POWER
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EUROPE

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POWER MODULES

New 4500V SPT+ HiPak Modules

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FOR POWER ELECTRONICS
AND TECHNOLOGY

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COVER STORY

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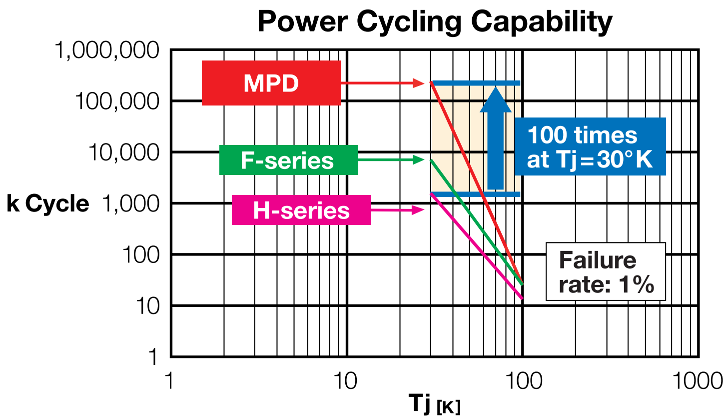

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New Markets for Power Electronics

"In regions where automobile use has already reached high levels, we can look forward to the introduction of vehicles with new technologies and concepts. Concerning the environment, Toyota has positioned hybrid technologies as core technologies that can contribute to resolving environmental issues, and we will undertake development with a commitment to leading the advancement of such technologies. We will continue to enhance our hybrid vehicle lineup", stated Toyota's President Katsuaki Watanabe. A hybrid version of the Lexus LS is starting with sales in Japan and gradually going global will enhance the company's hybrid car offering. And in October 2006, the company started hybrid vehicle production in North America at Toyota Motor Manufacturing, Kentucky, Inc. (TMMK). The investment of $10 million will lead to an annual production of 48,000 Camry hybrids. Toyota, the undisputed leader in hybrid cars, and other Japanese automakers are focusing on improving hybrid batteries and making the vehicles cheaper. The cars now cost about €4,000 more than equivalent conventional vehicles. Toyota plans to introduce a new Prius by 2009 that will be smaller and cheaper than the current ones of around €25,000. The company expects a sharp increase in sales of its hybrid cars to more than 1.0 million units a year early in the next decade. "And we are also actively engaged in research and development for plug-in hybrids", Watanabe continued.

Plug-in hybrid electric vehicles (P-HEVs) are hybrid cars which can be plugged into a line outlet (for instance each night at home, or during the workday at a parking garage) and charged. Plug-ins run on the stored energy for much of a typical day's driving, depending on the size of the battery up to 100km per charge, and when the charge is used up, automatically keep running on the combustion engine. A person who drives a distance shorter than the car's electric range every day would never have to dip into the fuel tank. Environmental impacts of plug-ins should be compared with those of conventional vehicles on the basis of emissions over the entire fuel-cycle, meaning the emissions associated with the extraction, processing, distribution and final use of the energy that propels the car. While for conventional vehicles, these include emissions that result from extracting and processing crude oil as well as tailpipe emissions, for plug-ins emissions produced by power plants providing the electricity for charging the vehicles' batteries must be taken in consideration. But a plug-in that is fully charged every night can reduce emissions by 50% due to the improved fuel economy and the non-production of tail pipe emissions during the electric driving phase.

In 1998, Audi showed the Duo plug-in hybrid, based on the Audi A4, at PCIM and other motor shows. At the time, hybrid propulsion was considered as a promising solution to Europe's inner city emissions problems. Audi AG leased 10 Duo P-HEVs to Solarmobilverein Erlangen in the city of Erlangen/Bavaria as part of ELCIDIS (Electric Vehicle City Distribution), an advanced mobility project funded by the European Commission. Solar recharging stations were envisioned, but were not built. The fleet trial ended in August 2001. About 60 Audi Duo P-HEVs were built. However, few customers were prepared to pay twice the price as the base model A4 equipped with an identical diesel engine, and series production was stopped. And this was the end of Europe's HEV visions for a long time. But the success of Japanese car makers was a wake-up call, hopefully.

Due to recuperation of kinetic energy, operation of the internal combustion engine with maximum efficiency, and combustion engine shutdown at idle hybrid cars show a significantly improved fuel economy for standard city based drive cycles. However, the automotive environment challenges the power electronics controllers with extreme temperatures and requirements for low weight/low volume and zero defect over 15 years lifetime. Furthermore, cost reduction by factor of 4 until 2020 is a prerequisite for allowing widespread hybrid technology. To meet these challenges, research in power electronics has to focus on functional integration/modularisation of various converter systems; advanced thermal management; homogeneous (space/time) power conversion/multi-cell converters; advanced EMI filtering; high temperature magnetics/capacitors/sensors/control ICs; application of wide band gap power semiconductors; fault tolerant converter/motor systems; stress analysis/reliability prediction; and multi-domain/scale/level modelling and simulation.

PEE's panel discussion on hybrid car technology (PCIM 2007, Hall 12 booth 357, May 23, 16.00-17.00) with heavy industrial participation will focus on the role of power electronics and already existing solutions for hybrid electric vehicles. All PCIM visitors and conference attendees are heartly invited to take part. See you there!

Achim Scharf
PEE Editor

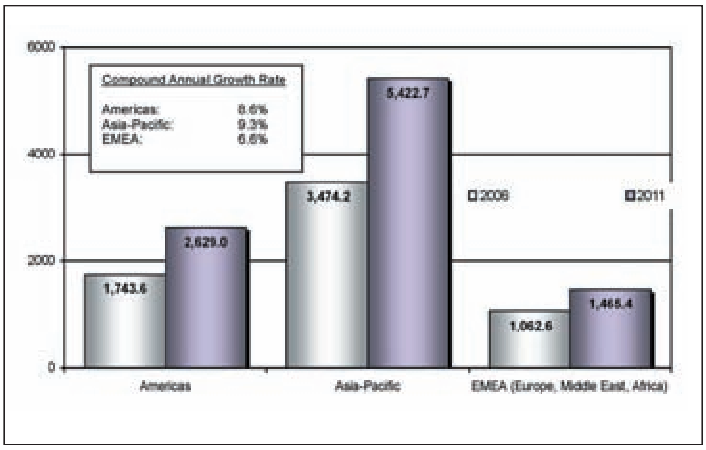
Market for Internal AC/DC Switching Power Supplies Growing Worldwide

Worldwide shipments of internal AC/DC switching power supplies exceeded $ 6.3 billion in 2006, according to a recent study by Venture Development Corporation. Revenues are forecast to grow at a compound annual growth rate of 8.7% through 2011.

All major geographic regions will see growth in shipments, with those to the Asia-Pacific region forecast to increase the most. "Already accounting for over 55% of the worldwide internal AC/DC switching power supply market, Asia will continue to grow faster than any other major geographic region. Favourable manufacturing costs are still enticing electronics manufacturers to add capacity in Asia, and most power supply vendors have followed suit to also take advantage of the lower labour costs and to locate their facilities closer to those of their customers, to reduce lead times and transportation costs", says VDC's analyst Brian Greenberg. China accounts for close to 60% of all shipments to Asia and, by itself, will continue to be the largest destination for internal AC/DC switching power supplies in the world. Merchant power supplies are sold to others as a component rather than consumed by the manufacturer for integration into another product. Most OEMs have become leaner and more focused on their core technologies and rely on specialised vendors to provide them with their AC/DC power supplies.

www.vdc-corp.com

Merchant shipments ($ million) of Internal AC/DC switching power supplies segmented by region   Source: VDC



Standard for Power Conversion

IPC – Association Connecting Electronics Industries has completed the final draft of the 'Performance Parameters for Power Conversion Devices' (IPC-9592) standard and is making it available for industry review. All comments are due no later than June 2, 2007.

The 100-page proposal was developed by the IPC Power Conversion Subcommittee chaired by Dr. Scott Strand, program director, Power/Cooling Procurement Engineering, Integrated Supply Chain, IBM. The subcommittee is part of the IPC OEM Critical Components Council. The document standardises the performance parameters for power conversion devices including, but not limited to, the computer and telecommunications industries. Power conversion devices refers to AC/DC and DC/DC modules, converters and printed circuit board assemblies. The specification also sets the requirements for design, qualification testing, conformance testing, manufacturing quality processes and regulatory requirements. "This is a comprehensive document that will be of significant value to both customer and supplier", Strand comments. "We started developing the document in September 2006 and I am confident we can finalise this consensus standard by the third quarter of 2007". IPC maintains a European office in Stockholm/Sweden. To review and discuss industry comments, IPC will hold a power conversion standards meeting June 26–27, 2007, at the Renaissance Schaumburg Hotel & Convention Center, in Schaumburg, Ill./USA. Meeting information and a registration form are available at www.ipc.org/PCSMeeting.

International Rectifier Completes Sale of PCS Business to Vishay

IR completed the previously announced sale of its Power Control Systems (PCS) business to Vishay Intertechnology, Inc. for approximately $290 million in cash.

The PCS business consists of the company's non-aligned and commodity product segments. Product lines included in the divestiture are certain discrete planar MOSFETs, discrete diodes and rectifiers, discrete thyristors, multi-chip modules not including integrated circuits and certain other specified products.

www.irf.com

Microchip Opens Design Centre in Romania

Microchip Technology Inc. announces the inauguration of a new state-of-the-art Design Centre in Bucharest, Romania. The new centre forms part of Microchip's worldwide network of Design Centres located in India, Switzerland, California and Arizona.

"Bucharest was chosen as the location for our newest Design Centre because it takes us closer to our customers who are increasingly turning to Eastern Europe for design and manufacture. It is only by working closely with our customers that we can understand the challenges they face and ensure that we are developing the right products for them," explained Rich Simoncic, vice president of Microchip's Analog and Interface Products Division. Besides microcontrollers the company offers power management and conversion devices; thermal measurement and management devices; mixed signal products and interface devices.

www.microchip.com

POWER MANAGEMENT

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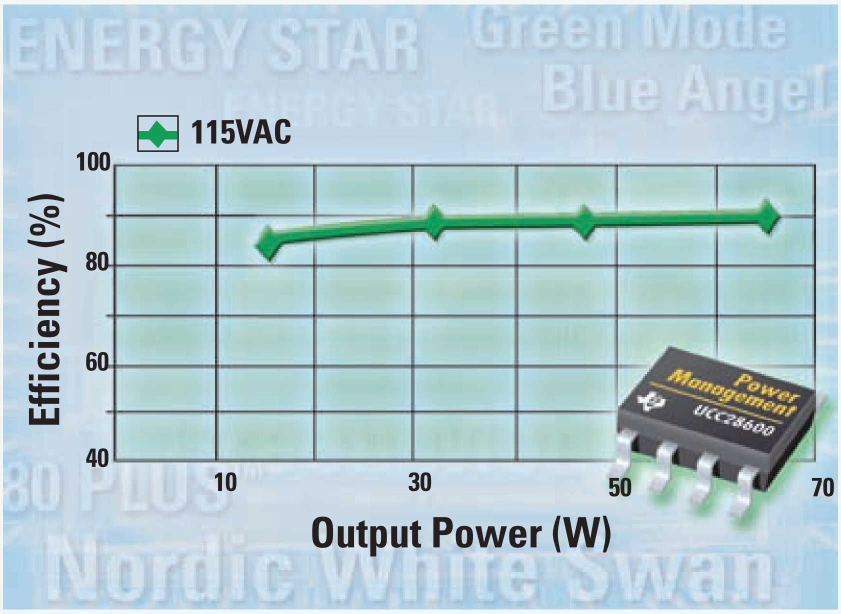

▶ Applications

- AC adapters
- Standby power supplies for DLP® HDTVs and LCD-TVs
- PDP-TVs and set top boxes
- Energy efficient power supplies: <250 W

▶ Features

- Quasi-resonant mode operation for reduced EMI and low switching losses
- Low standby current for system no-load power consumption: <150 mW
- Green-mode status pin to disable PFC controller at light load
- Low startup current: 25 µA (max)
- Multi-functional pins offer high-performance features in small, 8-pin SOIC

The new 8-pin, quasi-resonant, **UCC28600** green-mode controller from TI provides high power efficiency in full and light-load operating conditions and decreases power consumption in no-load standby mode. The device enables standby power supplies in HDTVs, LCD and plasma digital TVs to achieve active-power mode efficiencies in excess of 88% and no-load power consumption levels below 150 mW. Additionally, the UCC28600 improves power efficiency in notebook PC and gaming system AC adapters that support 40 W to 200 W.

Device	Start-up Current	Start-up Threshold Voltage	UVLO Hysteresis	Standby Current	Gate Drive Sink/Source	1k Price Starts
UCC28600	25 µA (max)	13 V (typ)	5 V (typ)	550 µA (max)	1 A/0.75 A	$0.49

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Towards Digital Power Systems

TI's third-generation Fusion Digital Power controllers and new plug-in modules manage more intelligently power systems with up to four independent digital-control loops and up to eight phases, while improving energy efficiency up to 30 percent during light load conditions. Samples are already available, volume production is expected for the third quarter.

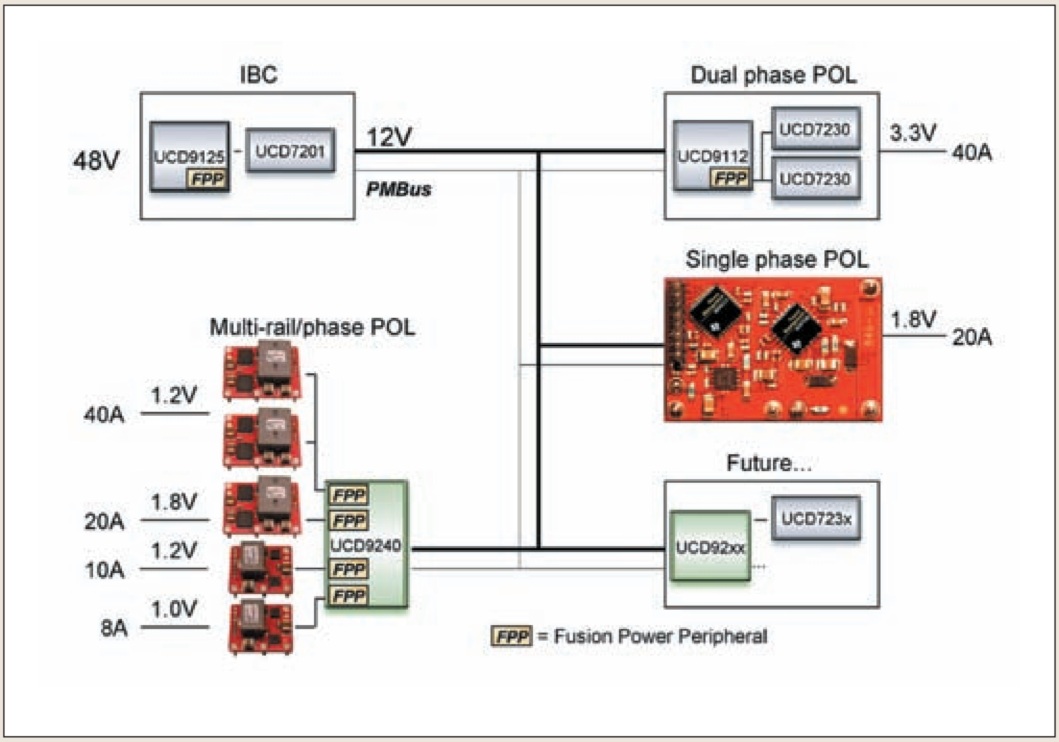
The UCD9240 is a digital synchronous buck PWM controller that can control up to eight power stages in multi-phase configuration or up to four feedback outputs with two phases per output. "This device provides enhanced configurability and control for point of load (POL) applications while saving more than $40 in system cost through the integration of previously external functions such as sequencing, tracking and margining", says François Malléus, TI's EMEA Business Development Manager.

The device is configured using a serial interface that conforms to the PMBus version 1.1 protocol supporting up to 100 interface commands for control, configuration and management of the power supply. "The switching frequency of up to 2MHz, output configuration and feedback compensation are programmed through the design tool's graphical user interface; this software comes for free and allows for programming all relevant parameters without writing any line of code", Malléus underlines.

Each control loop consists a very high speed digital control loop with individual digital three-pole/three-zero compensators and a high resolution (250 picoseconds) digital PWM. In addition to implementing a digital control loop, the UCD9240 is able to monitor and manage power supply operating conditions and report the status to the host system through the PMBus. The management parameters are configurable through the PC Design Tool. The Design Tool also allows the power supply designer to easily configure the digital control loop characteristics and generate the expected performance by displaying Bode plots for each controlled power stage.

On multi-phase power stage outputs, the UCD9240 incorporates digital current balancing. The average current in each phase is monitored and the duty cycle for each phase adjusted to balance the average current. In addition, the UCD9240 supports 'shedding' one or more phases (ganged power stages) based on the average current demand. When a phase is dropped or added the UCD9240 automatically adjusts the phase of each PWM output to minimise output ripple, as well as any needed change in loop compensation. In addition to the new controller family, TI introduced two new plug-in power modules that further simplify the DC/DC converter design by providing a high-degree of configurability when used with the UCD9K family of controllers. The PTD08A010W and PTD08A020W 10-A and 20-A modules integrate the inductor, FETs and TI's UCD7230 driver with current sense capability plus integrated short circuit protection to provide stable and reliable operation of the power supply while protecting the system. This 3rd generation digital power systems controller and associated power modules will be shown at PCIM 2007.

www.ti.com/digitalpower, PCIM Hall 12/134

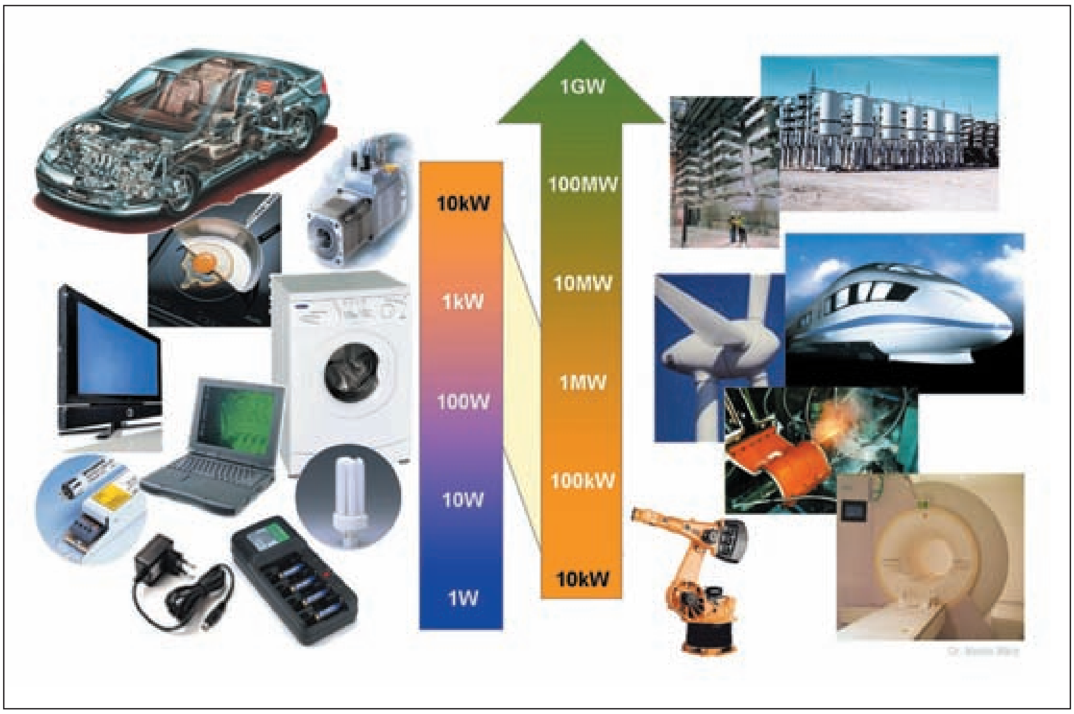


Digital power systems example using TI's 3rd generation digital power controller

Hot Topic Energy Efficiency

Energy saving, improved energy efficiency and environmental protection are ubiquitous topics in society, in Europe and globally. Despite many efforts to save energy, demand for electricity is expected to grow, and much faster in comparison with other energy sources over the next three decades. Power electronics is the key technology to controlling the flow of electrical energy from the source to the load precisely, according to the requirements of the load.

