POWER ELECTRONICS EUROPE

ISSUE 8 – NOV/DEC 2009

IGBT DRIVERS

Advantages of Advanced Active Clamping

THE EUROPEAN JOURNAL FOR POWER ELECTRONICS AND TECHNOLOGY

Also inside this issue

Opinion | Market News | Electric Vehicles | Automotive Power | Power Semiconductors | Power Module Test | Products | Website Locator

Power Density – next Level of Energy efficiency

A complete solution for Commercial, Agriculture and Construction Vehicles

As electrification in Commercial, Agriculture and Construction Vehicles becomes a standard, Infineon offers a complete IGBT module portfolio dedicated to these applications. The reliability requirements of power switches in terms of extreme vibration and extended cycling capabilities have been practically implemented. Due to new joining techniques, optimum thermal impedance and longer lifetime for the power modules have been achieved.

Key features:

- 600V, 1200V and 1700V IGBT modules in full/half-bridge and chopper configurations for both AC and switched reluctance electric machines
- 2 times higher power cycling capability at tvjop=150°C operating temperature e.g. 2 mio@ΔTj=40K
- up to 5 times higher thermal cycling compared to industrial modules
- extended lifetime compared to industry standard modules

[www.infineon.com/cav]

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

Production Editor Elaine Gladwell
Tel: +44 (0)1322 380057

Editorial/Advertisement Administration
Clare Jackson
Tel: +44 (0)1732 886495
Fax: +44 (0)1732 886149

Circulation Manager Anne Backers
Tel: +44 (0)208 647 3133
Fax: +44 (0)208 669 8013

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

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

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

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

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

Publisher Ian Atkinson
Tel: +44 (0)1732 886495
Fax: +44 (0)1732 886149
Email: IATKINSONTMI@aol.com
www.power-mag.com

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Editorial information should be sent to The Editor, **Power Electronics Europe**, PO Box 340131, 80098 Munich, Germany.

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CONCEPT
INTELLIGENT POWER ELECTRONICS

SCALE-2 Low Cost Driver Cores

The two new cores **2SC0108T** and **2SC0435T** are re-defining the standard for 1700V IGBT drivers. Thanks to consistent integration, a sensational price/performance ratio has been achieved. For as little as **US$20 respectively US$30** for 10k items, drivers are available that offer not only reliable separation and UL-compliant design but also the precise timing that is characteristic of the SCALE-2 driver family. Typical applications are wind power and solar installations, industrial drives as well as power supply equipment of all kinds.

Features

- Safe isolation to IEC 60664-1
- 8A or 35A gate drive current
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- ±8ns jitter
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- Power supply monitoring
- Short-circuit protection
- Embedded paralleling capability
- Superior EMC (dv/dt > 75V/ns)

CT-Concept Technologie AG, Renferstrasse 15, CH-2504 Biel, Switzerland, Phone +41-32-344 47 47

www.IGBT-Driver.com

Power for a Greener World

Global semiconductor revenue is set to contract by 16.5% in 2009, according to market researcher iSuppli. This follows a 5.4% decrease in 2008. However, revenue is expected to rise by 10.6% in the fourth quarter of 2009, compared to the same period in 2008. The fourth quarter will mark the first quarter in 2009 that revenue has risen, compared to the same period a year earlier.

This has helped Munich-based Infineon Technologies, not only the market leader in power semiconductors, but also active in automotive, communication, and security markets. Fiscal year 2009 was also an extremely challenging year for Infineon. Revenues were Euro 3,027 million, down 22% compared to the 2008 fiscal year, reflecting the strong contraction of the semiconductor market in all of the company's target markets such as automotive, industrial or communication. But the company is hopful of turning the situation back round. "The first half of the year saw a sharp fall in revenues. Fortunately, the downslide did not continue in the second half of the year. As the global economy recovered slightly, so our business picked up in the second half of fiscal year 2009 – even though it was still distinctly below the previous year's level. A major milestone was the refinancing of the bonds falling due in the 2010 financial year. We successfully placed new convertible bonds which were several times over-subscribed. Yet the greatest contribution by far to the refinancing was made by the capital increase. Almost all the subscription rights were exercised, which we regard as a strong sign of confidence", CEO Peter Bauer said. "Many didn't believe we'd be able to master the task. To cap the dubious honour of penny stock status, we were thrown out of the German stock index DAX. We took decisive action and turned the tables. The refinancing was successfully resolved. The share price increased more than ten-fold from its all-time low of 35 euro cents in April to today. We returned to the DAX in record time".

