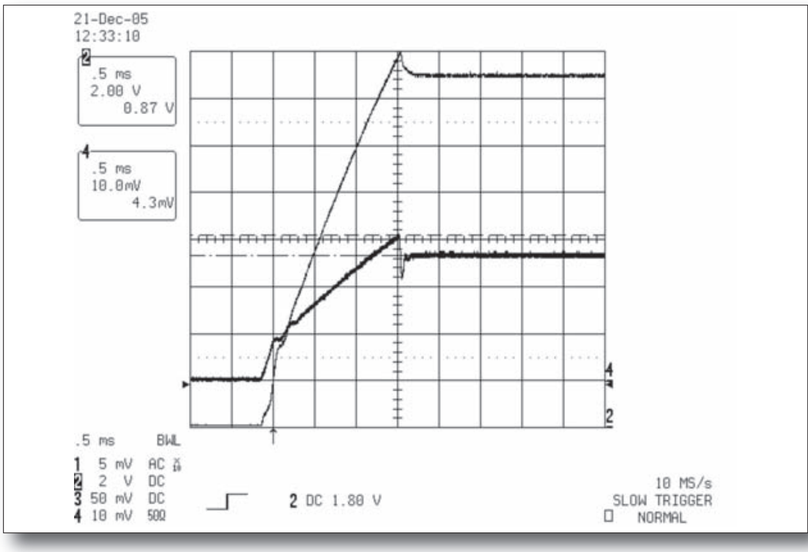



**Figure 6: AHP27015S soft start test waveforms**

often dictate operating them at a common frequency. These converters have both a synchronization input and output. The sync input port permits synchronization to any compatible external frequency source operating between 500kHz and 700kHz, while Sync output can provide a drive signal to drive five additional converters in synchronization. This is also useful when operating these converters in parallel to produce a higher power level at the same regulated DC bus voltage. When paralleling the converters it is important to keep in mind a few recommended set-up and operation guidelines to ensure equal current sharing amongst all paralleled converters.

Most of the electronics loads work more reliably when the DC power is supplied softly such that the voltage linearly rises to the final value in a few milliseconds. This feature is build in the AHP converters and Figure 6 shows slowly rising output voltage waveform with respect to time and resultant soft rise in input current.

It is necessary to protect each DC/DC converter's output from over-load or short circuit. This helps isolate a problem and protect the converter, load and other subsystems. Likewise, the DC/DC converter also has a protective feature to prevent unduly loading the input bus or to be affected by any transients traveling in or out of the input bus. The AHP270XX series meet all performance requirements during normal voltage transients, abnormal steady state voltages and abnormal positive voltage transients. Operation of the devices will be interrupted during abnormal negative voltage transients, but the devices will resume normal operation once the bus voltage returns to a steady state value within range. Figure 7 shows that conducted noise waveforms are well below the limits.

Thermal and electrical stress analyses reveal adequate margins to ensure that all components in the DC to DC converter operate well below their allowable stress limits. The AHP models can be qualified through 1000 hour Group C Life Test. Some models are qualified through 100 temperature cycles from -65°C to +150°C and 1000 hour life test.

The converters are hermetically packaged, utilizing copper core pins with rugged ceramic feed through to minimize resistive DC losses. The AHP270xxx converters are tested at 265V +/- 5VDC input, operating at 50% output power for vibration in accordance to Method 2026 of Mil-Std-883, test condition II, letter E, 14 hours per axis. The units are vibrated over a period of six total days, each axis takes two days. The maximum level is 18.7 grms.