Power Electronics covers the Gigawatt power e.g. in energy transmission lines down to the very low milliwatt power Source: ECPE



According to a position paper on 'Energy Efficiency – the Role of Power Electronics' (based on the results of a European workshop held on 7 February 2007 in Brussels, organised by ECPE European Center for Power Electronics in cooperation with EPE Association), today 40% of all energy consumption is in electrical energy, but this will grow to 60% by 2040. On the other hand, the share of electrical energy which will be controlled by power electronics e.g. in variable speed drives, will increase from 40% in 2000 to 80% in 2015. Power Electronics is responsible for the reliability and stability of the whole power supply infrastructure from the sources, the energy transmission and distribution up to the huge variety of applications in industry, transportation systems, office appliances and the home. Power Electronics is a cross-functional technology covering the extreme high Gigawatt (GW) power e.g. in energy transmission lines down to the very low milliwatt (mW) power needed to operate a mobile phone (Figure 1).

High energy saving potentials

Many market segments such as domestic and office appliances, heating, ventilation and air conditioning, digital consumer, communication, factory automation and drives, traction, automotive and renewable energy, can potentially benefit from the application of power electronics technology. Advanced power electronics could, for example, realise savings of more than 50% in energy losses in converting from mains or battery voltages to that used in electronic equipment (Figure 2).

Motor drives use 50 to 60% of all electrical energy consumed in the developed world. By using power electronics controlled motor drives a potential reduction in energy consumption of 20 to 30% is achievable. In home appliances, electronic thermostats for refrigerators and freezers can yield 23% energy saving, and an additional 20% can be saved by using power electronics to control

Major consumers of electrical energy and savings potential Source: ECPE/Infineon)

	Energy Split: ww		Energy saving potential
Con. power supply: - stand-by, - active, ...	Others 14%	- stand-by - active	>90% >>1%
I&C, Computing power supply, ...	Internet 10%	80+ / 90+	>>1%
EC-Ballast Daylight dimming HID, LED, ...	Lighting 21%	Electronic control	>25%
Factory autom. Process engineering, Heavy industry, Light industry, ...	Motor control 55%	Variable Speed Drive (VSD)	>30%
Transportation: Train, Bus, Car, ...		VSD + Bi-directional energy flow	>25%
Home appliance: Fridge, WM, HVAC, ...		VSD	>40%

compressor motors (with three-phase PMDC motors). The connection of renewable energy sources to power grids is not possible without power electronics: photovoltaic power electronic converters optimise the efficiency of PV solar panels, inverters are necessary for wind generators etc.

In automotive applications electric and hybrid drive trains are only possible with efficient and intelligent power electronics. X-by-wire concepts operated by power electronics will generate saving potential of more than 20%.

New concepts for power supplies can improve overall efficiency of 2 to 4% by reducing low power and standby consumption or a reduction in losses of 14 to 30%. Digital control techniques can further reduce energy consumption. In general lighting power electronics can improve the efficiency of fluorescent and HID ballasts by minimum 20%. Advanced power electronics for dimming together with light and occupancy sensing can save on average an additional 30%.

Actions required

Power electronics has more that 40 years history in Europe and has set many milestones in industry. Power semiconductor devices and smart control ICs have been the key technology driver for the last two decades. In the next two decades, however, packaging and interconnection technologies, high power density system integration together with advancements in Si devices and system reliability will dominate the power electronics development.

Therefore, Europe has to invest in various areas with focussed R&D effort e.g. in a next generation of semiconductors, advanced device concepts and high temperature (wide band gap) power semiconductor materials (SiC, GaN, diamond); new concepts for pure Si and/or SiC system design; semiconductor elements allowing higher voltage and power; and advanced materials (isolation, thermal conductivity, passives, sensors) for system integration and harsh environment, incl. nanostructure materials and filled polymers.

In packaging new interconnection technologies for ultra-high power density systems and high temperature electronics; advanced thermal management; high temperature magnetics, capacitors, sensors, control ICs; advanced EMI filtering and high level of passive integration; system cost reduction by standardisation of mass producible power electronics building blocks; and functional system integration (reduce losses, costs, weight and size, optimise cooling) or integrated mechatronics e.g. for fridge compressors, air conditioners and pumps should be developed.

New topologies for further standby power reduction and digital power conversion and smart power management are required, as well as smart and simple dimming concepts in lighting; smart control of street lighting; high efficient light sources (LED/OLED) and their power electronic drivers; and higher level of integration e.g. for more compact energy saving lamps.

In the 'Action Plan for Energy Efficiency: Realising the Potential' from October 2006, the European Commission has underlined the importance of this topic for Europe. In the next step, the potential must be realised by establishing a European R&D Platform for power electronics supported by the European Commission. ECPE will support this process by a European initiative of academia and industry to jointly develop power electronics research and technology roadmaps. Eight working groups for key applications and systems using power electronics have been formed with experts from industry' as well as from university and research institutes. The vision is that these medium to long term research roadmaps (up to 2020) will become a guideline for power electronics research in Europe and help industry to prepare for upcoming technology challenges.

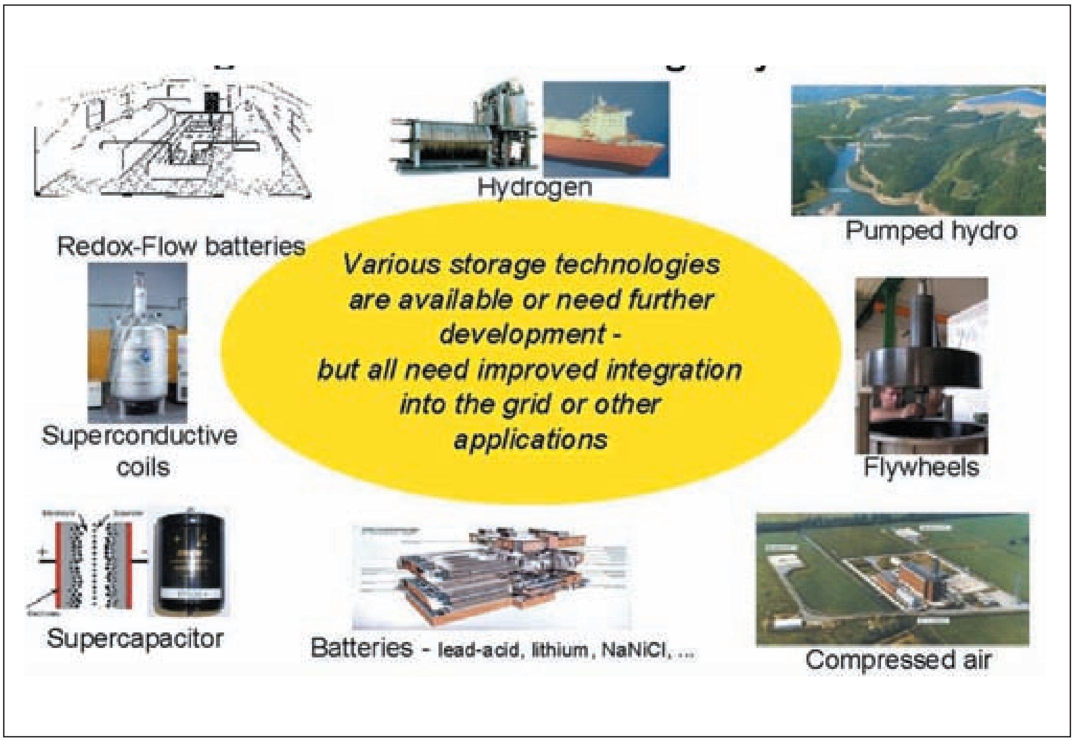
Areas of interest

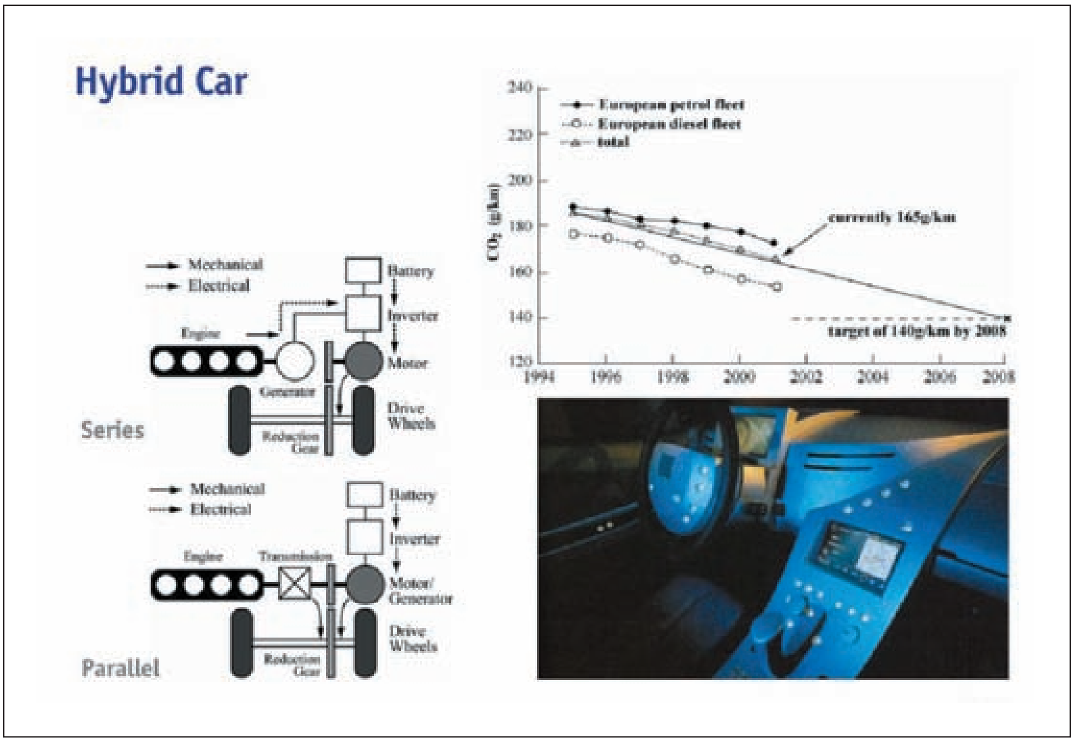
Power Generation & Distribution and Energy Storage, Transport and Mobility, Industrial Drives, Information and Communication Technologies, Home Appliances, and Lighting are the application areas of interest, chaired by leading European scientists.

High voltage (High Voltage Direct Current - HVDC) transmission, static VAR compensators, dynamic voltage restorers (DVRs) and medium voltage static transfer switches (MVSTS) are existing applications of power electronics in distribution and transmission systems to improve power quality and reduce transmission losses. "More power electronics are being used on the generation side to convert electrical power, often from DC to 50Hz fixed frequency AC. Power electronics is also indispensable to link future storage systems to the power grid. It is anticipated that in the future all electrical energy will flow at least once through silicon", says Prof. Dr. R. De Doncker (RWTH Aachen/ Germany).

Power electronics not only makes the power systems more flexible and stable, but allows significant energy savings in partial loads (maximum power point tracking) and major investment cost savings as new and lighter power sources can be realised. "To break through in the field of power generation, distribution and storage systems, power electronics research should focus on increased reliability with simpler control, better packaging, power electronic building blocks; lower cost through optimised cooling, improved packaging, lower

Storage technologies for electrical energy
Source: ECPE/RWTH Aachen





Example for energy efficiency in transportation, the hybrid car Source: ECPE/ETH Zurich

losses, smaller weight and size; more integration at higher temperatures with integrated cooling; and finally interfacing with utility communication systems", Doncker added.

Analysis of the potential evolutionary development of silicon-based power electronics in HVDC and and Flexible AC Transmission Systems (FACTS) indicates performance and cost limitations that will prevent effective implementation of the 'New Unified European Electricity Grid'. Similarly, the cost of silicon-based power electronic systems will limit the penetration of small distributed generators (DG) in Europe's Electricity Supply Grid. "In comparison, high-voltage silicon carbide (SiC) based technology, with SiC device ratings between 10 and 15kV have the potential of offering the performance advances and system cost reductions required to allow effective implementation of a European Grid and to enable deep penetration of DG", comments Roger Basset from UK-based Areva T&D. These SiC devices would be exploited as part of a new class of Voltage Source Converters (VSC) that would be dramatically more reliable and energy efficient than those currently in silicon. Such devices will provide substantial reductions in the size of the entire HVDC and FACT systems allowing, for example affordable increase in capacity of transmission lines into cities.

"Europe's strength in HVDC and FACTS positions it to rapidly achieve global leadership in SiC-based technology thus allowing it to timely provide the technology required to implement the future electricity grid. As a consequence, funding of a European programme needs to be made a high priority. This programme would pull together Europe's distributed expertise and manufacturing base to effectively compete against US and Japan based competitors. Such a project would protect existing jobs in the European power electronics and power industries, whilst providing affordable and reliable electricity and societal to European Citizens.

The required European-level programme of work would have synergies to that required for SiC electronics for the automotive industry. However, there are unique requirements, e.g. low-cost, thick epitaxial growth techniques, new high-voltage insulation and new circuit designs. Overall, the application of SiC in VSC HVDC will power electronics to 'come of age' and become the new standard for power transmission", Basset adds.

Chairman for the sector Industrial drives is Dr.P. Barbosa from ABB. "The Kyoto protocol establishes that by 2012 Europe must reduce 8% (340Mton) CO_2 emission compared to the levels of 1990. In 2000, the total EU-15 electricity consumption was 2,570TWh. Out of this, industry use accounted for 950TWh. Industrial motors and drive systems alone consumed the bulk electricity, that is, 610TWh or 64% of the total industrial consumption. 180TWh is the potential to save energy using variable speed drives (VSDs), which accounts for 80Mtons of CO_2 reduction. As a result, industrial VSDs can accomplish alone 24% of the required CO_2 reduction per the Kyoto protocol. If we consider the EU-25 member states, the potential to save energy increases to 200TWh or 100Mtons of CO_2 reduction. It is amazing to notice that in terms of power plant requirements, the energy that can be saved is equivalent to 45GW of installed generation capability, that is, 130 fossil fuel 350MW power plants or enough energy to supply a whole country the size of Spain. The conclusion is that savings justify by themselves a massive investment on industrial VSDs", Barbosa stated.

The matter of fact is that today's VSD technologies are fully capable to provide the savings. above. So, what is motivating us to doing more research in this area? "Indeed, to improve the performance and widen the acceptance of VSDs we have to make them more reliable, lower cost, more efficient, more compact, and easier to manufacture and easier to use. To accomplish results in the issues listed above, we will need to develop technology in the multidisciplinary areas mentioned such as power semiconductors, passive componets or packaging", Barbosa added.

Passive components have not shown a fast development track record in the last 30 years. For this reason, size, operating temperature and frequency are barriers which are easily reached by state-of-the-art components. There is a great need to develop new/better materials for capacitors, inductors, transformers and filters. As a result, higher energy density materials, such as nano-magnetics and nano-dielectrics are required to achieve compactness, higher operating temperature, and higher frequencies. Power semiconductors have developed much faster than passive components in the last 30 years. The invention of the insulated gate bipolar transistor (IGBT) and the integrated gate commutated thyristor (IGCT) have been responsible for major breakthrough in industrial VSDs. Clearly, further loss reduction is needed for high voltage IGBTs (>1700V). In addition, operating at higher temperatures is extremely beneficial to slashing cost related to thermal management. To make it possible to improve the performance of power semiconductor devices further development of Si IGBTs, super-junction devices and new wide-band gap components based on silicon carbide (SiC) or gallium nitride (GaN) are necessary.

"Home appliances is a special application field where cost is the main driver. They use 30% of all electricity generated, produce 12% of all energy-related CO_2 emissions, are the second largest consumer of electricity, and are the third largest emitter of greenhouse gas emissions. From a manufacturer's view washing machines and dishwashers are close to the technological limit of efficiency, refrigerators and freezers are close to the least life cycle cost, industry investments were in average €1 billion per year over the last decade and +30% in the last five years, and 70 to 90% of products are in class A or better", says Home Appliances Chairman Prof. Dr. A. Consoli from University of Catania/Italy. "But there is a large market of small appliances where motor efficiency is still in the order of 5 to 10%. Efficiency of the larger appliances ranges within 50 to 60%. New solutions such as Permanent Magnet motor drives must be adopted".

Power electronics can also help to improve efficiency at the converter stage by introducing new solutions for power components and sensing (Intelligent Power Modules, hybrid integration, IGBT drivers, PFC, current sensing), as well as at the control stage enhancing efficiency and reliability of the home appliances (sensorless control, field weakening operation, reliability of torque and power estimation, dynamic maximisation of torque/current ratio, load identification algorithms).

"To make lighting significantly more efficient than it is today, several high-risk scientific research projects should be initiated", states Chairman Prof. ir. M. Hendrix from Philips Lighting. "Fast, high voltage (400 to 800V) and high temperature (120 to 250°C) switch technologies e.g. SiC or ESBT including their drive and protection mechanisms should be very inexpensive. A cost-breakthrough for lighting is possible when both high voltage (diodes and switches) and low voltage IC processes (controllers) can be combined on the same die. Cost can be saved with an order of magnitude faster microcontrollers with on-chip very high resolution (nanosecond) timers. High speed can be used to circumvent costly hardware - fast ADC and DACs with off-chip components. Higher processing speed and faster timers allow direct driven switches and adaptive on-line dimming algorithms for very efficient high-intensity, and thus energy-saving, discharge lamps. High-temperature electrolytic capacitor replacements, e.g. high-temperature polymers should also be researched".