I think that's good news, not only to have a world-class semiconductor manufacturer located in Europe, but also to have the leading power semiconductor and power module manufacturer here. This will hopefully lead to a more rapid adoption of green technologies not only in products, but also in society and political actions. Energy efficiency and renewable energy sources are also becoming more and more important for Infineon. Energy efficiency remains a perennial hot topic, despite the economic crisis. The prospect of a long-term rise in energy prices is making consumers rethink. Semiconductors are indispensable for implementing these energy policy objectives. Particularly high growth rates are to be expected in renewable energies, but also in more efficient motor drives. In the automotive industry, the call for fuel-efficient and low-emission vehicles is also spurring a growth in long-term demand for semiconductors. Automakers are working on raising the efficiency of internal combustion engines to meet CO_2 targets. High-performance semiconductors are needed for the purpose. The same applies to alternative drive technologies in hybrid and electric vehicles, whose importance is gaining in momentum.

Recently Europe's largest research project to advance the development of electric vehicles has been launched under the leadership of Infineon Technologies. The E3Car (Energy Efficient Electrical Car) project brings together 33 automotive companies, key suppliers, and research facilities from a total of eleven countries to collaborate on boosting the efficiency of electrically-driven vehicles by more than one-third. The goal of the project is to extend the travel range of electric vehicles by up to 35%, with a battery unit of the same size as a current baseline. Alternatively, this means battery units up to 35% lighter and more compact, while providing the same travel range as a current baseline, will be possible. As part of the E3Car project and by the end of 2011, Europe is targeting research on innovative electronic components that play a key role in electric vehicle power consumption. Research will focus primarily on semiconductor components and power modules that control the supply and distribution of power in electric vehicles. These are used in the powertrain, which consumes most of the car's energy, as well as in power converters and Lithium-ion batteries.

Also, a new trade fair for electric mobility has been established in Munich and was running successful (195 exhibitors, 10,600 visitors) from October 13-15. "With ECarTec, we are establishing a new Expo in Germany's trade fair landscape that exclusively deals with the topic of electric mobility. An event of this kind is unique", said Robert Metzger, organiser of eCarTec. At this fair, German utility RWE presented charging stations equipped with already standardised plugs for charging purposes, one of the prerequisites for broader internationa acceptance for e-vehicles.

These efforts will hopefully help the European automotive industry defending their leading position, since other countries in Far East are planning to catch up rapidly. In April 2009, Chinese officials announced their plan to make China the world's largest producer of electric cars. The Renault-Nissan Alliance will work with China's Ministry of Industry and Information Technology (MITI) to help set up battery recharging networks throughout the city of Wuhan, the pilot city in the country's electrical vehicle pilot program.

Though this market is in its infancy it is forecast to grow rapidly, first with hybrid electric vehicles. The following pages will illustrate the potential market and related technologies from various angles.

Enjoy reading!

Achim Scharf
PEE Editor

ABB Semiconductors receives IRIS Certificate

ABB has been awarded a certificate of compliance with International Railway Industry Standards (IRIS Certification) for its high power semiconductor components. The certification was awarded to ABB Switzerland Ltd, Semiconductors; ABB's manufacturing plant for power semiconductor components such as IGBT's, IGCTs, Thyristors and Diodes used in the railway industry for rolling stock, as well as for track side supply. The certificate follows four earlier awards for ABB'ts traction transformers and medium-voltage products, surge arresters, converters and motors.