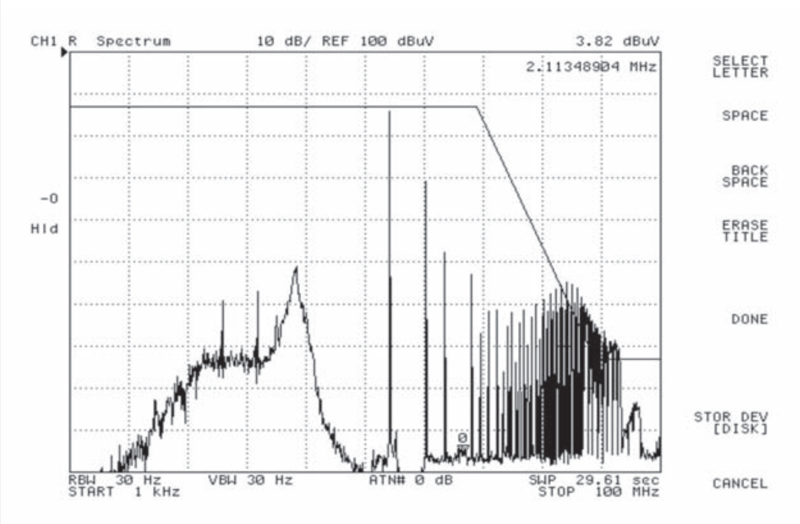



**Figure 7: AHP27015S conducted emissions waveforms**

## Conclusions

Present and future aviation, whether civil or military, will be subject to more and more adaptation of electronic subsystems replacing, pneumatic, hydraulic and mechanical subsystems. Long term reliability is the primary focus of all these advances. Even though these electronic subsystems are intrinsically reliable they heavily depend upon a stable and extremely reliable DC power source. It is here that the DC/DC converters play their role.

# 30W Radiation Hardened POL Regulators

The latest introduction is the SBB series of non-isolated, radiation hardened Point-of-Load (POL) voltage regulators. The new devices are designed to maximize efficiency in space applications including satellites requiring long mission life up to 15 years or 100Krads of total ionizing dose (TID).

The SBB series delivers high efficiency of up to 89%, allowing the use of a smaller heatsink to reduce overall size and weight of the system. The new devices, suitable for designs using new digital signal processors, ASIC and FPGA technologies, feature 30W output power or output current of 14A. Standard outputs of 1.0V, 1.2V, 1.5V. 1.8V, 2.5V, and 3.3V can each be adjusted to ±10% of a nominal output for precise output setting. Integrated input and output filters are also featured to ensure low noise performance for stand-alone operation without the need for external filter components.

With high efficiency performance well suited to the high power requirements of two-stage distributed power architecture design applications, the SBB Series addresses the need to reduce size and weight, as well as the increasing needs of FPGA and other digital circuitries for increased bandwidth, data processing speed and the higher processing power requirements of digital electronics on-board spacecraft. The SBB Series was developed using proven space-level design methodology that includes discrete-based PWM controller and components with known radiation performance fully de-rated to the requirements of MIL-STD-1547.

Weighing less than 55 grams in a compact form factor, other key features of the new devices include 4.5 to 5.5V input range, SEE LET (Heavy Ions) greater than 82 $MeV.cm^2$ /mg, under voltage lockout (UVLO), remote sense compensation, adjustable output voltage, power OK (POK) status, and remote on and off control.

**Radiation hardened POL regulators for space applications**


# Intelligent Solar Hotspot Prevention

STMicroelectronics announced an innovation for solar panels aimed at allowing more of the energy from each cell to reach the power grid, replacing the simple bypass diode with an intelligent device that enhances efficiency and offers the same package outline. ST's new SPV1001 contains a low-loss power switch and a precision controller. Directly replacing bypass diodes, which are used to prevent hotspot effects, the SPV1001 protects the energy normally lost in each diode. Compared to the use of diodes, the integrated power switch provides negligible leakage current when the PV panel is producing energy. ST's BCD6 chip fabrication process provides the key to this advance by integrating efficient power components with logic control circuitry. In addition to package options enabling one-for-one replacement of bypass diodes in the solar panel's junction box, the SPV1001 is available in an MLPD package that can be laminated directly into the panel, due to the device's ultra-low-profile and minimal power losses. This will simplify electronic design and assembly while also boosting system reliability.