In transportation, power electronics is a key enabler for realising energy efficient vehicles with hybrid powertrains (Figure 4). "Due to recuperation of kinetic energy, operation of the internal combustion engine with maximum efficiency, and combustion engine shut down at idle, hybrid cars show a significantly improved fuel economy for standard city based drive cycles. However, the automotive environment challenges the power electronics controllers with extreme temperatures and requirements for low weight/low volume and zero defect over 15 years lifetime. Furthermore, cost reduction by factor of 4 until 2020 is a prerequisite for allowing wide spread of hybrid technology", states Prof. Dr. J.W. Kolar from ETH Zurich/Switzerland.

"To meet these challenges research in power electronics has to focus on functional integration/ modularisation of various converters systems; advanced thermal management; homogeneous (space/time) power conversion/ multi-cell converters; advanced EMI filtering; high temperature magnetics/ apacitors/sensors/control ICs; application of wide band gap power semiconductors; fault tolerant converter/motor systems; stress analysis/reliability prediction; and multi-domain/scale/level modelling and simulation", Kolar points out. Similar research requirements exist for more electric aircraft where hydraulic actuators are supported or replaced by power electronics controlled electromechanical actuation. Reduction of aircraft weight, fuel economy, easier maintainability and aircraft design flexibility are main drivers in this area.

PEE's panel discussion on hybrid car technology (PCIM 2007, May 23, 16.00-17.00) with heavy industrial participation will focus on the role of power electronics and already existing solutions for hybrid electric vehicles (HEVs).

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www.ecpe.org, PCIM Hall 12/466

Keynote on Energy Efficiency and Building Blocks

The PCIM 2007 conference is grouped into the sections Power Conversion, Power Quality, and Intelligent Motion. In total approximately 150 papers will be presented.

Ten of the 24 sessions are dedicated to power electronics; in total 43 presentations will give an overview on the state-of-art in power electronics within the sessions Automotive, Thermal Management, DC/DC Conversion, Innovative Power Devices, High Power Modules, Low Power Packages, Thermal Characterisation, AC/DC Conversion and UPS/Special Converters.

Session 5B on Thursday (May 24) at 10.00-12.00 will deal with Energy Saving and Improved Energy Efficiency via Power Electronics. Exemplary results from ECPE's study on energy efficiency; the impact of motor Drives on energy efficiency and energy efficiency in lighting are the main subjects of this session.

"The rising demand for energy in all forms and the recent series of dramatic increases in energy prices have made it evident that energy must be used more efficiently. Today, we are in a position where technologies for realizing substantial energy savings already exist. Unfortunately, these technologies have not yet been used up to their full potential, although a number of voluntary standards and labels in the field of energy efficiency have been suggested and introduced. To reach these goals, new highly efficient power electronic technologies are needed as an enabling factor to reduce today's massive waste of energy while keeping the conveniences of technical progress", says Manfred Schlenk, Infineon Technologies, Germany. The significant potential for saving energy through the use of power electronics will be highlighted in his first PCIM keynote on May 22, 9.15am.

Power drive systems

The total industrial electrical energy consumption in Europe (EU-25) based on the year 2005 equals 3600TWh. Between 65% and 70% of this (2500TWh) usually is transformed in mechanical energy to drive different applications in industrial processes.

Motor driven systems can be classified in four different categories according to the specific requirements for the various applications, each of them with a different energy saving potential: a) fixed parameters with fixed speed motors, b) fixed parameters with variable speed drives, c) adjustable parameters with fixed speed motors, and d) adjustable parameters with variable speed drives.

The biggest potential for improvement of the process quality including energy efficiency is evidently in case of c) when required variable process parameters had been realized with fixed speed motor driven systems. The most prevalent example of energy waste is fluid control using a fixed speed pump and a mechanical throttle for parameter control running in partial fluid flow. Just switching to a variable speed drive and removing the throttle results in an energy saving of about 30 to 50%, including increased process controllability (see Figure 1).

Even in case a) energy efficient motors exist (EFF1), which allow a 40% reduction of losses compared to inefficient motors (EFF3) under the provision of an appropriately matched power size (in order to avoid over-sizing). In practical cases the simplified life cycle assessment shows that 99% of the total users cost of an energy saving motor (15kW) during 15 years of running time are spend only on energy and only 1% on the initial investment (purchasing price). Replacement by energy efficient motors is thus, in the case of more than 2000 operational hours per year, provided that the old unefficient motor is to be replaced or repaired.

In case of b) or d) the additional energy saving potential might be less as the system is already running in an optimised way. System efficiency analyses and improved drive application are the provisions for optimising motor driven systems. The on-site agreement with the system-user will result in an average energy saving amount of 1% p.a. for variable speed driven systems and 0.2% p.a. for the replacement by energy saving motors, when the industrial consumption is taken as a basis.

At the end of the day, in EU-25 a saving potential of 43TWh p.a. which equals 19 fossile power stations or 19 Mio. t of CO_2 p.a. is realistic just by win-win measures, with payback times of less than two years for the system users of brownfield installations. Therefore 16 Mio. t of CO_2 p.a. equalling 16 fossile power stations can only be achieved by using the key technology of power electronic components.

Lighting

Today, sufficient technical solutions exist to produce more efficient and less power consuming ballasts for fluorescent lightings. According to the energy efficiency index (EEI) developed by CELMA (the federation of national

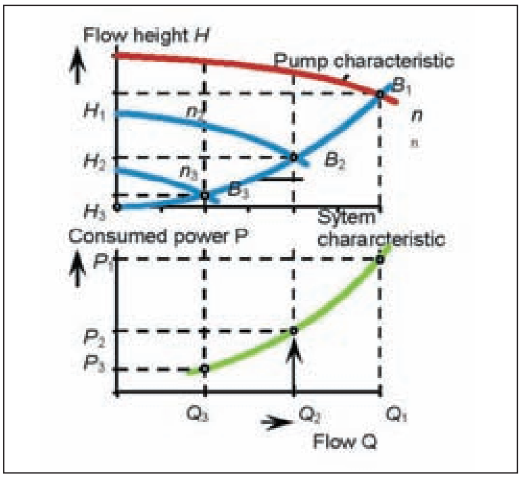


Figure 1: With variable speed driven pump, the fluid system characteristic remains unchanged, whereas the pump characteristic (red line) can be lowered to reduce consumed power (green line) at partial material flows
Source: Infineon

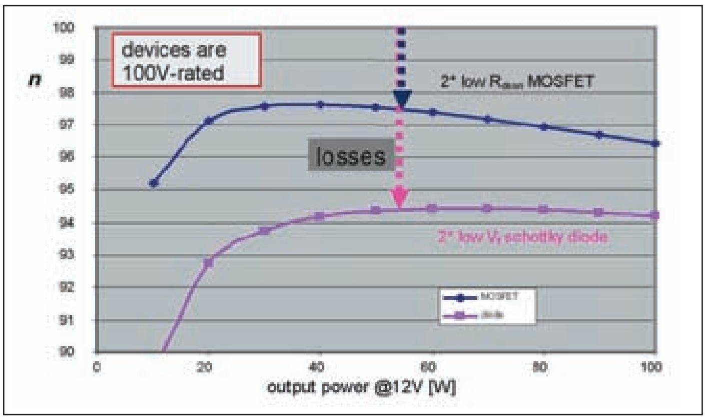
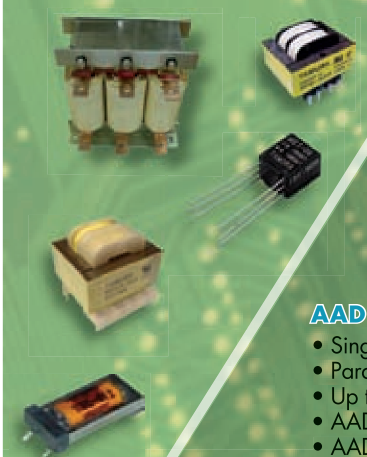
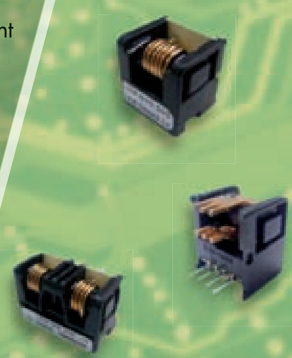


Figure 2: Efficiency Increase by using synchronous rectification Source: Infineon



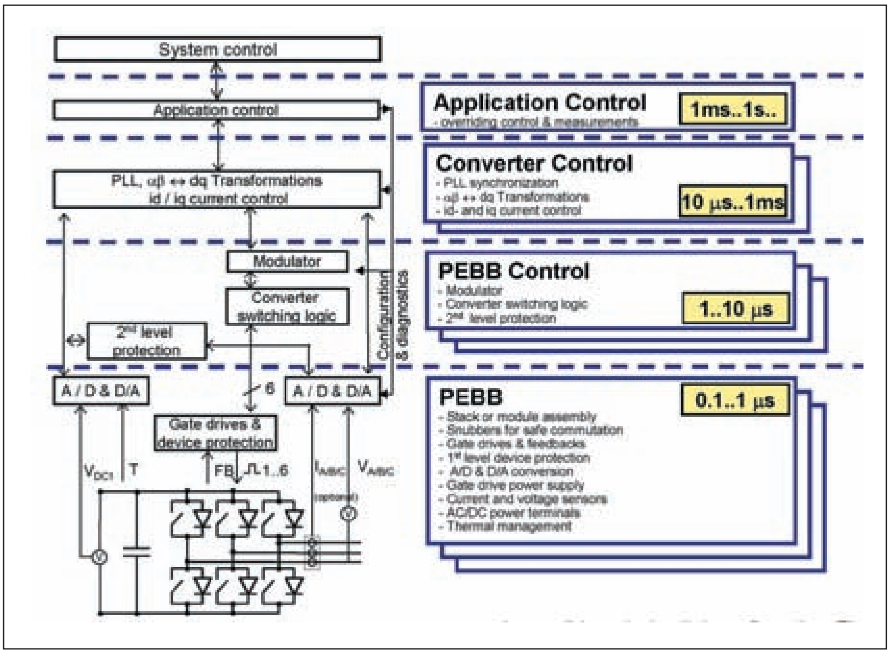


manufacturers associations for luminaries and electro-technical components for luminaries in the European Union), ballasts are classified by their energy consumption and losses. This classification takes both parts of a system into account, the lamp and the ballast. Directive 2000/55/EC initiated by the European Commission also refers to the EEI and demands improving the efficiency of lighting systems by limiting the ballast losses.

Electronic ballast for fluorescent lighting saves up to 25% of the energy compared to magnetic lamp ballast. Further reductions are feasible by using daylight linked dimming systems. This is an enormous source of potential savings, simply because of the large role that lighting plays in the industrial world. It is estimated that lighting amounts to 15% of the world total electricity consumption. This means that a saving of approximately 30% of energy used in lighting leads to 4% reduction in total electricity consumption.

With dimmable electronic ballasts it is possible to reach the highest level of efficiency in fluorescent lighting. In the near future, a switch from fluorescent to possibly HID (short-term) and finally to LED illuminants is foreseeable. With both, HIDs and LEDs, it is possible to improve the efficiency of lighting systems significantly.

Figure 3: PEBB and its possible levels of integration Source: ABB



Standby power and IT-equipment

Today's advanced design solutions and technologies make it possible to significantly reduce standby consumption. Standby is a particularly urgent reason for new compulsory regulations, because of its increasing importance, and due to the fact that it plays a relatively small role for the individual user, but implies an enormous saving potential at the level of national economies.

Standby efficient controllers save 90% energy compared to conventional standby controllers. In the case of European TV sets, the realization of the saving potential of standby power losses alone would correspond to one nuclear power plant. This potential could be reached by turning the savings recommendations of the IEA into compulsory practice.

There are currently in Europe around 200 million TV sets. Their power consumption during standby operation during the day reaches approximately 200Wh/day or 73kWh/year assuming 20h runtime in stand-by mode. This results in an annual power consumption in Europe of approx. 14.6 billion kWh/year and an annual energy consumption by standby operation of 2000MW. Standby efficient controllers could save 90% energy compared to conventional standby controllers.

Figure 2 shows the efficiency of a 100W output stage of a power supply. By replacing conventional diodes with more efficient ones, an efficiency increase up to 4% can be easily achieved.

Server Power Supplies: Energy saving IT equipment leads to an efficiency increase of 1% compared to conventional equipment. The estimated number of servers worldwide in 2006 is 9.5 million and estimated to increase by 30 million servers until 2011. Given an average power usage of one server of 1200W, the overall power usage of servers worldwide is 36GW. Saving only 1% in this kind of IT equipment would already imply saving the output of a conventional hydroelectric power plant.

Even if large investments and many efforts are needed to realise these saving potentials, Europe already is one of the world leaders in developing energy efficient technologies.

Challenges for the Power Semiconductor Technology

"For many years, miniaturisation and increased functionality have been major drivers of semiconductor technology. This is also largely true for power semiconductors. Low-loss power electronics devices using high-efficiency power semiconductors are required today. Other drivers are downsizing, weight saving, and cost reduction, in particular in the case of hybrid electric vehicles", Schlenk argues.

Power Electronics Research and Education in China

The second keynote on May 23 will be given by Prof. Dehong Xu from Zhejiang University (China). The leading universities in China on power electronics are introduced with respect to their highlighted research topics, education circumstance and influence. Then national research institutes related to power electronics are introduced with respect to their research direction and products and contribution to the country. Some information about key power electronics companies in china and market scale information will also be provided. In addition, the paper will introduce China Medium & Long Rang Science and Technology Plan and the 11th 5 years R&D Plan which is related to power electronics. Finally, the paper will foresees the future power electronics market needs in China from a technologies point of view.

High Power Electronics, Trends of Technology and Applications

The third keynote on March 24 will be given by Dr. Peter Steimer, ABB Power Electronics and MV Drives (Switzerland). "A platform-based approach for power electronics systems requires the definition of basic building blocks and is essential for mature and emerging applications. The most important key functional components in power electronics are the power electronics controller and the power electronics building block (PEBB)", Steimer explains.

Power electronics is a key technology for energy conversion in multiple areas like power generation, transmission and distribution, industrial applications, and transportation. Already, mature applications may be found in static excitation systems for generators, traditional HVDC transmission systems, high current rectifiers for DC loads, adjustable speed drives, and converters for rolling stock.

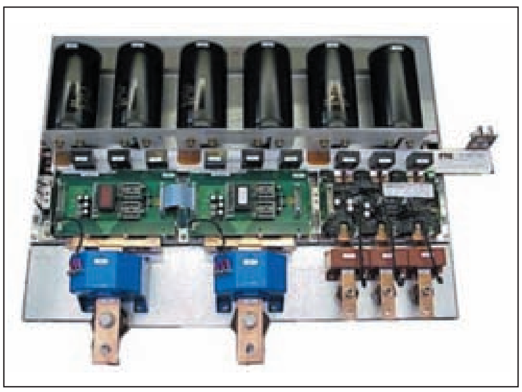


Figure 4: PowerPak – IGBT PEBB based on low-voltage IGBT module technology Source: ABB

Important emerging applications for high power electronics have been evolving, like new distributed power generation based on wind turbines, new FACTS solutions like back-to-back interties for coupling AC systems and STATCOM for voltage control and new voltage-source converter based HVDC transmission systems.

Power Electronics as a key technology will be divided in the power semiconductor technology and the integration in Power Electronics Building Blocks (PEBBs) with defined interfaces used in multiple applications.

The functionality of a PEBB as a basic building block can be defined as power conversion including power supply for gate drives and sensors; stack or module assembly including gate drives; voltage, current and temperature sensors including A/D conversion of sensor signals; switching control inclusive pulse generation for gate drive; communication with control; and primary protection. The interfaces of a PEBB can be defined as auxiliary power interface; control interface; power interfaces; and cooling interface.

With this proposed definition, the complexity of power electronics systems can be reduced due to basic building block and interface definition. The interface with the highest complexity is that between the PEBB and the control. This interface may also have a different definition and functionality depending on the degree of integration within the PEBB. To achieve a clearly defined, scalable and easy to implement interface between the control and the PEBB, it is proposed that, in very high power applications, additional intelligence be included within the PEBB. This additional intelligence should be based on the level PEBB control (Figure 3), which includes the functionality 1) modulator with switching logic and 2) the 2nd level of protection. This additional intelligence should be physically located close to the power part of the PEBB as distributed intelligence.

Based on low voltage IGBT modules a compact IGBT PEBB (Figure 4) has been developed, based on SPT technology with a six-pack topology, which can also be used in a dual switch configuration. The maximum output power of the water-cooled IGBT PEBB, equipped with three IGBT modules, is in the range of 500kVA. Based on the IGCT technology a very compact NPC IGCT PEBB, called PowerStack (Figure 5), serving multiple medium-voltage applications has been introduced and first commercial installations were commissioned in the year 2000. The maximum output power of the water-cooled IGCT PEBB in a three-phase configuration is in the range of 9MVA. The system voltage with the 4500V or 6000V IGCTs is limited to 3300 or 4160V correspondingly. To further improve the power density of the IGCT PEBB technology the ANPC IGCT PEBB has been developed, which is able to deliver up to 16MVA output power.

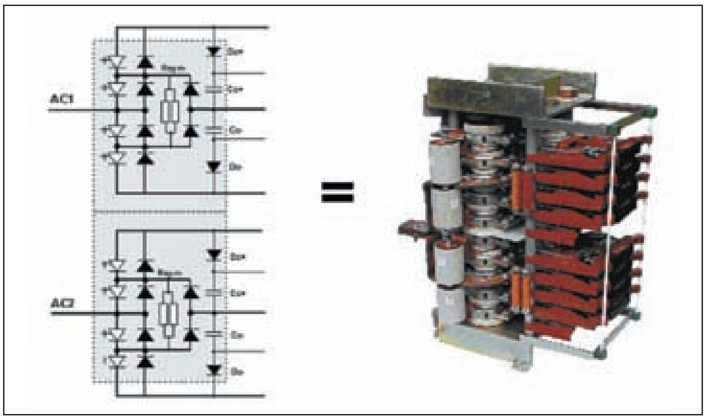


Figure 5: PowerStack - NPC IGCT PEBB based on medium-voltage IGCT presspack technology Source: ABB

"The IGBT is the leading technology in the power, range up to a few MVA, with a dominating position in low voltage applications. The IGCT is the leading technology in medium voltage applications with an impressive reference list in a high number of demanding applications. Future innovations will introduce blocking voltages up to 10,000V. Applying IGCT technology in high power PEBBs makes it possible to deploy synergies of PEBB designs over multiple applications due to defined interfaces. These definitions enable a platform-based approach to power electronics applications", Steimer predicts. The full tutorial and conference programme is available on PCIM's website.

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Comprehensive Conference Programme

Besides the keynotes, PCIM 2007 will present 150 papers from 11 countries. Below is an overview on selected power electronic subjects.

Automotive

Session 1A on May 22 (10.30-12.30) will focus on automotive applications and is chaired by power electronics veteran Bruce Carsten.

Michael Stadler from University of Applied Sciences Ingolstadt/ Germany will present a 'Soft-switching converter using current controlled non-linear inductors' for the 42V/14V automotive electrical power system. Switching losses have been reduced using current controlled non-linear inductors to provide soft-switching of the active switching devices. The paper presents the analysis, design and experimental results of the converter and its control circuit.