ABB Switzerland Ltd, Semiconductors has a long history as supplier of high power semiconductors for the railway industry. For many years, locomotives, high speed trains and mass transit have been equipped with Thyristors, Diodes, GTOs and IGBTs. ABB's Thyristors, Diodes and IGCTs have been installed in track side supply units with ratings up to 400MW. With the on-going investments to increase the production capacities at its factory in Lenzburg and by investments in development of new products ABB Switzerland Ltd, Semiconductors will continue to be a reliable partner for supply of high power semiconductors for the railway industry.

IRIS is an internationally recognised standard for the evaluation of railway industry management systems. Developed by UNIFE, the Independent Association of European Railway Industries, and supported by system integrators, equipment manufacturers and operators like Bombardier Transportation, Siemens Transportation System, Alstom Transport, Ansaldo Breda, SBB and SNCF, it is an extension of ISO9001 and ISO/TS 16949 with a strong focus on project management and continuous improvement.

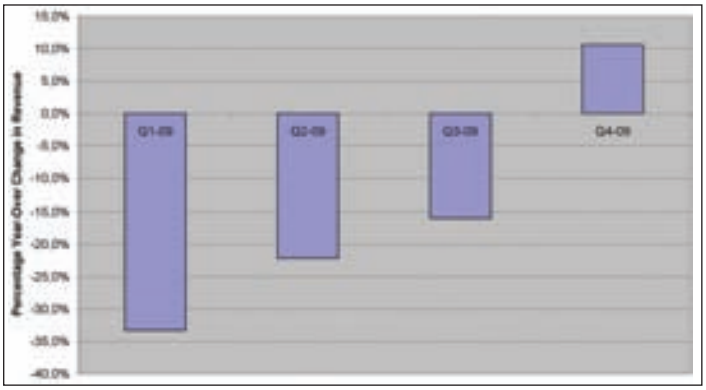
www.abb.com/semiconductors

Semiconductor Recovery Commences

Although global semiconductor revenue is set to decline in 2009 for the second consecutive year, quarterly year-over-year growth is expected to finally return to the market in the fourth quarter, signaling the start of the industry recovery, according to market rearcher iSuppli.

Global semiconductor revenue is set to contract by 16.5% in 2009. This follows a 5.4% decrease in 2008. However, revenue is expected to rise by 10.6% in the fourth quarter of 2009 compared to the same period in 2008. The fourth quarter will mark the first quarter in 2009 that revenue has risen compared to the same period a year earlier. "The seeds of the current recovery were sown in the second quarter", commeted analyst Dale Ford. "During that period, manufacturers began to report positive book-to-bill ratios, indicating future revenue growth. This was followed by another sequential increase in revenue in the third quarter. Meanwhile, semiconductor inventories returned to more normal levels in the third quarter after chip suppliers shed stockpiles. They did this by slashing costs dramatically in order to reduce unsold inventory they'd been carrying since the beginning of 2009".

While these signs are encouraging, and sequential quarterly increases in revenue will continue into 2010, this growth will not be sufficient to lift semiconductor revenues back to pre-recessionary levels until the 2011-2012 time frame. The pattern of a weak first half of the year followed by a strong second won't be relegated to 2009 alone. iSuppli forecasts that the first two quarters of 2010 will see revenue that is slightly down compared to the fourth quarter of 2009, but the second half of the year will deliver a strong performance. This will result in 14% growth in global semiconductor revenue in 2010, ending the two-year losing streak. Subsequent years will see a return to single-digit percentage growth in the semiconductor industry as conditions stabilise.



iSuppli's forecast and estimate of year-over-year percentage semiconductor sales for all four quarters of 2009 Source: iSuppli

www.isuppli.com

Semikron Solution Centres Network expands to China

SEMIKRON's Peter Frey is proud to announce the opening of the Chinese Solution Centre focusing on the renewable energy market

Nuremberg-headquartered SEMIKRON expanded its global network of solution centres to Zhuhai, China. The new solution centre specialises in the design and manufacture of SEMISTACK power assemblies, for wind generators and solar power inverters in China. Chinese customers can now benefit from 'made in China' power assemblies with flexible and customized designs, local technical support, fast deliveries and competitive pricing.