**www.st.com**

# 4000A Current Transducer for Rail Traction


More widespread European cross-border train operation imposes stringent requirements in energy monitoring. Thus LEM has created a measurement technology that enables high levels of accuracy in on-board monitoring of train power consumption. The devices comprise transducers for current and voltage, and a new energy meter. Used together, they enable designers to meet or exceed existing and planned specifications: they also offer the same levels of accuracy to system designers working in other areas of high-power electrical supply. Current, in the high-accuracy power transducer suite, is monitored by new introductions to LEM's ITC 4000 or ITC 2000/1000 ranges. Certified to Class 0.5R, the ITC 4000 employs an advanced closed-loop (compensated) current measurement design based on the Fluxgate principle. Nominally rated at 4000A, the ITC 4000 will measure +/-6000A, consuming less than 80mA (at zero primary current) to under +/-340mA (at 4000A primary current) from a supply voltage of +/-24V to its measurement (secondary) circuit. For voltage measurement to the same standards or precision, LEM offers its DV series voltage transducer that spans 1200-4200V RMS. Introduced with an accuracy performance of Class 1, further development has taken the DV Series to Class 0.75 accuracy. The DV offers (as an active device) current consumption of 19-23mA, measurement frequency bandwidth of 12kHz, and an insulation voltage of 18.5kV. Completing the measurement technology package is LEM's EM4T II single-phase energy meter, also rated to Class 0.5R accuracy: this form of accuracy specification is according to the proposed EN 50463 standard that will unify measurement practices for trans-border train operation across Europe. The EM4T II is a four-channel device that records data such as load profile, and train data and location (from GPS inputs) at regular intervals. Used in conjunction with the capabilities of the ITC 4000 current transducer, the EM4T II logs bi-directional power flow, enabling monitoring of energy usage even under regenerative braking.

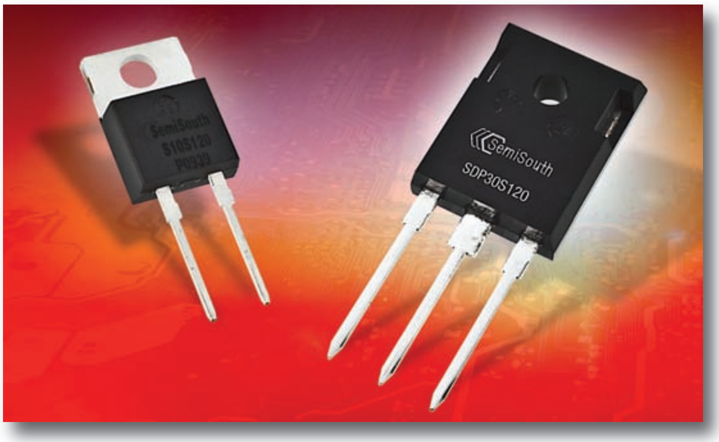
**www.lem.com**

# More IGBTs in Vincotech's Power Modules

Vincotech announced the successful qualification of a new IGBT series with best-fit freewheeling diodes by FUJI Electric. The power range for the relevant chipset reaches from 1200V 8A to 150A, as well as from 600V 10A to 200A and will complete the company's PIM (CIB), six-pack and half-bridge (duals) product roadmap in several module packages. All qualification tests were passed successfully resulting in a full technology release of the chipsets for base-less modules like flowPIM® or MiniSKiiP®. Products are available upon request and flow modules can be delivered with solder pins as well as with Press-fit technology. Vincotech has also extended its range of MiniSKiiP® PACK modules with Infineon's IGBT4 versions covering 8A to 150A for 1200V in three different housings. They are available in three sizes targeting motor drive applications with up to 40kW as well as power generation and UPS installations. These MiniSKiiP® PACK modules incorporate a 3-phase output inverter (SixPack topology) and an additional thermistor for temperature measurement. All MiniSKiiP® PACK products are also available on demand with pre-applied thermal grease for easy use and a perfect junction to the heat sink, as well as with lids in two different heights.

**www.vincotech.com/en/products**

# 5-30A SiC diodes in TO-220 and TO-247 packages




SemiSouth announced a wide range of SiC power Schottky diodes including the 30A rated SDP30S120 - the highest current 1200V part to be commercially available in a TO-247 package. The 1200V, ROHS-compliant product range spans 5-30A with lower current (5A and 10A) diodes packaged as T0-220 parts for drop-in replacement, while 10A, 20A and the 30A devices are offered in the TO-247 package. All diodes in the family are designed with an advanced integrated junction barrier technology to simultaneously enable low forward voltage with low leakage currents and high power density for compact power designs. Other features include negligible reverse recovery. Particularly the 30A parts can benefit many applications including solar energy where they can be used in the boost sector of solar inverters to dramatically improve efficiency. Other uses include SMPS, PFC devices, induction heating, UPS and motor drives. According to SemiSouth 60A parts will be available in the very near future, which are particularly interesting for manufacturers of 30kW solar inverter systems.