Peter Beckedahl, Semikron International, Nuremberg/Germany (Hall 12/411), will introduce 'A new power module family for automotive applications' (see our related feature). Automotive and high end industrial applications require a new approach for power modules to fulfil the requirements in terms of power density, cost and reliability. In this new power module family, the base plate less pressure contact technology will be taken to the next level, combining the pressure spreading system and the bus bars into a single laminated structure, providing ultra-low inductivity, low over-voltages and a soft switching behaviour.

A 'Cascaded Boost-Buck DC/DC-Converter for Dual-Voltage Automotive Power-Nets with Overlapping Voltage Ranges' will be introduced by Dieter Polenov, BMW Group, Germany. The topology of the cascaded boost-buck-converter is capable of bi-directional energy transfer in dual-voltage automotive power-nets with overlapping voltage ranges. A prototype converter with non-symmetrically cascaded half-bridges was developed and realised. Possible operation modes are introduced, implementation and experimental results are discussed.

Thermal Management

The parallel session 1B 'Thermal Management and Stresses' is chaired by Prof. Josef Lutz from Technical University Chemnitz/Germany.

Michael Hertl, Insidix/France will give a paper entitled 'Experimental identification of failure risks due to thermo-mechanical stress in power electronics' which introduces a new experimental tool for the analysis of failure risks due to thermo-mechanical stress in power electronics. Application examples include the detection of CTE mismatch and heatsink related reliability problems on electronics boards for automotive applications.

Marco Feller, TU Chemnitz will discuss the 'Power Cycling of IGBT-Modules with different current waveforms' by two power cycling tests which have been performed. One power cycling test was realised with half-sine current and the other with DC. The results of these tests are shown in this presentation.

Frank Osterwald, Danfoss Silicon Power, Schleswig/Germany (Hall 12/325) will introduce 'Sprayed stress reducing interlayers for highly reliable large solder joints'. The increasing demands in terms of reliability of power modules in automotive applications lead to new packaging solutions. An alternative to AlSiC baseplates is a baseplate with a stress reducing interlayer. A way to deposite comparably thick interlayers is to spray powder of the desired materials to the baseplates. In this paper, the use of cold gas technology for the layer deposition will be discussed. It will be shown, how stress reducing interlayers

This year's PCIM conference will feature 24 sessions with 150 papers. A selected overview on power electronics will be given below

increase the reliability of power modules.

Ronald Eisele, University of Applied Sciences Kiel/Germany presents a paper on 'Pressure sintering for thermal stack assembly'. The increasing demands in terms of temperature cycling capability of thermal stacks require an advanced bonding and joining technology. Silver pressure sintering technique is used to achieve highly thermo-mechanical stress resistant layers by avoiding creeping behaviour of common soft solder alloys. The result of thermal cycling tests and the influence of the layer thickness is discussed.

Thermal characterisation is the subject of session 4B on May 23 (14.00-16.00), chaired by Uwe Scheuermann, Semikron Elektronik/Germany.

Uwe Drofenik, ETH Zurich/ Switzerland will talk about the 'Modelling the Thermal Coupling between Internal Power Semiconductor Dies of a Water-Cooled 3300V/1200A HiPak IGBT Module'. Calculating the transient junction temperature of power semiconductors is important for analysing converter reliability or investigating short-term overload conditions. A dynamic thermal model, including the mutual thermal coupling of neighbour dies, that can be easily integrated into a circuit simulator is essential to perform such a task. In this paper, a suitable thermal model for a 3300V/1200A IGBT module based on numerical 3D-simulations and infrared temperature measurements will be discussed.

Thies Wernicke, Fraunhofer IZM/Germany (Hall 12/342) will introduce 'Measurement techniques for the thermal characterisation of power modules'. Thermal characterisation of power semiconductor devices is commonly done by single-pulse measurements which do not represent the usual operation conditions of power semiconductor devices. The accuracy of this simplification is evaluated by measurements in periodic switching applications based on different methods including high speed high resolution IR thermography.

Markus Billmann, Fraunhofer IISB/Germany (Hall 12/627) introduces 'Thermal shielding techniques for power electronic devices in high temperature applications'. This paper evaluates different methods to find a solution for heat shields inside integrated power electronic systems. Different device types with different heat impacts and possible protection measures are discussed. Arrangements of heat shields with no extra cost that reduce radiated as well as convection based heat impact are preferred.

"With ten sessions, power electronics are the main part of PCIM 2007 conference. This event is an unique symbiosis between exhibition and world-class conference", states Uwe Scheuermann, Head of PCIM's Advidory Board Power Electronics

Frank Bertling, University of Dortmund/Germany will present a paper on 'Real-time prediction of the steady state temperature of circuit components as a tool for power electronic circuit testing'. Demonstration of prediction methods for the steady state temperature of circuit components: During thermal run-up, momentary temperature values and slope are analysed to calculate an approximation of the temperature that will be reached at the end of thermal run-up. This reduces the time consumption for optimisation and other tasks requiring parameter variations as a full thermal run-up only needs to be performed for the determined optimum or selected characteristic operating points.

DC/DC Power Conversion

The third parallel session 1C will be chaired by Prof. Alfred Rufer, EPFL, Switzerland.

Here, Tomokazu Mishima from Kure College of Technology/Japan will present 'A novel high frequency transformer-linked Zero Current Switching asymmetrical half-bridge DC-DC converter for the low-voltage/large-current output applications'. In the newly-proposed DC-DC converter, ZCS is assisted by a switched-capacitor and loss-less inductor snubber, so ZCS mode commutation can be achieved in all switches for the wide output power variation. The converter operation and its feasibility are verified by simulations and experiment results.

Khairy Sayed, Kyungnam University/South Korea will introduce 'A New Soft-Switching PWM High Frequency Half-Bridge Inverter Linked DC-DC Converter with Diode Clamped Active Edge Resonant Snubbers'. This paper presents a novel circuit topology of voltage source half-bridge soft switching PWM inverter type DC/DC converter with DC rail high and low side active edge resonant snubbers. Under the proposed high frequency inverter link DC/DC power circuit, all the active switches in the half-bridge arm and DC bus lines can actively achieve ZCS turn-on and ZVS turn-off commutation operation.

Paul Yeaman, Vicor/USA (Hall 12/431) presents 'A Direct, high efficiency, high power density 48 – 1.xV 100A solution for microprocessor applications'. This solution enables high voltage, low current to be distributed throughout a system, minimising distribution losses, while providing low voltage, high current direct from the 48V input in the most efficient manner possible. This solution is also extremely small, minimising the required footprint at the microprocessor core, and extremely fast, eliminating the need for bulk capacitors at the point of load.

Osvaldo Enrico Zambetti, STMicroelectronics/Italy (Hall 12/412) will give a paper on 'Load Transient Boost technology to improve the performances of multiphase controllers with the load frequency variation'. Recently, there has been a huge increase of current rate drawn by new Intel and AMD processors. Multimedia applications and dual core architecture make it more and more difficult to control the core voltage during load transients. To reduce the solution's total cost, it is necessary to improve transient controller performances. A novel non-linear control, so called LTB technology, brings benefits not only for system cost, but also for output impedance with the load frequency variation.

The afternoon session 2C will be chaired by Prof. Dehong Xu, Zhejiang University/China.

Mutsuo Nakaoka, Kyungnam University/South Korea present an 'Interleaved ZCS Boost DC-DC Converters Using Quasi-Resonant Switch Blocks for PV Interface and Its Performance Evaluations'. This paper presents design and control of three-cell interleaved boost DC/DC converters using Quasi-Resonant Switch Blocks for PV Interface. A coupled inductor of energy storage inductors is used. This integrated magnetic design structure reduces size and improves the converter performance, both steady-state and transient.

Werner Berns, National Semiconductor/Germany (Hall 12/329) will give a paper on 'Design and optimization of emulated peak-current mode controlled buck regulators'. Peak-current-mode control is typically used to improve dynamic performances of switching DC/DC synchronous rectification buck regulators, thanks to the benefits of such control technique consisting in a single pole feedback loop gain transfer function and better immunity to noise. The aim of this paper is to illustrate the results of such investigation, which provide the constraints that must be considered in the design of emulated-peak-current-based synchronous rectification buck regulators.

Fulvio Lissoni, STMicroelectronics/ Italy (Hall12/412) introduces 'A new compact monolithic step-down synchronous regulator manages high current conversions'. This paper will detail the main features, performance results and possible application ideas of a new monolithic step-down synchronous regulator for high current conversions.

Juan M. Martínez Sánchez, Infineon Technologies/Austria (Hall 12/404) will talk about 'Optimising efficiency in isolated DC/DC converters'. The rapidly growing power demands of the computing and communication equipment set the goals for new power converter

technologies. Higher power density and faster dynamic behaviour become the challenges for designers. In this paper the distribution and mechanisms of losses in isolated DC/DC converters and capabilities of power MOSFET technologies will be reviewed.

Power semiconductors

Innovative Power Devices are the subject of Session 2A chaired by Eric Carroll, ABB Semiconductors/ Switzerland on May 22, 14.00-16.30.

Masahito Otsuki, Fuji Electric Device Technology/Japan (Hall 12/407) will introduce 'The 6th generation 1200V advanced Trench FS-IGBT chip technologies achieving low noise and improved performance'. The 6th generation IGBT chip technologies used for motor drive application is described in this paper. The 1200V advanced trench-FS IGBT has been developed based on the concepts of the 'low noise' and 'performance challenge'. An optimised trench-gate structure enables faster IGBT gate-drive with smaller resistance while keeping the noise peak within the EMC regulation. A remarkable improvement in the turn-on characteristics has been achieved.

Alexander Ciliox, Infineon Technologies/Germany (Hall 12/404) will give a paper on 'Degrees of freedom for optimisation of IGBTs for 400V AC-line applications', addressing the question how a variation of the requirements on short circuit robustness and blocking voltage translates to a change of chip performance. Focus is the optimisation of IGBTs for 400VAC power line applications. Measurements of the increased performance are shown, as well as the handling and the safe turn off of short circuit conditions are discussed in detail.

Holger Huesken, Infineon Technologies, introduces 'A new high voltage diode technology for UPS-applications'. Uninterruptible power supplies in the lower output power range of a few kVA usually require 1200V power devices operating at switching frequencies of 20 to 25kHz. A new diode design which achieves less switching losses at a superior softness level will be introduced and it will be compared to other existing diode technologies. A test in a UPS accompanies these considerations in combination of Infineon´s most recent TrenchStop2 IGBT technology.

Lutz Goergens from Infineon Technologies Austria will speak about 'Requirements and trade-offs for modern low-voltage MOSFETs'. Miniaturisation, increased efficiency, higher power density and energy saving are driving the wide range of applications from power conversion to motor-drives for low-voltage MOSFETs. Facing various operation modes, cooling concepts, reliability requirements and power-ranges new silicon-technologies new packaging concepts and also improved layouts are required. In this paper, these requirements and the resulting trade-offs between layout, packaging and technology will be discussed.

Arnost Kopta, ABB Switzerland Ltd, (Hall 12/506) will introduce 'High Voltage SPT$^+$ HiPak Modules rated at 4500V'. Following the introduction of the new generation of 1700V and 3300V Soft-Punch-Through (SPT$^+$) IGBT HiPak range, the next generation 4.5kV HiPak IGBT modules employing the newly developed SPT$^+$ IGBT and Diode technologies is introduced. The new devices exhibit significant loss reduction in terms of saturation voltage and switching losses, while exhibiting higher SOA capability when compared to the previous range (see our cover story in this issue).

High power modules

High Power Modules are the subject of session 3A on May 23 (10.00-12.00) which will be chaired by Reinhold Bayerer, Infineon Technologies/Germany.

Yasuyuki Kobayashi, Fuji Electric Device Technology/Japan (Hall 12/407) will introduce 'The New concept IGBT-PIM with the 6th-generation V-IGBT chip technology'. The new PIMs up to 1200V-150A with optimised design using newly developed the 6th generation Trench-FS IGBT dies have lower noise radiation characteristics and smaller footprint.

Masafumi Horio, Fuji Electric Device Technology, will give a paper on 'Investigations of high temperature IGBT module package structure'. This paper investigates high temperature IGBT module from package issue and reliability. One of the subjects is keeping power cycling capability, because aluminum wire lifts off from die electrode caused by degradation. Avoiding wire lift off, we put epoxy resin on die and DCB substrate. Epoxy resin assisted greatly in maintained good wire bond adhesion to IGBT die. This structure has 6 to 8 times longer power cycling capability against current gel structure.

Thomas Grasshoff, Semikron International/Germany (Hall 12/411) will introduce 'A new non-isolated power module concept'. The new non-isolated module concept combines the ideas of a pressure contact system with direct heatsink contacting. The thermal impedance is much lower compared to other assemblies and enables overload currents two times higher compared to conventional isolated baseplate modules. The module is used in applications with high thermal and power load cycling requirements like motor start and protective circuit applications.

Low power packaging

Session 4A on May 23 (14.00-16.00) will cover 'Low Power Packages' and is chaired by Ulrich Kirchenberger, STMicroelectronics/ Germany.

Ghafour Benabdelaziz, ST Microelectronics/France (Hall 12/412) will introduce a 'Solid state intelligent AC Switch'. This paper deals with the first solid state 'Intelligent AC switch' combining safety functions with an Alternative Current Switch (AC Switch). This new circuit is able to detect AC switch failure modes or its junction over- temperature and to send an alarm signal to the MCU. This signal allows to power off the application and to avoid the AC load to become uncontrollable (for example, driving a relay on the mains power AC line).

Alan Elbanhawy, Fairchild Semiconductor/USA (Hall 12/601) will talk about 'Power Integration; The wave of the future'. One of the most competitive fields in the DC/DC converter business is the core converter for personal computers where given a reasonable performance cost is the most important factor that determines the success or failure of a given design. Integrated power modules have not proven to be very successful in this niche with the exception of a couple of very specialised examples where the space and performance requirements are much more important than price.

Marco Honsberg, Mitsubishi Electric Europe/Germany (Hall 12/421) will introduce 'A new SOI single chip inverter IC implemented into a newly designed SMD package'. The die of the single chip inverter IC containing control part with extended protection functions, level shifting function and lateral 1A or 2A/500V class IGBT structures is mounted on a leadframe which itself is located upside down in the newly constructed compact SOP package.

Thomas Hunger, Infineon Technologies/Germany (Hall 12/404) will present a 'Numerical and experimental study on surge current limitations of wire-bonded power diodes'. The surge current capability (I^2t) of power diodes is studied. Experimental investigations show a linear behavior of the trade off between the maximum peak current before destruction and the pulse width in a double-logarithmic plot for pulse widths <10ms. This is studied in detail by means of a finite element analysis. Physical limitations and possible improvements are discussed. The impact of higher

"Power Electronics is the key technology for energy savings", says Leo Lorenz, Head of PCIM's Advisory Board

EiceDRIVER™ – IGBT Gate Driver ICs with Coreless Transformer Technology

Applications: industrial drives, UPS, welding and various applications

INFINEON TECHNOLOGIES offers with its new EiceDRIVER™ family two new outstanding IGBT Gate Driver ICs for applications up to 1,200 V blocking voltage. Both products are based on the coreless transformer technology which combines the advantages of fast inductive signal transmission and isolation with compact IC driver stage design.

THE **1ED020I12-S** is a single channel IGBT Gate Driver IC in a PG-DSO-16 package providing galvanic isolation according to VDE 0884-10 (draft). Features like V_{CEsat}-detection, two-level-turn-off, bidirectional signal transmission and Active Miller Clamp complete the picture of this new Driver IC which will become a new standard in the IGBT power stage design for medium- and high-power applications.

Key features:

- Single channel isolated IGBT Driver
- For 600 V / 1,200 V IGBTs
- Bidirectional signal transmission
- 2 A rail-to-rail output
- V_{CEsat}-detection
- Two-level-turn-off
- Active Miller Clamp

THE **2ED020I12-FI** is a two channel Driver IC offering a reliable and cost-effective solution for driving IGBT power stages which provides air and creepage distances up to 900 V link voltage. The IC is included in a PG-DSO-18 package. Important protection features are already integrated.

Key features:

- IEC 61000-4-4 compliant
- Tolerant to negative transient voltage
- Matched propagation delay for both channels
- 3.3 V and 5 V TTL-compatible inputs
- UVLO, shutdown and interlock inputs
- Floating channel designed for direct supply and bootstrap operation

For module information please go to: www.infineon.com/igbtmodules

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Never stop thinking

The roughly 280 exhibitors at PCIM 2007 exhibition are looking for more highly-qualified visitors than 2006 (5,783 visitors)

maximum operating temperature is also considered.

Power electronics control

Session 3B on May 23 (10.00-12.00) is entitled 'Control in Power Electronics' and will be chaired by Prof. Alfred Rufer, EPFL/Switzerland.

Michele Sclocchi, National Semiconductor/Italy (Hall 12/329) will talk about 'The impact of open-loop OP-AMP dynamic response on the design of high-frequency DC/DC switching regulators'. The OP-AMP error amplifier is the core of voltage control feedback in most of DC/DC switching regulators. Its ideal action is to enable the circuit realization of compensation networks having a given location of zeros and poles, designed according to the expected dynamic performance of the voltage regulator. The paper illustrates and discusses in detail the problem of the impact of real OP-AMPs characteristics on the design of feedback error amplifiers for high-frequency dc-dc buck converters.

Stéphane Bréhaut, SATIE/France will give a paper on 'Gate driving of a 3.3kV IGBT chopper by an 8bits encoded wireless transmission'. The limitation of optic technology is not the high-voltage insulation but the fragility of the optic fibres with vibrations and temperature. However, regarding the performances that can be reached by radio frequency (RF) wireless links, investigations on this technology in order to control high power IGBTs at 1.8kV are presented.

C. W. Fung, University of Hong Kong/China will present 'Minimum configuration design for digital control of power converters', describing the design of a digital controller for switching power converters. A design procedure for minimum configuration design for digital control of power converters is established. A design example based on a buck converter is presented and was verified by hardware. Engineers can use this as a guideline to design low cost digital control power converters.

Bernhard Strzalkowski, Infineon Technologies/Germany (Hall 12/404) will introduce a 'High performance IGBT-driver in microtransformer technology providing outstanding insulation capability'. The Coreless Transformer Technology, compared with optocoupler technology enables the design of IGBT-drivers with lower propagation delay, lower variation of propagation delay, lower pulse width distortion and lower device to device mismatch regarding propagation delays. This technology avoids others weaknesses of optocouplers and provides higher working temperature by no degradation of transmitted signal level.

Olivier Monnier, Texas Instruments/ France (Hall 12/134) will give a paper on 'Digital Control Maximises System Integration for Multi-phase/ Multi-output DC/DC systems'. The main theme in the paper is going to be integration and channel density.

Passive components

Session 2D on May 22 (14.00-16.30) covers Passive Components/ Technologies and is chaired by Prof. Enrique J. Dede, University of Valencia/Spain.

Acacio Amaral, ISEC/Portugal will use 'Fourier analysis to estimate the influence of parasitic elements of aluminum electrolytic capacitors in steady regime of switch mode power supplies'. Switch mode power supplies (SMPS) are non-linear circuits, thus integrations techniques are usually used for simulation purposes. However, these techniques require the study of transient response to obtain state regime response. Using Fourier analysis, it is possible to study only the steady state response, and reduce substantially simulation time. Besides, using this technique, it is possible to determine some formulas that show the influence of capacitor's parasitic elements in steady regime.

Matthias Spang, Friedrich-Alexander University Erlangen/Germany will give a paper on 'Inductance of coils with rod cores as a function of core geometry and winding layout'. In this paper, the effect of winding layout and core geometry on the inductance of rod core inductors is investigated. Using the magnetic field of the air coil, we obtain the additional magnetic field due to the core by solving the field-equations by means of orthogonal expansion. Matrix calculus is introduced in order to obtain compact mathematical formulations. Analytical expressions for the required integrals are given. The results are in good agreement with measured values.

Daniel Kürschner, Institut für Automation und Kommunikation/ Germany, will talk about 'Optimisation of contactless inductive transmission systems for high power applications'. Over the last few years, many static or axis symmetric applications of inductive transmission systems for living areas and building services engineering have been developed. The specification of higher transferable electric power (>1kW) and larger positioning tolerances necessitates optimising the magnetic system. That means to improve the inductive coupling by optimising the type of resonant circuit (resonance capacitors in series or parallel to the coils) and the form of the ferrite components.

Energy efficiency

Session 5B on May 24 (10.00-12.00) deals with 'Energy Saving and Improved Energy Efficiency via Power Electronics' and is chaired by Prof.

Leo Lorenz, Infineon Technologies/China. He will give an introduction, overview, exemplary results from ECPE study on energy efficiency.

Peter Barbosa, ABB Switzerland (Hall 12/408), will discuss the 'Impact of Motor Drives on Energy Efficiency'. The target of this paper is to demonstrate the benefit of using motor drives to improve the efficiency of various processes in industrial and residential applications.

Dietmar Klien, TridonicAtco/Austria will talk about 'Energy Efficiency in Lighting: Concepts, Potentials and Challenges'. As one of the major consumers of electric power, the lighting business has a huge potential for energy saving. The presentation highlights the state of the art and trends in the domains of light sources and converter technology. Specific market requirements an technological challenges of the three important light-sources Fluorescent, High Pressure Discharge (HID) and LED are discussed. Concepts for top performance at lowest cost for the different converters are presented as an overview.

Ulf Schwalbe, ISLE Steuerungstechnik und Leistungselektronik/Germany will discuss' System advantages and semiconductor requirements of three-stage-DC/DC-converters for server SMPS applications'. This contribution will deal with the benefits and the challenges of three-stage-DC/DC-converters. They will be compared to two-stage-DC/DC-converters for high power and highest efficiency power supplies focusing on server, telecom AC/DC applications as a major market place for advanced system solutions. The practically realised pre-regulated and post-regulated circuits for 12V/800W output have been analysed. The presented results have been extracted from simulations and practical measurements.

Current sensors

Sensors are the subject of session 6C on May 24 (14.00-16.00) chaired by Dan Jones, Incremotion Associates/USA.

Claude Gudel, LEM/Switzerland (Hall 12/402) introduces 'A transducer at the limits of current measurement accuracy'. The current transducer subject to the proposed paper is targeting performances at the limit of what is commonly industrially done, with typically a 0.01% measurement accuracy for a maximum current of 900A, a 200kHz bandwidth and a noise and hysteresis level close to zero. One of the key challenges in this case was to design the transducers in a 'simple' way, to be easily manufactured and thus, produced in a cost competitive way.

Klaus Reichert, Vacuumschmelze/Germany (Hall 12/130) will give a paper on 'Closed-loop current sensing systems with magnetic field probe, incorporating a new sensor signal conditioning IC'. This presentation touches the applications for closed-loop magnetic current sensors, the principle of the compensation-type sensor and the function of the magnetic field probe. It compares the different types of closed- and open-loop sensing principles in terms of accuracy, drift and noise. The functional blocks of a new signal conditioning IC, as well as its additional functions, are described. The last part touches the processing and evaluation of the output signal of the sensing system.

John Cummings, Allegro Microsystems/USA, will talk about how 'Achieving small form factor high speed low noise current sensors'. This paper will teach how closed loop performance can be met with a low cost open-loop architecture. By creating a high bandwidth open loop part with fundamentally lower noise coupled with a faster response time, and we are able to realise a small size surface mount current sensors with a high level of system integration.

William Ray, Power Electronic Measurements Ltd., England (Hall 12/648), will give a paper on 'Calibration of rogowski transducers with non-inverting OP-AMP integrators'. Rogowski transducers with non-inverting op-amp integrators have two time constants which must be accurately matched to ensure that the transducer sensitivity is constant over the operating frequency range. The paper discusses the problem of setting sensitivity at low and high frequencies and presents a method using current pulses to ensure constant sensitivity over the frequency range.

These selected subjects represent only a small portion of PCIM's conference programme. For more details visit **www.mesago.de/de/PCIM/Programm/index.htm**

AS

Panel on Power Electronics in Hybrid Electric Vehicles

Power Electronics Europe will organise a panel discussion on 'Hybrid Electric Vehicles – Example for Efficient Use of Power Electronics', which fits well in the discussion on fuel economy and reduced CO_2 emissions. The event will take place on March 23 from 4.00 – 5.00 pm in the forum (Hall 12 booth 357) and is open to all PCIM visitors free of charge.

The subjects to discuss will cover the role of power semiconductors and capacitors, as well as measurement techniques to realise efficient and economical electric drives that assist the combustion engine in HEVs, and that will save energy through regenerative braking. Panelists will come from EPCOS, Fraunhofer IISB, Infineon Technologies, Isabellenhütte, LEM, Maxwell, SEMIKRON and Tyco Electronics.

HEVs are gaining more attraction due to high energy prices and the public pressure on reducing CO_2 emissions, particularly in Europe and the USA. The global energy consumption is expected to double in the next 20 years. Throughout Europe alone, the consumption is predicted to rise by 60% until 2030. Higher energy demand represents a challenge from the point of view of oil and gas reserves, as well as reduction of gas emissions. For these reasons, energy efficiency in industry has become high priority. Today, we are in a position where technologies for realising substantial energy savings already exist. To reach these goals new highly efficient power electronic technologies are needed as enabling factor to reduce today's massive waste of energy while keeping the conveniences of technical progress.

Due to recuperation of kinetic energy, operation of the internal combustion engine with maximum efficiency, and combustion engine shut down at idle hybrid cars show a significantly improved fuel economy for standard city based drive cycles. However, cost reduction by factor of 4 until 2020 is a prerequisite for allowing wide spread of hybrid technology. Nevertheless, the participating companies are looking for good business prospects in the near future, though the predicted production of 2 million HEVs in the year 2010 is relatively small compared to the worldwide production of 60 million conventional cars. Don't miss this opportunity to discuss with leading experts the application of power electronics under extreme environmental conditions!

AS

Power Supplies with Ultra-High Power Density

The pre-competitive research in power electronic systems in ECPE is based on long-term research roadmaps, and has its focus on automotive and industrial power electronic systems. The research activities are focussing at so-called demonstrator projects where new ambitious power electronic systems or sub-systems are developed and realised by leading European Competence Centres. This article describes results of the Demonstrator Programme 'Power Supplies with Ultra-High Power Density'.
Prof. J. W. Kolar, Electronic Systems Laboratory at the Federal Institute of Technology (ETH) Zurich, Switzerland

The power density of power electronic converters has roughly doubled every ten years since 1970. Propelling this trajectory has been the increase of converter switching frequencies, by a factor of 10 every decade, due to the continuous advancement of power semiconductor device technology. The continual development of power electronic converters is characterised by the requirements for higher efficiency, lower volume, lower weight and lower production costs. Power density is one Figure of Merit that indicates the improvement in the power electronic technology (Figure 1).

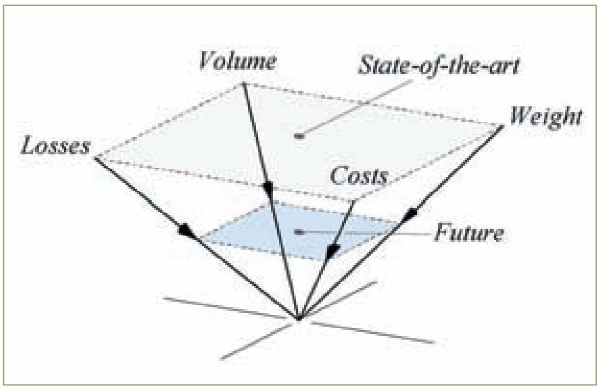


Figure 1: Driving forces for power electronics development

The trend has been for a large increase in the power density over the last few decades and covers the complete cross-section of applications and converter types. The trend line, in the figure below, for industrial systems is differentiated from research only systems, since typically, ten years is needed for the full introduction of a new concept into industry. Based on today's technology there are power density barriers (marked in Figure 2) that could limit the future increases in power density.

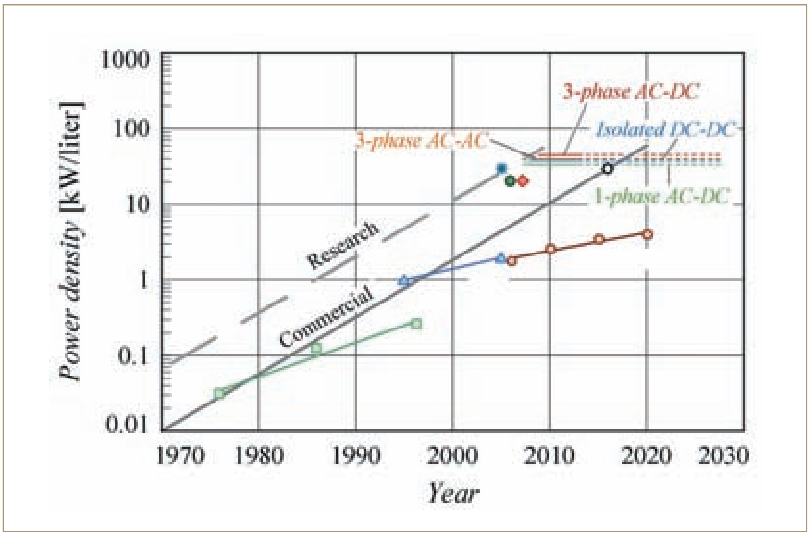


Figure 2: Power density trends of commercial and research systems and density barriers

ETH Zurich has been striving to push towards the power density barriers for both AC/DC and DC/DC converters. Only through considering the complete system, in terms of topologies, semiconductors, modulation, thermal, magnetics and packaging has it become possible to reach power densities of 10kW/litre (164W/in^3). Two demonstrators have been constructed to prove the advanced concepts.

Three-phase 10kW unity power factor PWM rectifier

The three-phase rectifier (Figure 3) is based on a three-switch, three-level Vienna Rectifier topology. It is designed to operate over a wide line-to-line input voltage range of 160 to 480VRMS, with a nominal input voltage of 400VRMS, output DC voltage of 800V and nominal power output of 10kW. The high power density is achieved by increasing the switching frequency to 400kHz, which results in low volume EMI filters and boost inductors, while still maintaining a high efficiency over 95%. To minimise the switching losses, a combination of a CoolMOS and SiC diodes are used in a custom power module. Semiconductor device cooling is provided by a water cooler, although it is possible to achieve a similar power density using an optimised forced air cooled heatsink. The rectifier is fully digitally controlled using an Analog Devices DSP.

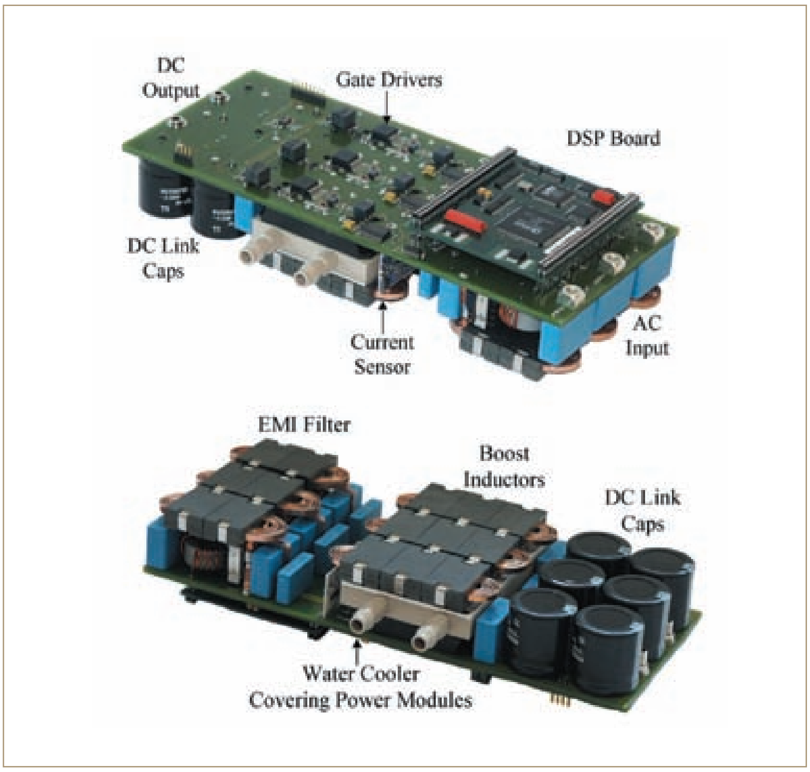
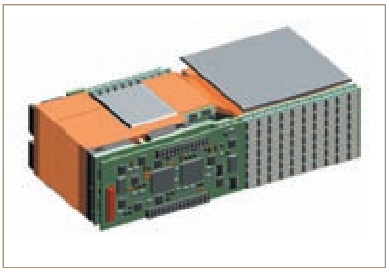


Figure 3: 40 kHz, 10kW/litre, 10kW, water-cooled Vienna Rectifier with dimensions of 250 x 100 x 45mm

5kW isolated DC/DC converter

This high power density, 5kW DC/DC converter (Figure 4) is based on a series-parallel resonant converter topology. ETH Zurich has developed an optimisation procedure that considers the switching frequency, semiconductor and passive losses, and thermal performance in order to maximise the power density. The optimal operating switching frequency of the converter is in the range of 100kHz. For improving the thermal management a non-standard construction technique is used in which heat transfer components extract the heat from the transformer and conduct it to a second heatsink where it is dissipated. A high pressure fan is mounted between the copper semiconductors and transformer heatsinks. Ceramic capacitors are used for the high voltage and low output voltage bus capacitors in order to reduce the volume. Furthermore, the converter is fully digitally controlled using a TI DSP and Lattice FPGA. The predicted efficiency is approximately 96%.

Figure 4: 3D CAD drawing of 10kW/litre, 5kW DC/DC converter



System Integration in Industrial Drives

The main goal of the ECPE Demonstrator Program 'Industrial Drives – System Integration' is to significantly reduce the converter size of an industrial drive for an asynchronous machine compared to state-of-the-art commercial units. The best power density on the market for inverters in the power range of concern (~2kW) is about 1kW/l. Thereby, the development of the key technologies in the project is focused on compact design, manufacturability and costs. **Prof. J. A. Ferreira, Electrical Power Processing research group (EPP), Delft University of Technology, The Netherlands**

Refinement of the currently employed construction and system integration methods might lead to some incremental improvement in the power density, but in order to increase the power density a few folds, novel and unconventional approaches are required. It is envisaged in this project that this goal can be achieved by pursuing the two concepts hybrid integration of power electronics and advanced thermal management. The demonstrator program is currently in its last phase, where the final demonstrator is being designed and built.

Integrated power modules

Benefits of integration in power electronics are manifold: it is a means to achieve compact products, reduce the number of construction parts in an assembly and thus, decrease the total cost, increase reliability by reducing the number of interconnections in the assembly etc. Since a typical power electronic assembly contains a large diversity of components, monolithic integration in the way that it revolutionised microelectronics is not feasible due to fundamental, manufacturing and economic limits. Therefore hybrid integration is an option of choice.

The converter is broken down into sub-circuits based on power level and heat density and each sub-circuit is manufactured in suitable technology. These sub-circuits are referred to as Integrated Power Electronic Modules (IPEMs). In this project, the converter is broken down into three IPEMs.

The Ceramic IPEM has a planar profile and makes use of the established power module technology base and contains the high heat density semiconductor power devices assembled on a ceramic DBC substrate. State-of-the-art power module packaging technologies from the industry partners (such as EasyPack by Infineon and MiniSkiiP by Semikron) that allow for small footprint, low profile IPEM necessary for achieving a high power density are used. Furthermore, SiC diodes are used as the freewheeling diodes in the inverter in order to reduce losses (a loss reduction of 30% has been achieved compared to Si devices).

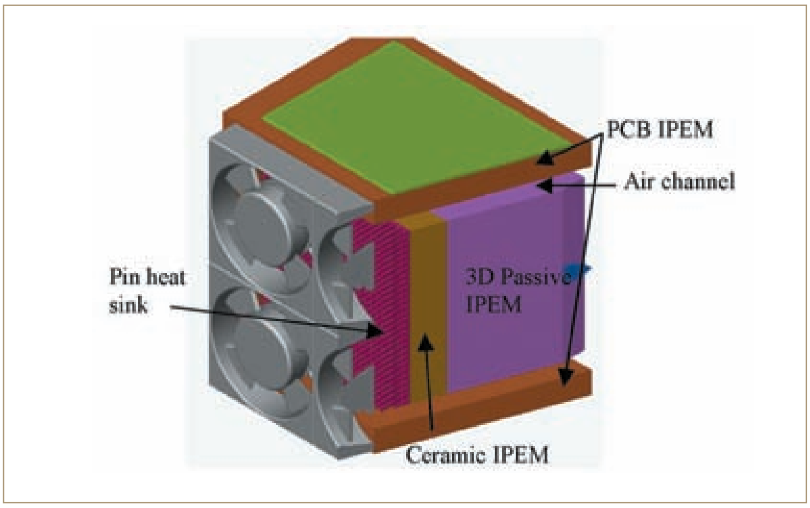
The planar PCB IPEM contains the auxiliary power supply, the electronic control circuitry and the gate drive circuitry assembled on a printed circuit board using PCB integration technologies for miniaturisation and low profile.

The 3D passive IPEM contains the large passive components of the converter such as the low pass filter and EMI filter. Due to the requirements for energy density, which implies volume, this IPEM makes use of the third dimension. Compared to the previous two IPEMs that use state-of-the-art technologies, this IPEM needed new integration concepts and is one of the main focuses of the project. The key technology utilised in this project is electromagnetic integration of passives, namely electromagnetic integration in electrolytic capacitor technology. A total reduction of the passive components volume of 40% compared to the benchmark converter is achieved by using this integration technology.