**www.semisouth.com**

# Step-Down Converter for Energy Harvesting

**With the new TPS62120 Texas Instruments offers an ultra-low power step-down converter for energy harvesting and low-power applications. The converter achieves 96% efficiency, and can generate a 75mA output current from an input voltage of 2V to 15V for energy harvesting and battery-powered applications, as well as 9V and 12V line-powered systems. The TPS62120 synchronous converter features a power save mode to provide high efficiency over the entire load current range, reaching 75% efficiency at loads down to 100µA. During light load operation, the device operates in a pulse frequency modulation (PFM) mode, consuming only 11µA of quiescent current. The TPS62120 also maintains smooth, efficient operation at higher currents by transitioning automatically from its power save mode to a fixed-frequency pulse width modulation (PWM) mode.**

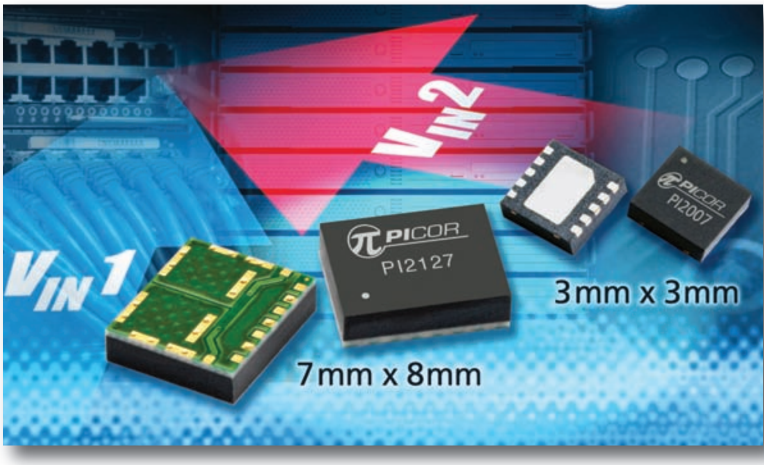
**www.ti.com/tps62120-preu**

# Step-Up Converter for Energy Harvesting


Linear Technology announced the LTC3105, a synchronous boost converter that incorporates maximum power point control (MPPC) and starts up with inputs as low as 250mV. The device operates over a wide input range of 0.2V to 5V, making it suited for harvesting energy from high impedance power sources including photovoltaic cells, thermoelectric generators (TEGs) and fuel cells. The internal 400mA synchronous switches maximize efficiency while its Burst Mode® operation offers quiescent current of 22uA. A user-programmable MPPC set point maximizes the energy that can be extracted from any power source without collapsing its internal voltage. The LTC3105 offers an auxiliary LDO that delivers up to 6mA of output current to power external microcontrollers and sensors while the main output is charging. Once fully charged, the main output can deliver voltages as high as 5.25V with up to 100mA of output current.