Advanced thermal management

Based on a review performed in the initial stages of the project, the volume occupied by heatsinks and air in commercial units exceeds 50% of the total volume. A different thermal management approach is needed to achieve a significantly higher power density, while keeping the components operating in their allowed temperature range. The approach taken in this project is based on the concept referred to as integrated converter housing (I-housing) which is an aluminium casing that contains the three IPEMs, is forced air cooled using a fan and serves as a heat collector and a heatsink for the three IPEMs. The overall shape and the texture/profiling of the surfaces is to be designed so that the heat is removed in a

Figure 1: **3D layout of the integrated drive converter**



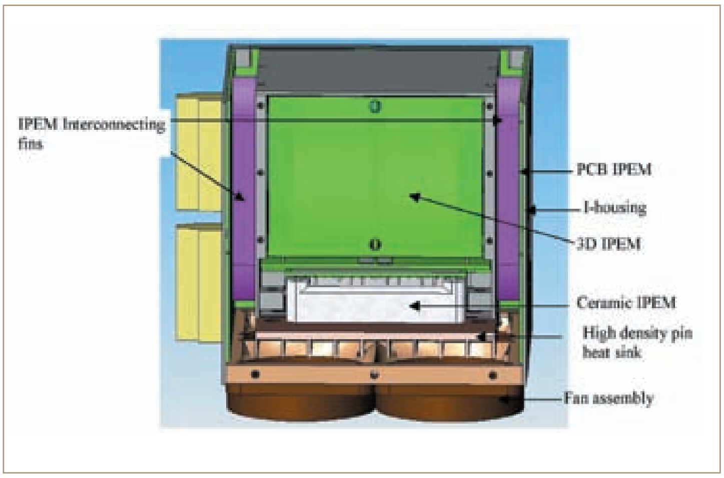


Figure 2: Complete assembly of the integrated drive converter

way that the components of the IPEMs will operate at their desired temperatures.

A number of I-housing concepts, differing in shape and profile of the I-housing as well as the type of air flow, were investigated. The concepts were evaluated on the basis of the heat removal effectiveness, shape complexity and ease of manufacturability. The first step in determining the concepts viability was an experimental approach, since a purely analytical approach was too time-consuming due to complex geometries and complex air-flow. Thermal mock-up structures of two concepts were built and the heat transfer was simulated by means of power resistors excited with the amount of heat predicted to be dissipated in each IPEM. Both were proven feasible with the maximum temperature rise under the full load excitation below 50°C, which means that with the maximum ambient temperature of 50°C the components still operate below their maximum allowed temperatures.

The concept referred to as the Turbine concept is chosen to be pursued further due to its simpler shape and manufacturability. In the next phase, a detailed thermodynamic and thermal modelling was performed, which resulted in a complete I-housing design. Experimental evaluation showed a good correlation between the designed and measured values of temperature rise. Figure 1 shows the cross-section of the system and the prototype of the I-housing.

Ease of assembly in manufacturing is of great importance for any new technology demonstrator or product as this significantly influences the cost and therefore the chances of the demonstrator becoming a successful product on the market. Each of the three modules, the Ceramic IPEM, the 3D IPEM and PCB IPEM are self-standing units that are plugged into each other to make the system. The electrical interconnections between the IPEMs are based on PCB connectors of different types and shapes. This allows for a simple plug-in principle assembly of the system. Figure 2 shows the cross section of the complete assembly, with the three IPEMs, I-housing and interconnecting structures.

Future vision and scope

The goals of this program are to lay the ground work of a new generation of technology that will give the European power electronics industry a competitive edge by introducing a new system integration and thermal management approach that allows for achieving very high power densities in air cooled systems, a few folds higher than that of the state-of-the-art products on the market. The approach is not limited to industrial drives and can be applied to any power converter in a few kW power range. Secondly, by filling the existing gap of integration technologies for hybrid integration of power electronic circuits, in particular technologies for integration of large passive components. By using the ECPE network, special technologies are being developed that can be used in industrial drives and also other applications. Thirdly, by developing an integrated design methodology that takes into account electrical, thermal and spatial issues of a power converter.

Only in this way, the ever-increasing demands for compact, efficient and reliable power converters can be successfully integrated into the system.

System Integrated Drive for Hybrid Traction in Automotive

The integration of the power electronic inverter with an electrical machine in the automotive powertrain is in the focus of the ECPE automotive Demonstrator Programme where the existing cooling circuit from the internal combustion engine is also used for the direct liquid cooling of the power electronics. The mechatronic integration of motor and power electronics leads to an ultra-high power density of 75kVA/l for the inverter. The high temperature of the cooling medium of up to 115°C in combination with this high power density poses a unique challenge. **Martin März, Fraunhofer Institute of Integrated Systems and Device Technology (IISB), Erlangen, Germany**

An optimised thermal design is necessary to master this thermal challenge. All temperature-sensitive components, passives and semiconductors, have to be thermally connected to the cooling system which provides a sufficient cooling capacity although working on a very high temperature level. On the module level, the optimised thermal design has to provide a homogeneous distribution of the chip temperature of the power semiconductors.

Figure 1: **Electric drive with the power electronics, both integrated into the clutch-box screwed at the gear-box**

Towards an integrated inverter drive

For the latest generation hybrid drive there was a strong request for a solution that completely fits into the existing drive train of a passenger car. The clutch-box was designated as the housing, in which an electrical drive unit with a mechanical output power of 50kW and a maximum torque of 220Nm had to be integrated together with the complete inverter. But the conical, tuba-shaped housing with internal studs and ribs considerably complicated the integration challenges.

The basic internal arrangement of the components is shown in Figure 1. A permanent magnet excited synchronous machine (PM machine) provides a very high power density and a high efficiency even in the low speed range. By using a whole-coiled winding (single teeth coils), the winding overhang could be greatly reduced, resulting in an increased active motor length. The torque disadvantage, caused by the conical housing and the thereby restricted motor diameter, could be equalized this way. The electrical circuitry of the motor windings corresponds to that of a classical three-phase machine. Thus, only three power interconnections between motor and inverter are necessary. Multifunctional winding interconnections prevent a heat transfer out of the hot windings into the power electronics.

In order to achieve an optimum usage of the available package volume, a ring-shaped DC-link capacitor has been developed in cooperation with EPCOS AG. This capacitor provides a capacitance of 500µF (450V). Its concentric, nearly coaxial terminals form the DC-link bus-bar and allows for a very low parasitic DC-link. The ripple current rating of this capacitor is several hundred amperes and thus far beyond the actual ripple current load. The self-heating, caused by the inverter ripple current, is therefore negligible. However, in order to protect the capacitor against the high ambient temperature of up to 140°C, it is thermally coupled to the cooling jacket.

Thermally stressed power modules

As can be seen from Figure 2, three half-bridge power modules are placed at the periphery of the water cooling jacket that surrounds the whole electric machine. The remaining sections at the periphery are used for the control board, the current sensors and the EMC filter. Since the system is also intended as a test platform for different power module designs, special attention has been put on a modular and assembly friendly construction.

Special attention has been paid to an optimised thermal design of the power modules. The inverter drive is inserted in the existing coolant cycle of the ICE. The available coolant flow is about 8 litre/min and the maximum allowable total pressure drop 200mbar. An optimisation of the back-side structure of the modules is necessary in order to minimise the thermal resistance between the power semiconductors and the coolant, but not to exceed the maximum allowable coolant pressure drop. The cooling efficiency of a finger-structure varies with its geometry - namely the finger thickness, shape, height and surface roughness - as well as the spacing and arrangement of the fingers. An important issue in this context is that the parameters of the coolant, especially the viscosity of the water-glycol mixture, greatly vary along with the temperature.

The realised power modules showed a specific thermal resistance junction-coolant ($R_{th,jc}$) of 0,45Kcm^2/W at a coolant flow rate of 8 litre/min and a pressure drop of 60mbar, both of which were close to the predictions from simulation. With respect to the coolant flow, the three power modules are connected in series, thus the specification of a total pressure drop of 200 mbar was achieved.

The prototype was built on a machined Cu base plate. This, of course, is no solution for series production, partly because of cost issues, but mainly because of reliability issues of the DCB to base-plate solder joint. Due to the passive temperature cycles to be sustained (approximately 11.000 cycles with a mean temperature swing of 100K), an AlSiC base plate could be a choice to reduce the thermal mismatch between base-plate and DCB substrate to an acceptable low level at a small expense of thermal efficiency.

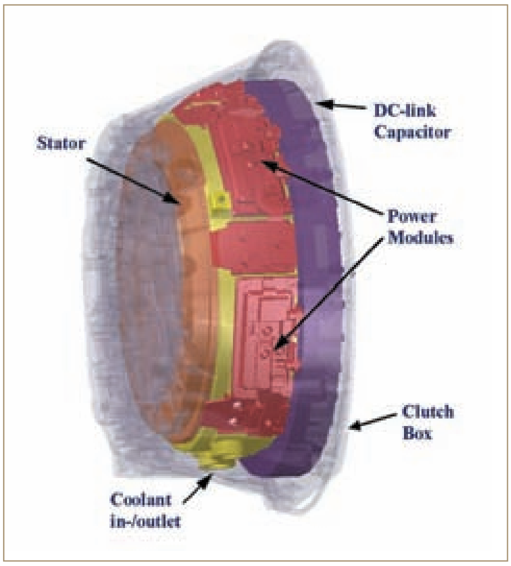


Figure 2: X-ray view on the second generation inverter drive (50kW), integrated into the clutch-box

Outlook

Simultaneous engineering (electrical, mechanical, thermal) is an imperative prerequisite for a mechatronic integration of power electronics. Consistently following this way, an inverter drive for hybrid traction could be integrated into the clutch-box of a passenger car, i.e. in an environment and package volume that had been considered as absolutely useless for high power electronics so far. 3D integration, new components and sophisticated thermal management solutions opened the way to a system with unique power density. The next steps aim on a further optimisation of the system reliability, manufacturability, and modularity.

Film Capacitors for DC Link Applications

The DC link of advanced frequency converters requires well adapted capacitor solutions. Traditionally, the segment of small and medium power converters <100kW has been exclusively served with electrolytic capacitors, while polypropylene film capacitors have been used for the high power range. Due to the improvements achieved in the performance of basic material, as well as optimised metallisation and winding processes, nowadays film capacitors are a possible alternative for a broad range of DC link circuits in the voltage range of 350 to >6500VDC. **Jens Luthin, Product Marketing Manager Power Capacitors, EPCOS AG, Munich, Germany**

Decisive for the decision to either use electrolytic or film capacitors are factors like maximum DC link voltage, applicable current and frequency spectrum, ambient temperature, requirements for low inductance, low losses and compact design. While electrolytic capacitors possess low specific costs per capacity, film capacitors represent an attractive option if high currents are applied and long life expectancies are decisive. Besides classical industrial converter applications, film capacitor solutions are designed for medical devices and will find a broad application field in automotive electrical and hybrid electrical propulsion. Figure 1 gives an overview of power capacitor concepts.

Film capacitor technology

Film capacitors for DC link applications today are manufactured based on windings made of bipolar oriented polypropylene film (BOPP). The recent development of ultra thin films (<3.5µm) is opening the voltage range down to 350VDC. These kinds of films are typically metallised with aluminium (Al) or a zinc- aluminium (Zn/Al) alloy. A fundamental safety mechanism all metallised film capacitors are possessing is the so-called self-healing property (Figure 2).

Impurities of the PP film are annealed by

Figure 1: Overview of power capacitor concepts

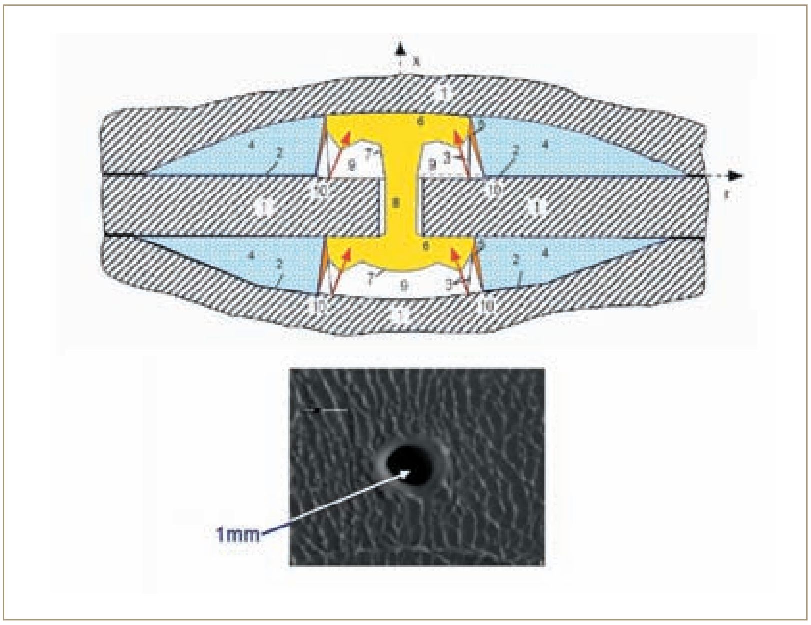


Figure 2: **Self-healing property of film capacitors**

creating small arcs resulting in little holes in the PP film surrounded by insulating conglomeration of residual material. Special metallisation profiles might be generated depending on the load conditions specified for the capacitor solution desired. The metallisation can be done with a segmentation pattern, including a fuse structure to master heavy load conditions. The connection of the electrodes is provided by a zinc layer sprayed onto the winding contact areas. Based on the desired mechanical concept and the electrical parameters required, three basic types of windings are available: round, flat or stacked (Figure 3).

Besides the sensitive process conditions of winding and drying, the basic means of impregnation used for film capacitors are gas, oil and different types of resin. Overload conditions are usually creating an extended number of self-healing events and lead to the creation of gases. Fully encapsulated film capacitors can be equipped with over-pressure disconnector constructions or pressure switches to improve safety conditions. Overload scenarios applied to film capacitors mostly lead to an open circuit condition, while electrolytic capacitors mainly fail by causing a short circuit.

Specification range of film capacitors

The specification range for DC link film capacitors is a multi-dimensional room (Figure 4). Besides nominal voltage, capacity and maximum current several other parameters may influence the design of a film capacitor. During the specification of a film capacitor, it is advisable to closely investigate the true voltage load including ripple voltage, repetitive voltage peaks, as well as rarely occurring surge voltages.

The voltage is determined by the thickness of the PP film used for the capacitor. State of the art design rules consider a field strength of approximately 150 to 250V/µm film thickness depending on the further design parameters. Design target is to implement the minimum film thickness that can be tolerated in order to reduce space consumption and optimise the utilisation of material.

Specifying the capacity (C), it is worthwhile to consider the minimum allowable capacity value needed for the application, including the decrease of capacity throughout the lifetime of the component ($\Delta C/C$). Compared to electrolytic capacitors which usually lose about 10% of the initial capacity or more, film capacitors are typically designed not to loose more than 3% capacity during the lifetime expected. IEC conform type tests using certain conditions for accelerated aging are applied to simulate and confirm the drop of capacity. In advanced and fast switching IGBT converters especially, the DC link current frequency spectrum must be well considered during the layout of the film capacitor. The main switching frequency, as well as high frequency fractions in the frequency spectrum, can cause strong heating of the capacitor, and if the switching frequency of the system is too close to the resonant frequency of the DC link, an internal busbar set-up is needed to avoid overloading the component. The aging process of a film capacitor can be approximated by a first order chemical reaction and may be described with an Arrhenius equation [1]. Basically, the electrical field strength combined with the temperature of the capacitor are the driving factors for the aging process. While the field strength is

Figure 3: **Different types of polypropylene windings**

defined through the voltage applied on a certain film thickness, the temperature inside the capacitor results from the losses (mainly dielectric and ohmic losses) [2] causing a temperature rise in excess to the ambient temperature.

It is very important not to exceed the hot spot temperature of the capacitor which would lead to structural changes in the PP film material which are reducing the expected lifetime. For standard designs, the typical hot spot temperature is around 85°C. If film capacitors shall be subjected to very high ambient temperatures, derating rules for the field strength need to be applied. In order to achieve highly integrated converter designs with advanced power density especially in automotive the requested temperature range goes up to about 125°C [3]. Besides the temperature aspects, the geometric requirements including the terminal configuration can also be a design driving factor deciding over the choice of winding style [4].

Classification of electrolytic compared to film capacitors

As a main factor for the classification of DC link capacitors, the voltage level is decisive. The voltage level below 450VDC is clearly dominated by electrolytic capacitors and is expected to remain the domain of this technology for long. The exception are the automotive applications (starting at approximately 350VDC) requiring the most compact designs with ultra low inductance, high current capability and operation temperatures significantly >100° C.

To achieve more than 500VDC, electrolytic capacitors need to be put in series connection, whereas film capacitors can be adjusted to different voltage levels by using small steps of different PP film thicknesses. Today, film capacitors for classical DC link applications are used up to 6500VDC. Below 100µF standard DC film capacitors in stacked or wound technology are used. Up to 900VDC, we talk about the low power range of power capacitors and around 20mF can be realised in one individual capacitor housing. Components with >900 VDC are usually called high power capacitors [5].

A further classifying aspect can be the terminal design. Electrolytic capacitors are equipped with snap in or screw terminals while film capacitors may be designed with a broad variety of alternative options. Small size film capacitors posses soldering pins or fast in connectors. On the high power side screw terminals are used. Apart from the standard options, special low power capacitors are designed with various flat blade type connectors, internal thread solutions up to busbar like configurations. In that range, the need for ultra-low inductance is apparent.

A third classifying aspect can be the encapsulation concept. Electrolytic capacitors usually have phenol resin top discs, aluminium cases and a shrinkage tube surface. Some film capacitor designs use a similar case concept with nylon or epoxy top discs. Typically, film capacitors are manufactured with plastic boxes or cases and furthermore with aluminium, steel or fibre enforced plastic housing. Depending on the impregnation concept, one facet of a capacitor can only be covered with a polyurethane or epoxy resin surface. In some applications with limited load, environments with low humidity, or in case the component is implemented in a sealed housing, it is favourable to use a non encapsulated naked capacitor design (Figure 1).

Application related design aspects

Several aspects to be considered for the design of DC link capacitors have already been named. From the application side, various additional factors should be considered. The load conditions for the capacitor can be either of a very dynamic nature; for example to be found in cranes, elevators or industrial equipment with cyclic load; or the operation is more like a constant, slowly or seldom changing load, for example in propulsion, transportation or pump drives. In case an energy reserve is needed to adjust to a dynamic changing load requirement, the DC link must be installed with more capacity. In high temperature environments, a compromise between the loss characteristics and the life expectancy should be found to optimise the capacitor design to the true specification conditions.

Critical temperature profiles and load cycles have to be closely analysed and even simulated to ensure the suitability of certain capacitor solutions. Life expectancy is the central element of capacitor design. The layout has to be designed to achieve the expected lifetime under the specified conditions. In power electronics capacitors are usually designed to remain unchanged throughout the entire life of the end device. In some applications, the maintenance and exchange of components can lead to enormous extra costs. For example converter driven wind power systems used in an off shore wind park should have the lowest achievable maintenance level and it is advisable to avoid the exchange of capacitors. To adjust to a critical very low volume availability, capacitor concepts using stacked or flat windings must be evaluated.

Based on the philosophy of the converter design, either modular set-ups or system integration has to be considered. In cases where the DC link of a certain converter design shall be adapted, for example, to different power stages, discrete capacity steps should be defined, being able to build up various DC link banks with a limited number of capacitor units. In cases where a project will use only one capacity rating, an integrable, optimised and technically well adjusted single capacitor layout is the preferable solution.

Quality is a major concern in various applications. Comparing the costs of different DC link capacitor options, not only the price per capacity should be considered, but a system cost analysis

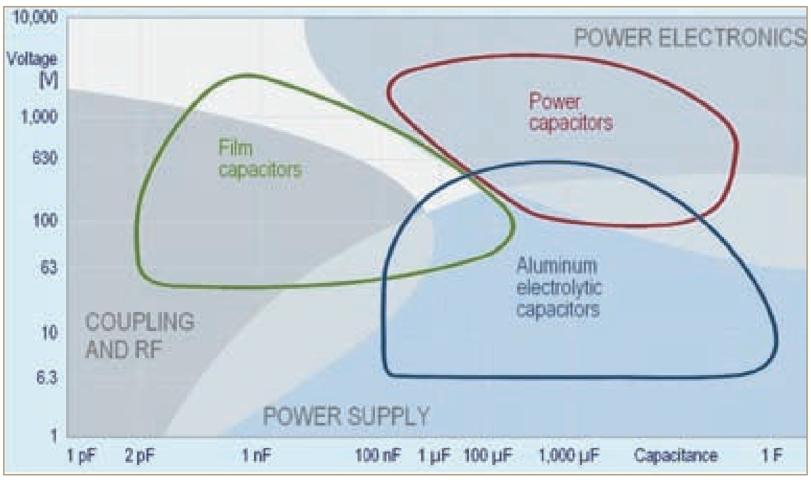


Figure 4: Specification range of power capacitors

should be made, including mounting requirements and labour time, busbar configuration, secondary materials and expectable maintenance requirements. Quality is a major concern in many aspects. In case an x-ray system equipped with a poor DC link capacitor solution is failing during operation, the consequences might be of very critical nature. If high power converters are built, solid encapsulation and safety mechanisms are advisable, as malfunction under overload conditions can have severe consequences considering the high energy stored in the component. Lifetime requirements shall be well adapted to the true requirement. The mission profile of an automobile converter is revealing that maximum capacitor load is only applied for a very limited amount of time. The overall life cycle of a car only seldom exceeds 12000 hours and the average current load is rather low. Consequently, highly integrated capacitor designs used at elevated temperatures can be designed close to the technological limits [4].

Guideline for the choice of DC link capacitors

In the past, certain specification ranges were determined by specific technologies and standard components. With the wider use of variable frequency converters, the increasing number of different concepts and technological approaches, and also the range of different Power Capacitors used is opening up.

In general, the fast development in converter technology, mainly driven by improvements of the semiconductors and the advanced software solutions, is impacting the business of capacitors as passive components. While, some years back, the specific capacity in a DC Link solution was about 100µF/kW, nowadays modern converter designs can work with 10µF/kW and in research projects it has been shown that this value can be further significantly reduced. For the capacitor manufacturer, that trend is accompanied with the request of integration and higher specific load.

It is not easy to apply a simple schematic in order to decide which kind of capacitor technology is the optimum one for a specific DC Link solution, but some easy rules can be applied: In many cases, the design driving factor for a DC link bank with electrolytic capacitors is the current. If it is possible to reduce the capacity to 30 to 50% and to apply an integration concept with optimised electrical and mechanical connection, a power capacitor could be an adequate solution at a comparable cost base. Decisive for the future success of power capacitors in small and medium size DC link circuits will also be the further progress in reduction of series resistance (R_s) and consequently losses. Typical R_s values are 1,5mΩ but with heavy duty designs today 0,5mΩ can be reached. Besides the rough general rule, many individual factors such as extra long life expectancy, exceptional mechanical requirements, elimination of hazardous materials, ultra low inductance, system integration, weight reduction could also influence the decision as to which capacitor technology should be implemented.

Conclusion

The DC Link application will gain importance for capacitor manufacturers. The market of converters and drives is growing in the magnitude of 10% per year and the demand for DC link solutions is increasing related to that, but it must be considered that the specific capacity inside the DC Link circuits is shrinking. At the same time, the technical requirements for the capacitors are increasing and the different applications require a highly diversified range of solutions. Consequently, adequate attention has to be allocated to the different specification ranges to properly adapt the progress in electrolytic and film capacitor development to the needs of the market coming up with innovative solutions.

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New 4500V SPT+ HiPak Modules

The next generation 4.5kV HV-HiPak IGBT modules employ the newly developed SPT+ IGBT and diode technologies. The new devices have significantly lower conduction and switching losses, while exhibiting higher SOA capability when compared to the previous generation modules. **A. Kopta, M. Rahimo, U. Schlapbach, ABB Switzerland Ltd, Semiconductors**

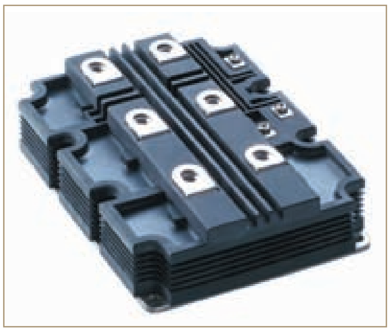


Figure 1: The 4.5kV HV-HiPak module comprising the newly developed SPT+ chip-set

Development trends in power electronic systems continue to demand power devices with continuously improving characteristics in terms of reduced losses, increased ruggedness and improved controllability. Following the introduction of the new generation of 1700 and 3300V SPT+ IGBT HiPak range, ABB now introduces the next generation 4.5kV HV-HiPak IGBT modules employing SPT+ IGBTs and diodes.

The SPT+ IGBT platform has been designed to substantially reduce the total semiconductor losses, while increasing the turn-off ruggedness above that of the current SPT technology. The SPT+ platform exploits an enhanced carrier profile through planar cell optimisation, which is compatible with ABB's rugged cell design.

The new cell technology significantly increases the plasma concentration at the emitter, which reduces the on-state voltage drop without affecting the turn-off losses. Due to the combination of the enhanced cell design and the soft-punch-through (SPT) buffer concept, the SPT+ IGBT technology enables ABB to establish a new technology-curve benchmark for the 4500V voltage class. The on-state losses of the new 4.5kV IGBT exhibit an approximately 30% reduction, as compared to the standard SPT device, while keeping the same Eoff value. The new 4.5kV HV-HiPak modules will provide high voltage system designers with enhanced current ratings and simplified cooling, while further enhancing IGBT and diode robustness.

4.5kV HV-HiPak module design

The 4.5kV HV-HiPak module (Figure 1) is an industry-standard housing with the popular 190 x 140mm footprint. It uses Aluminium Silicon Carbide (AlSiC) base-plate material for excellent thermal cycling capability as required in traction applications and Aluminium Nitride (AlN) isolation for low thermal resistance. The HV-HiPak version utilized for the 4.5kV voltage class is designed with an isolation capability of 10.2kVRMS.

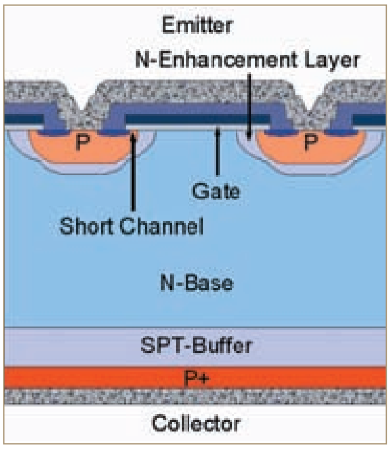
To achieve the high reliability required by its targeted applications (e.g. traction), the HV-HiPak module has been optimised for operation in harsh environments. This has been accomplished by designing the 4.5kV SPT+ chips to have smooth switching characteristics and rugged performance, qualities that are essential in the high-inductance environments of high voltage power electronic systems. The internal wiring and layout of the module were optimised to minimise oscillations and current imbalances between the chips. Finally, the whole design was qualified by standard reliability tests including HTRB (High Temperature Reverse Bias), HTGB (High Temperature Gate Bias), THB (Temperature Humidity Bias 85°C/85% relative humidity), APC (Active Power Cycling) and TC (Temperature Cycling).

4.5kV SPT+ chip-set technology

The SPT+ IGBT platform was developed with the goal of substantially reducing on-state losses while maintaining low switching losses, smooth switching behaviour and high turn-off ruggedness of the standard SPT (Soft-Punch-Through) IGBTs. This was achieved by combining an improved planar cell design with the already well-optimised vertical designed utilised in SPT technology (Figure 2).

The planar SPT+ technology employs an N-enhancement layer surrounding the P-well in the IGBT cell. The N-layer improves the carrier concentration on the cathode side of the IGBT, thus lowering the on-state voltage drop ($V_{CE,on}$) without significantly increasing the turn-off losses. A further reduction of $V_{CE,on}$ was achieved by reducing the channel resistance by shortening the length of the MOS-channel. By optimising the shape of the N-enhancement layer, the turn-off ruggedness (RBSOA) of the SPT+ cell could be increased even beyond the level of the standard SPT cell. In this way, SPT+ technology not only offers significantly lower losses, but also an increased SOA capability.

Figure 2: SPT+ IGBT technology



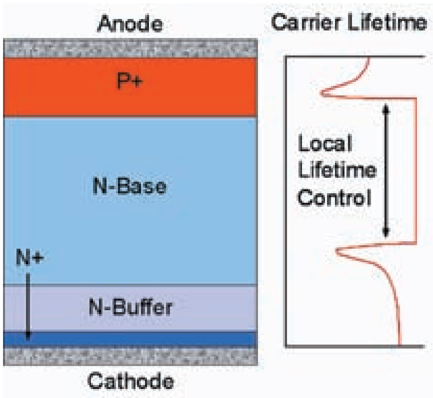
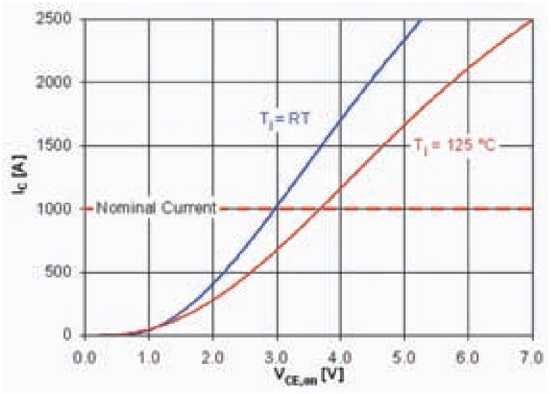
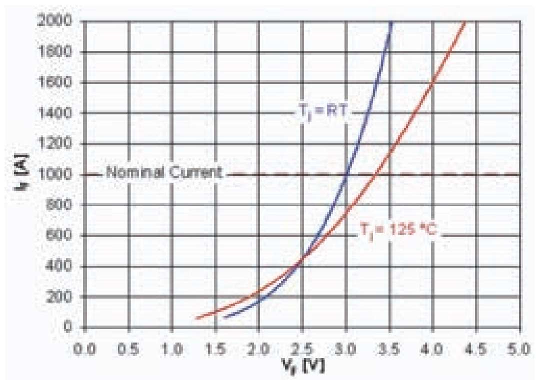


Figure 3: SPT+ diode technology





Figures 4a and 4b: Forward characteristics of a) 4.5kV SPT+ IGBT (upper) and b) 4.5kV SPT⁺ diode

Figure 3 shows a cross-section of the SPT⁺ diode. The new technology utilises a double local lifetime-control technique to optimise the shape of the stored electron-hole plasma. Due to the improved plasma distribution, the overall losses could be reduced, while maintaining the soft recovery characteristics of the standard SPT diode technology.

On the anode side, the SPT⁺ diode employs the same design as used in the standard SPT technology, utilising a high-doped P⁺-emitter. The anode emitter efficiency is adjusted using a first He⁺⁺ peak placed inside the P⁺-diffusion. In order to control the plasma concentration in the

N-base region and on the cathode side of the diode, a second He++ peak, implanted deeply into the N-base from the cathode side is used. In this way, a double local lifetime profile as shown in Figure 3 is achieved. With this approach, no additional homogenous lifetime control in the N-base is necessary. Due to the improved shape of the stored electron-hole plasma, a better trade-off between total diode losses and recovery softness was achieved.

4.5kV/1000A HV-HiPak electrical performance

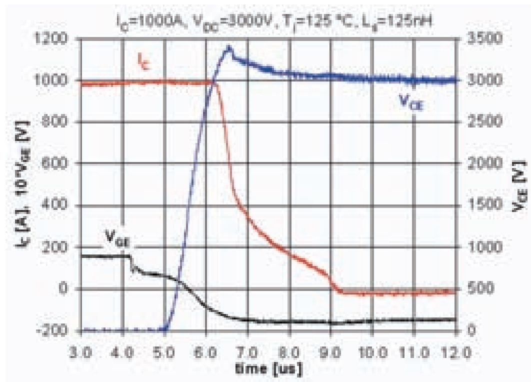
To verify the performance of the 4.5kV SPT⁺ chips and the HiPak module, extensive measurements were carried out. The nominal rated current of the 4.5kV HiPak module is 1000A, which corresponds to a current density of 50A/cm^2 for the IGBT and 100A/cm^2 for the diode. For dynamic measurements, the nominal DC-link voltage was 3000V, while SOA and softness measurements were carried out at 3600V.

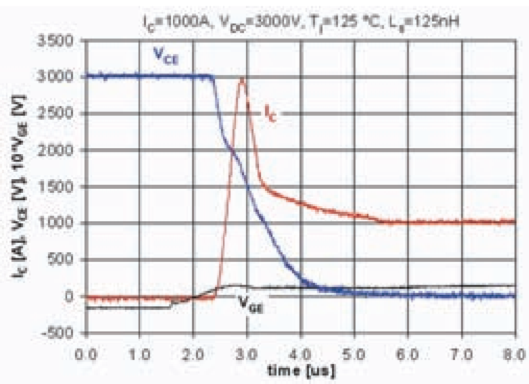
Static characteristics

In Figure 4a, the on-state curves of the 4.5kV SPT⁺ IGBT can be seen. The typical on-state voltage drop ($V_{CE,on}$) at nominal current and Tj=125°C is 3.65V. The SPT⁺ IGBT shows a positive temperature coefficient of $V_{CE,on}$, starting already at low currents, which enables a good current sharing capability between the individual chips in the module. In Figure 4b, the on-state characteristics of the 4.5kV SPT⁺ diode are shown. Due to advanced plasma shaping utilising a double He⁺⁺ irradiation, the diode has a strong positive temperature coefficient of V_F already well below the diode's typical on-state voltage drop of 3.4V.

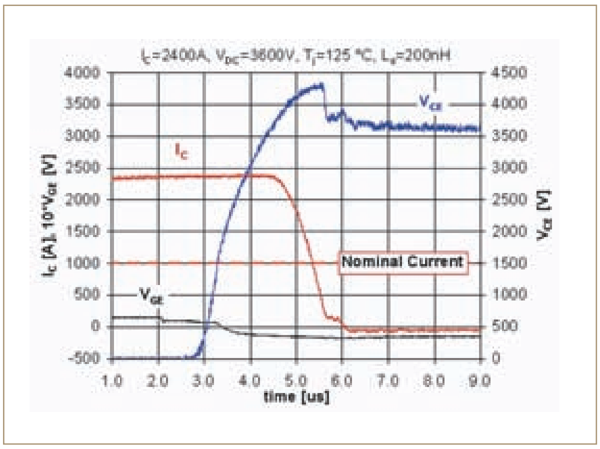
Switching characteristics

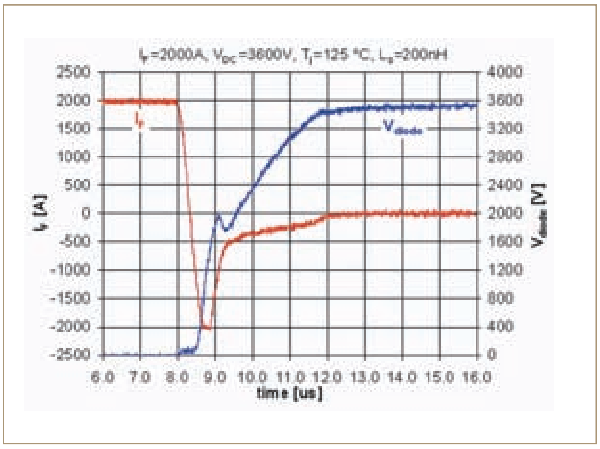
The switching characteristics are shown in Figure 5. Figure 5a shows the turn-off waveforms of the 4.5kV HiPak module measured under nominal conditions at 1000A and 3000V. Under these conditions, the fully integrated turn-off losses are 4.6J. The extremely rugged SPT⁺ cell enables the IGBT to be switched using a small gate-resistor,





Figures 5a and 5b: Turn-on switching characteristics of a) 4.5kV SPT⁺ IGBT turn-off under nominal conditions measured on module level with E_{off} = 4.6J (upper) and b) turn-on under nominal conditions (E_{on} = 3.6J)





Figures 6a and 6b: Turn-off switching characteristics of a) 4.5kV SPT+ IGBT turn-off under SOA conditions measured on module level (upper) and b) 4.5kV SPT+ diode reverse recovery under SOA conditions

resulting in a fast voltage rise, which reduces the turn-off losses. In the test shown, the module was switched off using an $R_{g.off}$ of 2.7Ω, which results in a voltage rise of 3100V/µs. The optimised N-base region combined with the Soft-Punch-Through (SPT) buffer allows the collector current to decay smoothly, ensuring soft turn-off behaviour without any disturbing voltage peaks or oscillations even at high DC-link voltages and stray inductances.

Figure 5b shows the turn-on waveforms under nominal conditions. The low input capacitance of the planar SPT+ cell allows a fast drop of the IGBT voltage during the turn-on transient. Thanks to high ruggedness and soft recovery behaviour, the diode can be switched with a high di_F/dt, which significantly reduces the IGBT turn-on losses. This, combined with the low-loss SPT+ diode brings the turn-on switching losses down to a typical value of 3.6J, while the diode recovery losses are 2.4J.

Turn-off and reverse recovery ruggedness

One of the advantages of the new 4.5kV SPT+ IGBT is its extremely high turn-off ruggedness, setting a new benchmark for this voltage class. Figure 6a shows a turn-off waveform at module level, where a current of 2400A was switched against a DC-link voltage of 3600V. The test was conducted with a gate resistance of 2.7W, without using any clamps or snubbers. This harsh test has been implemented as the standard SOA test made during the final outgoing production-level module testing. This is to ensure high quality and reliability of all shipped 4.5kV HiPak modules. Figure 6b shows the corresponding production level test of the diode reverse recovery SOA.