**www.linear.com**

# 48V/12V High-Side Active ORing



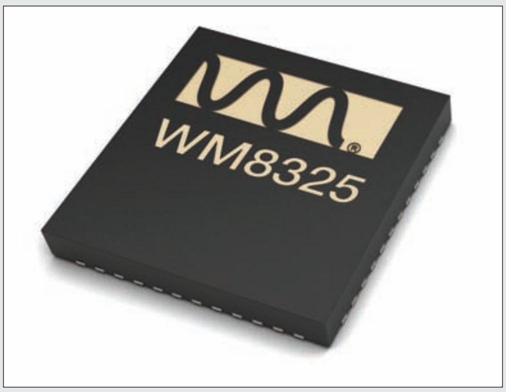

Picor's new active ORings are primarily intended for 12V and 48V high-side redundant bus applications; the PI2127 is a full-function active ORing solution and the PI2007 is a universal high-speed discrete active ORing controller. Both address a broad range of redundant intermediate bus requirements for high-availability systems such as servers, high-end computing, telecom and communications infrastructure systems. The PI2127 is a complete active ORing solution with an integrated MOSFET controller and a low on-state resistance MOSFET. The internal MOSFET maintains an on-resistance as low as 8.5mΩ resulting in very high efficiency and low power loss in steady-state operation, while also achieving very fast turn-off, typically within 80ns, during input power source fault conditions that cause reverse current flow. The PI2127 is a 60V-rated solution that delivers up to 12A over a wide range of operating temperature of -40°C to 140°C; in System-in-Package format. This controller IC is designed for use with single or paralleled N-channel MOSFETs in redundant power system architectures, optimized for use in 12V and 48V high-side redundant power architectures, including systems with a wide range input voltage of 36V to 75V that are also required to operate during input voltage transients up to 100V for 100ms. It enables an extremely low power loss solution with fast dynamic response to fault conditions, with 80ns reverse current turn-off delay time and 4A gate peak discharge current capability to turn off the MOSFET very quickly. The PI2007 also checks for shorted FETs at system power-up. Pairing the PI2007 with Picor's PI2003, which is optimized for low side operation, enables a complete high-side/low-side chip-set solution for wide-range 48V telecom applications.

**www.vicorpower.com/picor**

# High Current Monolithic Power Management IC

Wolfson Microelectronics plc has announced the WM8325 power management IC (PMIC), which delivers a cost-effective, flexible solution for portable multimedia applications. The device features four programmable DC/DC converters, including one which is capable of delivering up to 2.5A and eleven LDO regulators, four of which are low-noise for supplying sensitive analogue subsystems. Its optimised QFN package is designed to improve thermal performance and reduce parasitic components, enabling low cost four-layer PCBs. The package allows large PCB tracks for all high current paths, which improves transient performance. Also incorporated into the WM8325 is an on-chip regulator, which provides power for 'always-on' PMIC functions such as register map and the real-time clock, as well as offering autonomous backup battery switchover. A 12-bit auxiliary ADC also supports a wide range of applications for both internal and external analogue sampling, such as voltage detection and temperature measurement. The WM8325 is available for sampling in an 8x8mm, 0.85mm thick, 81-lead QFN package.

**www.wolfsonmicro.com**



## AC/DC Connverters

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

## Busbars


**www.auxel.com**
Auxel FTG
Tel: +44 (0)7714 699967

## Capacitors


**www.powersemiconductors.co.uk**
Power Semiconductors Ltd
Tel: +44 (0)1727 811110

## Certification

**www.productapprovals.co.uk**
Product Approvals Ltd
Tel: +44 (0)1588 620192

## Connectors & Terminal Blocks

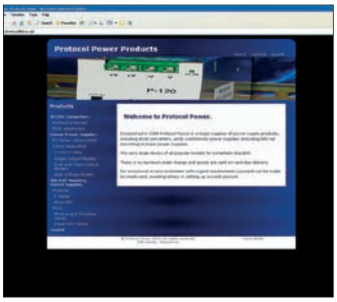
**www.auxel.com**
Auxel FTG
Tel: +44 (0)7714 699967