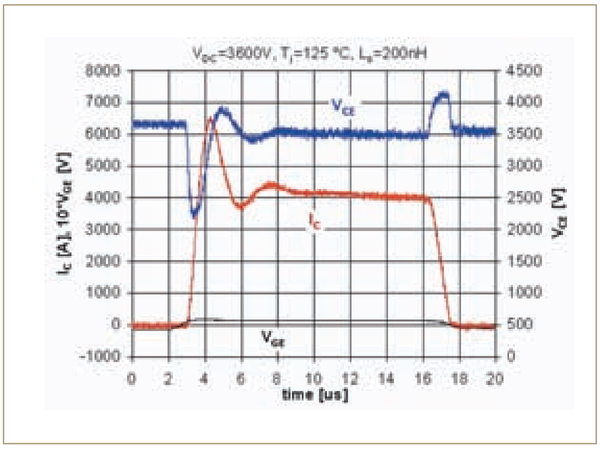


Figure 7: 4.5kV SPT+ IGBT short-circuit characteristics

Short-Circuit SOA

The short circuit waveforms of the 4.5kV HV-HiPak module can be seen in Figure 7. The IGBT was designed to withstand a short circuit at VGE=15.0V for all DC-link voltages up to 3600V and junction temperatures between –40 and 125°C.

The results presented demonstrate that by using the lower losses and higher SOA of the new 4.5kV HV-HiPak modules in future inverters, a 10 to 20% increase in total output current is predicted from simulations as shown in Figure 8. The new 4.5kV SPT+ technology will ultimately allow 1200A rated modules to be realised. The new modules will provide high voltage system designers with enhanced current ratings, simplified cooling and higher SOA margins.

The developmental product described in this article is intended for release in 2008. A full description of this product including surge current capability will also be presented at the PCIM Conference 2007.

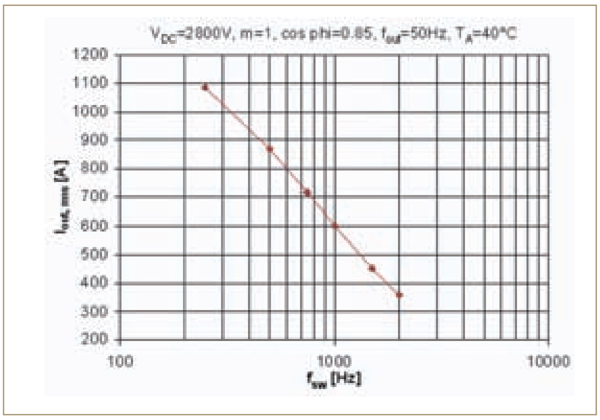


Figure 8: 4.5kV HV-HiPak module output current as a function of the switching frequency

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Simple Sensorless BLDC Motor Control

Controlling a BLDC motor without any position sensors is the subject of many researches and implementations. The scope of this article is to describe an original control method and to propose a simple, low cost implementation which is based on a general purpose microcontroller and an external ADC. It is shown that the third harmonic can easily be sensed and processed to control the rotation of the motor. This method offers both superior dynamic performance and easy implementation. **Thomas Hargé, Applications Engineer Data Conversion Division Europe, National Semiconductor, Fürstenfeldbruck, Germany**

A brushless (BLDC) motor behaves like a DC motor. The only missing parts are the brushes which are used to commute the current at certain positions of the rotor. Well, for BLDC motors this has to be done electronically. When and how? When the rotor reaches certain angular positions, just like with brushes. Figure 1 shows the currents (i_a, i_b and i_c) fed into each phases for the six position segments.

There are two ways to detect these positions; the first one uses position sensors like Hall-effect sensors or rotary encoders. The second estimates the position by measuring the back EMF, the back Electro Motive Force (BEMF). This voltage is generated in the windings by the rotation of the permanent magnet. In other words, it's a dynamo effect!

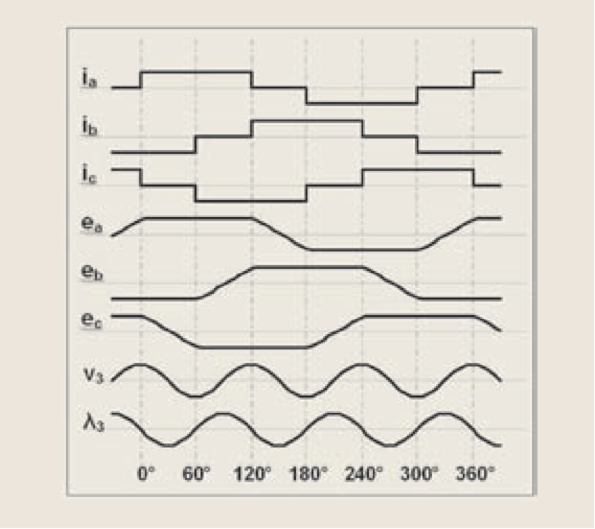


Figure 1: BLDC waveforms

Using the back EMF intelligently

Figure 1 shows this theoretical BEMF (e_a, e_b and e_c) of each phase of the motor. The trapezoidal shape is the result of the arrangements of the magnets and windings in the motor. A common way to control the motor is to detect the zero-crossing of the BEMF. It is based on the following principle; at each instant, the current is flowing from V_{DD} to ground via two windings. The third winding is open and no current is flowing through it. However, this winding is reacting to the rotating flux of the permanent magnet and a BEMF voltage is generated. When the BEMF of the non energised phase crosses the mid-voltage line, it means that the flux of the rotor's permanent magnet in the open winding changes direction - so the position of the rotor at this exact time is known. Unfortunately, it is not the position where the inverter should change the phase commutation. It is either 30° too early or 30° too late! This is generally compensated for by adding a delay in the loop which considerably degrades the dynamic performance of the motor.

Although it is based on the same physical phenomena, the third harmonic method is slightly different. It was shown that it can achieve better efficiency and, because it doesn't involve any delays, better dynamic performance. The whole theory is based on the following statement from Julio C. Moreira: "In a symmetrical three-phase Y-connected motor with trapezoidal air gap flux distribution, the sum of the three stator phase voltage results in the elimination of all poly-phase components (fundamental and all characteristics harmonics like 5th, 7th, etc.); only the zero sequence components are left from the summation. The resulting sum is dominated by the third harmonic component".

In other words, it states that the sum of the three terminals voltages is close to the third harmonic (V_3) of the BEMF. This is mostly due to the geometric arrangements of the windings in the motors that shape the magnetic flux into a trapezoidal waveform. The nice thing is that this signal is a nice clean sine-wave that run three times faster than the motor (see Figure 1). Moreover, the flux is linked to the 3rd Harmonic. Actually it can be estimated by integrating the voltage V_3. Figure 1 shows on the same time axis, the BEMF of one phase (e_a), the third harmonic (V_3) and the third harmonic of the flux (λ_3) compared to the commutation time, or the time when the windings should be commuted. It shows then pretty clearly that each time the flux is crossing the zero line, a commutation should be done. So it is possible to control the motor with only the third harmonic voltage!

Figure 2 shows the system implemented in 5 blocks. The first one acquires the third harmonic; the second one is integrating it and then estimates the flux of the motor. From this point, a zero crossing function determines the needed commutation time and triggers the state machine which controls the inverter - and the loop is closed!

A simple and cost-effective implementation

Although simple and cost-effective sound good together, these two adjectives rarely apply simultaneously. If a chip

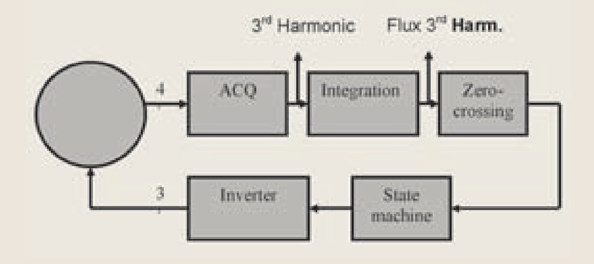


Figure 2: **Control block diagram**

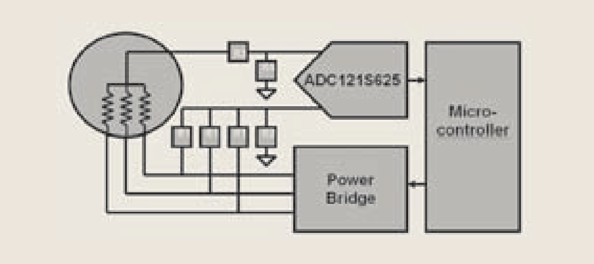


Figure 3: **Circuit schematics**

integrates all the needed functions, then the implementation is simple, but this rarely fits with the definition of cheap. On the other hand, discrete solutions could be cheaper, but usually at the price of multitudes of analogue circuits and discrete components.

Figure 3 shows the proposed schematic. The analogue front end is quite simple. It is a matter of summing the three phase voltages and subtracting the mid point voltage of the motor. The summation is easily implemented by three resistors (R1) tied together. A fourth resistor (R2) is used to reduce the amplitude of the resultant signal and to adapt it to the input level of the ADC. In the configuration of Figure 4, the summation point voltage (V_{sum}) is equal to (R2/(R1+3R2))(V_1 + V_2 + V_3). The other signal, the mid point of the motor (V_{mid}) is also scaled down by a voltage divider formed by R3 and R4.

Figure 4 shows the two real signals to acquire (V_{mid} and V_{sum}), as well as their difference (V_3). The first idea that comes in mind is to use an amplifier. Although this solution would have the benefit of bringing a low impedance signal to the ADC, to remove the common mode voltage and adjust the gain, it would also have some drawbacks. Among them are the offset and gain errors, the low frequency noise, and depending on the amplifier, some bandwidth limitations (see the PWM section for the effects of bandwidth limitation). It would also be possible to acquire directly both V_{sum} and V_{mid} with a two-channel ADC. This would cause a phase error due to different acquisition times from one channel to the other. There is another solution that makes sense: the use of an ADC with full differential inputs. For many users, differential inputs are reserved for high speed communications where the complete signal path is treated as differential. The signals need to be exactly symmetric, centered on a mid value and at the end it is not so simple and easy to use!

Well practically, a differential input is defined as follow: The result of the conversion is the difference of V_{in+} and V_{in-} compared to the ADC reference. Each input voltage must be within to the input range, and the difference must belong to $-V_{ref}$ to $+V_{ref}$. As long as these rules are respected, any common mode voltage will be eliminated. This is exactly what is needed in this case! It is also good to notice that changing the reference voltage results in changing the gain of the system. For this case a reference voltage of 750mV will ensure that the conversion result is close to the full scale of the ADC.

Once converted, the signal is transferred to the microcontroller through a standard SPI (Serial Peripheral Interface) interface. It is then up to the microcontroller to integrate the signal with an accumulator. An algorithm is needed to remove any offset created by un-matched resistors in the voltage dividers. Detecting the zero crossing is then a fairly simple task that requires no extra function or feature in the microcontroller. The control of the power stage is handled via six GPIOs (General Purpose Input/Output) that dictate the state of the inverter. A gate driving circuit is also needed to drive the power transistors.

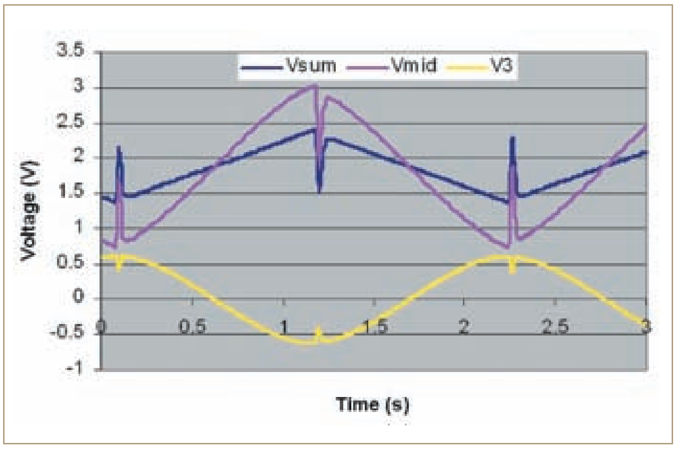
In Figure 4, it can be seen that the real measurements differ from the theory with a 'glitch' at the top and bottom of the V_3 signal. This glitch is generated by the commutation of the power stage and so it cannot interfere in the measurement of the commutation time.

At this stage, the expert in motor control may say: "Wait a minute, your system sounds nice, but what about the control of the motor, how can I change its speed?" The motor controlled like described is only the equivalent of a DC motor fed with DC voltage! The speed of the motor depends on its supply voltage and the torque which is applied to it. So we need to find an efficient way to vary the motor voltage with a fixed supply voltage. Let's use PWM (Pulse Width Modulation) and apply this to the low side power transistors. Will this work? Not directly!

Under PWM driving, the V_{sum} signal will bounce between its normal value and the rail, while V_{mid} will also bounce, but not with the same amplitude. It was demonstrated and measured that the amplitude of the notches in the third harmonic signal (V_3) are 1/6 of the DC bus voltage. The solution used here is to synchronise the ADC with the PWM signals. Thanks to the very high input bandwidth of the ADC121S625, it is possible to feed the modulated signal directly into the ADC and to demodulate it by synchronising the acquisition with the PWM signal. If the bandwidth is too low, the square signal is filtered out and the acquisition would be biased by a significant error!

The ADC121S625 has no input to trigger the acquisition, but due to its SAR (Successive Approximation Register) architecture the trigger can easily be controlled by the SPI hardware of the microcontroller. The sampling of the signal occurs on the second rising edge of the clock after the CS (Chip Select) signal was set low, so the programmer knows exactly the amount of time between the send command of the SPI and the real acquisition.

Figure 4: **Measurement of V_{sum}, V_{mid} and V_3**

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Zetex Semiconductors has introduced the first low side self-protecting MOSFETs in a SOT223 package to provide diagnostic feedback via a separate status pin. The facility aims to further increase the reliability of high-voltage automotive and industrial systems.

The latest additions to the IntelliFET product range, the ZXMS6002G and ZXMS6003G are 60V rated N-channel devices particularly well-suited to switch loads subjected to high in-rush currents, such as lamps, motors and solenoids. Providing protection against over-temperature, over-current and over-voltage fault conditions, the ZXMS6002G provides analog indication of normal, current limiting and thermal shutdown modes without the need for additional external components. The availability of such diagnostics enables the development of intelligent automatic fault responses. The ZXMS6002/3 devices have been specifically designed to be tolerant of 60V load-dump transients in automotive applications and unprotected 28V rail transients in industrial systems. Both can be driven directly from 5V microcontroller outputs.

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Shielded Coil Form Range includes SM Versions

Lodestone Pacific has expanded its Tunable, Shielded Coil Forms product line to include Surface Mount versions of its most popular sizes. They now offer outstanding performance and quality in an SMD package. In addition, several Toko and Cambion equivalents have been added to the product line.

The company has been an industry favorite for over 30 years. If you need to make variable inductors, transformers or oscillators with high Q, very good temperature stability, and long-term durability, these products are said to be the finest available. Especially well suited for Military, Aerospace, and Medical applications, these durable assemblies have been used 'from fishfinder to sidewinder', where stability and performance is critical.

Lodestone Pacific has been a key supplier to both ITT and General Dynamics for the SINCGARS (Single Channel Ground and Airborne Radio System) military radio for over 15 years and continues to create innovative versions of these popular products for the next generation of JTARS. (Joint Tactical Radio System) programs. Lodestone Pacific can also create custom or modified versions of these products to excel in almost any performance application.

The company has also introduced a new Engineering Sample Kit (Engineering Kit #2) to provide engineers and designers with as many samples needed to evaluate and prototype a new project.

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Shielded Current Transformers

VACUUMSCHMELZE presents a new family of current transformers designed specifically for use in IEC-standard electronic electricity meters. The new transformers also comply with an array of national standards for meters that are tamper-proof against manipulation attempts using external magnetic fields.

Electronic electricity meters are increasing in popularity all over the world. Free from mechanical wear and tear, they permit remote reading, are network-enabled and support multiple tariffs. However, rising energy costs are accompanied by an increase in the number of cases where meters of this type are subjected to manipulation. External magnetic fields can be used to influence the measuring circuit and reduce the power consumption registered. Although obtaining large permanent magnets with high magnetic induction was extremely difficult in the past, today such magnets are relatively widespread and easy to find. Integrated shielding has the benefit that shielding of the entire meter - a complex procedure involving high space requirements – is unnecessary, thus enabling compact meters to be designed that feature high immunity against external magnetic fields.

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New CSTBT IGBT IPMs

Mitsubishi Electric complements its portfolio of Intelligent Power Modules (IPM) with the L-series featuring CSTBT (Carrier Stored Trench Gate Bipolar Transistor) IGBT chips. The typical saturation voltage is specified at 1.5V for 600V and 1.9V for 1200V devices at junction temperature of 125°C. By including the newly-developed monolithically integrated driver IC the power dissipation of the control unit is decreased. A built-in circuit optimises the EMI performance by controlling the speed during the turn-on.

Another new feature is the miniaturised package, which is 32% smaller than previous generation. Furthermore, the rated current of the braking part was increased. The IPM L-Series is available for output currents in the range of 50A to 600A at a blocking voltage of 600V and for currents from 25A to 450A at 1200V (including 7-in-1 modules rated 300A/600V and 150A/1200V).

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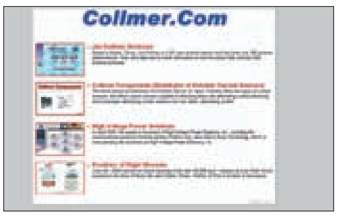

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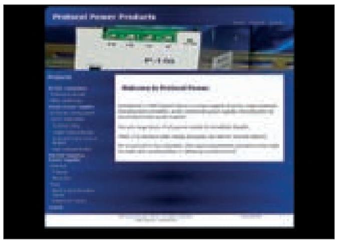

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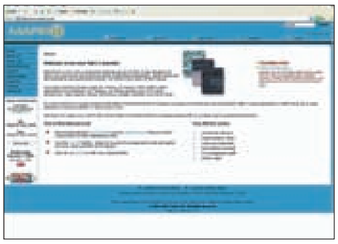

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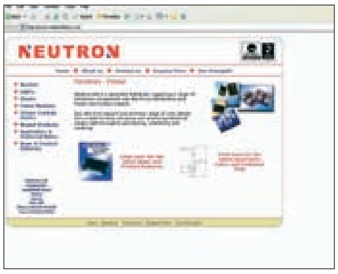

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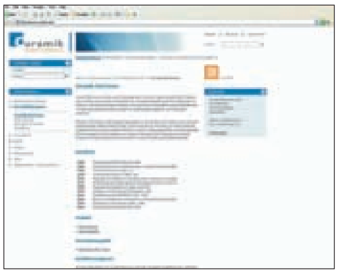

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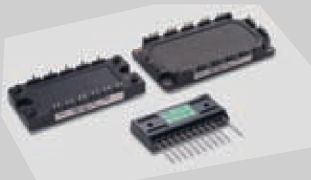

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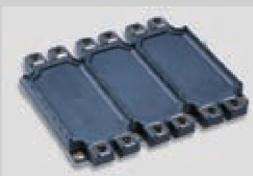

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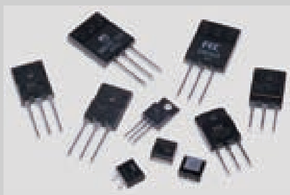

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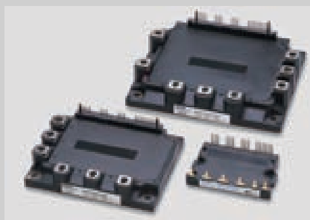

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