## DC/DC Connverters

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

## DC/DC Connverters

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399




**www.protocol-power.com**
Protocol Power Products
Tel: +44 (0)1582 477737

## Diodes

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028


**www.neutronltd.co.uk**
Neutron Ltd
Tel: +44 (0)1460 242200

## Direct Bonded Copper (DPC Substrates)


**www.curamik.co.uk**
curamik® electronics GmbH
Tel: +49 9645 9222 0

## Discrete Semiconductors

**www.digikey.com/europe**
Digi-Key
Tel: +31 (0)53 484 9584

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028

## Drivers ICS

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Fuses

**www.powersemiconductors.co.uk**
Power Semiconductors Ltd
Tel: +44 (0)1727 811110

## GTO/Triacs

**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

## Hall Current Sensors


**www.dgseals.com**
dgseals.com
Tel: 001 972 931 8463

## Harmonic Filters


**www.murata-europe.com**
Murata Electronics (UK) Ltd
Tel: +44 (0)1252 811666

## IGBTs

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028

**www.neutronltd.co.uk**
Neutron Ltd
Tel: +44 (0)1460 242200

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Magnetic Materials/Products

**www.rubadue.com**
Rubadue Wire Co., Inc.
Tel. 001 970-351-6100

## Mosfets

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028

**www.neutronltd.co.uk**
Neutron Ltd
Tel: +44 (0)1460 242200

## Optoelectronic Devices

**www.digikey.com/europe**
Digi-Key Tel: +31 (0)53 484 9584

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Packaging & Packaging Materials

**www.curamik.co.uk**
curamik® electronics GmbH
Tel: +49 9645 9222 0

## Power ICs

**www.digikey.com/europe**
Digi-Key Tel: +31 (0)53 484 9584

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Power Modules

**www.auxel.com**
Auxel FTG
Tel: +44 (0)7714 699967

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

**www.microsemi.com**
Microsemi
Tel: 001 541 382 8028

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Power Protection Products

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Power Substrates

**www.universal-science.com**
Universal Science Ltd
Tel: +44 (0)1908 222211

## Resistors & Potentiometers

**www.isabellenhuette.de**
Isabellenhütte Heusler GmbH KG
Tel: +49/(27 71) 9 34 2 82

## RF & Microwave Test Equipment.

**www.ar-europe.ie**
AR Europe
Tel: 353-61-504300


## Simulation Software

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

**www.universal-science.com**
Universal Science Ltd
Tel: +44 (0)1908 222211

## Smartpower Devices

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

## Switches & Relays

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

## Switched Mode Power Supplies

**www.biaspower.com**
Bias Power, LLC
Tel: 001 847 215 2427

## Switched Mode Power Supplies

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## Thermal Management & Heatsinks

**www.curamik.co.uk**
curamik® electronics GmbH
Tel: +49 9645 9222 0

**www.dau-at.com**
Dau GmbH & Co KG
Tel: +43 3143 23510

**www.denka.co.jp**
Denka Chemicals GmbH
Tel: +49 (0)211 13099 50

**www.lairdtech.com**
Laird Technologies Ltd
Tel: 00 44 1342 315044

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

**www.universal-science.com**
Universal Science Ltd
Tel: +44 (0)1908 222211

## Thyristors

**www.irf.com**
International Rectifier Co. (GB) Ltd
Tel: +44 (0)1737 227200

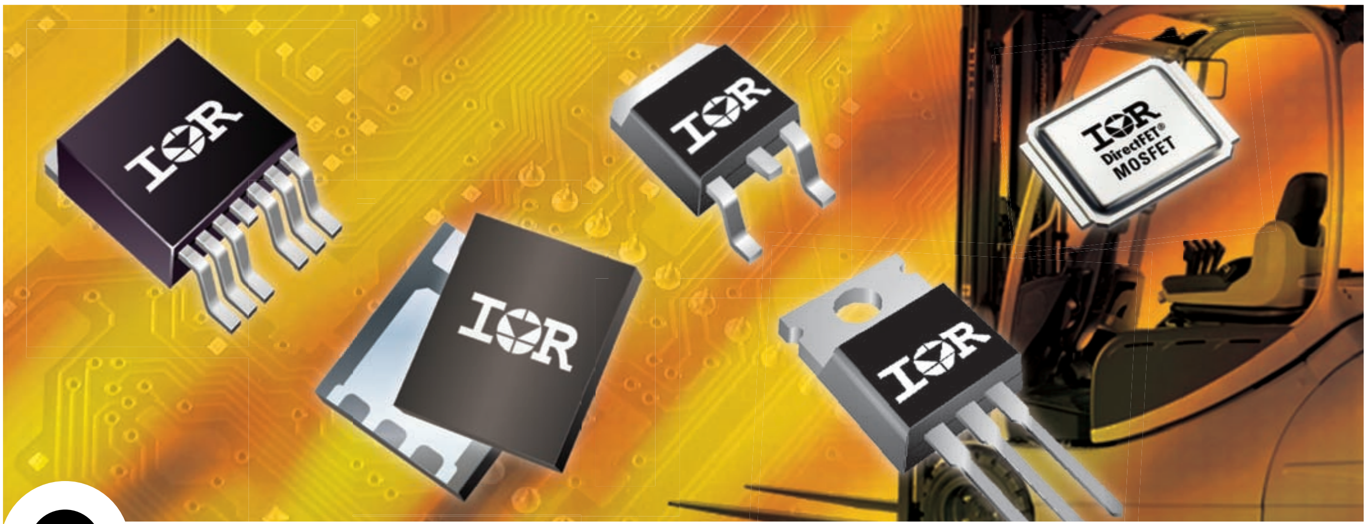
**www.mark5.com**
Mark 5 Ltd
Tel: +44 (0)2392 618616

## Voltage References

**www.irf.com**
International Rectifier Co.
(GB) Ltd
Tel: +44 (0)1737 227200

**www.power.ti.com**
Texas Instruments
Tel: +44 (0)1604 663399

## ADVERTISERS INDEX




# Rugged, Reliable MOSFETs for Industrial Applications

| Part Number | $V_{DS}$ (V) | $R_{DS(on)}$ Max. VGS=10V (mΩ) | $I_D$ (A) | $Q_G$ (nC) | Package |
|---|---|---|---|---|---|
| IRFS3004 | 40 | 1.75 | 195 | 160 | D²PAK |
| IRFB3004 | 40 | 1.75 | 195 | 160 | TO-220 |
| IRFH5004 | 40 | 2.6 | 100 | 73 | PQFN 5x6 mm |
| IRF7739L2 | 40 | 1 | 270 | 220 | DirectFET-L8 |
| IRFS3006-7 | 60 | 2.1 | 240 | 200 | D²PAK-7 |
| IRFS3006 | 60 | 2.5 | 195 | 200 | D²PAK |
| IRFH5006 | 60 | 4.1 | 100 | 67 | PQFN 5x6 mm |
| IRF7749L2 | 60 | 1.3 | 108 | 220 | DirectFET-L8 |
| IRFB3077 | 75 | 3.3 | 210 | 160 | TO-220 |
| IRFH5007 | 75 | 5.9 | 100 | 65 | PQFN 5x6 mm |
| IRF7759L2 | 75 | 2.2 | 83 | 220 | DirectFET-L8 |
| IRFP4468 | 100 | 2.6 | 195 | 360 | TO-247 |
| IRFH5010 | 100 | 9 | 100 | 65 | PQFN 5x6 mm |
| IRF7769L3 | 100 | 3.5 | 124 | 200 | DirectFET-L8 |
| IRFP4568 | 150 | 5.9 | 171 | 151 | D²PAK |
| IRFH5015 | 150 | 31 | 56 | 33 | PQFN 5x6 mm |
| IRF7799L3 | 150 | 11 | 67 | 97 | DirectFET-L8 |
| IRFP4668 | 200 | 9.7 | 130 | 161 | TO-247 |
| IRFH5020 | 200 | 59 | 41 | 36 | PQFN 5x6 mm |
| IRFP4768 | 250 | 17.5 | 93 | 180 | TO-247 |
| IRFH5025 | 250 | 100 | 32 | 37 | PQFN 5x6 mm |
| IRF7779L4 | 250 | 38 | 35 | 110 | DirectFET-L8 |

**Features**

- Low on resistance per silicon area
- Optimized for both fast switching and low gate charge
- Excellent gate, avalanche and dynamic dv/dt ruggedness

**The IR Advantage**

- Best die to footprint ratio
- Large range of packages
- Available from 40 V to 250 V

**Applications**

- DC Motor Drives
- Uninterruptible Power Supplies (UPS)
- DC-DC Converters
- Power Tools
- Electric Bikes

Your FIRST CHOICE for Performance

**For more information call +49 (0) 6102 884 311**
**or visit us at www.irf.com**

**Visit us in Hall A5, Booth 320**

electronica | New Munich Trade Fair Centre
09–12 November 2010

International IOR Rectifier
THE POWER MANAGEMENT LEADER