"The solution centre in China is a milestone for the development of power solutions for the fast growing renewable energy market, a market which is of great importance globally, and also in China. Our customers receive custom-designed power assemblies with guaranteed German quality and competitive pricing made in China by a team of specialists", commented Peter Frey, General Manager at Semikron International. "Additionally, our customers benefit from faster delivery, shorter response time and direct technical support".

The expertise of the company's Solution Centres, one on each continent, is combined within the network. They unify their resources in purchasing, development and service. Mutual assistance is given to capitalise on skills in different fields with varied local requirements. Each centre has its own team of application engineers, whose expertise is guaranteed by a policy of knowledge sharing within the network. In addition, the qualification and testing policy guarantees the promised functionality of the delivered product. They supply power assemblies into industrial markets such as wind, solar and hydro power, motor drives and elevators, power supplies, process control and transport. SEMIKRON technology powers 57GW of installed wind power capacity. The global total wind power capacity installed is 122GW (Source: BTM Consult ApS, 2009).

www.semikron.com

Shade and Light in Drives Market

The worldwide industrial drives market was estimated to be worth approximately $16.5 billion in 2008, with more than 20 million drive units shipped during the year. According to the latest statistics supplied by IMS Research, revenue growth was substantial in 2008, with market revenues increasing by 12.6% over 2007 levels. In contrast, the market is expected to decline by more than 10% in 2009 as a result of the global economic downturn.

The total industrial drives market comprises 7 product types – compact AC, standard AC, premium AC, DC, medium voltage, servo, and stepper drives. Of these, premium drives and medium voltage drives had the greatest growth in 2008, increasing by more than 20% over 2007 levels. This is linked to rapid growth of the major industry sectors that use these drives, namely renewable energy, oil & gas, mining, and metals. This growth is also attributed to the shift in focus from low-end to high-performance products, specifically by automation giants ABB and Siemens. These premium product categories are also expected to outperform the total industrial drives market during the global recession. However, the markets for motion control products, such as servo and stepper drives, are expected to perform poorly during the downturn. These rely heavily on the semiconductor, robotics, machine tool, and printing industries, sectors that have been severely depressed by the recession. As a result, the servo drives market is predicted to contract by nearly 20% in terms of revenues in 2009, while the stepper drives market is forecast to decline by more than 8%.

"The EMEA region continues to be the leading consumer of industrial drives. Total drive revenues for EMEA were approximately $7 billion in 2008, accounting for more than 43% of the worldwide market. The region represents the largest geographic market for all 7 industrial drive types, but has a significantly greater proportion of sales into the higher-end product categories, accounting for more than 58% of 2008 global premium drive revenues", commented analyst Sarah Sultan. "After witnessing growth of 15% in 2008, the industrial drives market in the EMEA is projected to decline by 14% in 2009. The 2009 market contraction is expected to be more significant in the EMEA than in the Americas, but less severe than in Japan. The Asia Pacific drives market is the only regional market forecast to have positive growth in 2009. The positive outlook is attributed to continued economic expansion in China, where GDP is forecast to increase by nearly 9% this year, and the focus on energy conservation by the Chinese government, witnessed in both the recent stimulus package and the existing Top-1000 program, which targets a 20% reduction in Chinese industrial energy consumption over a five-year period".

Production data collected by IMS Research indicate that while EMEA has been the largest manufacturing location for industrial drives through 2007, Asia Pacific became the largest producer of drives in 2008 after continued increases in low-end product manufacturing in the region. The largest design center for drives has been Japan, although it is predicted that beginning in 2011 the EMEA region will overtake Japan as the largest design centre for industrial drives.

In contrast, Variable Speed Drives (VSD) in Home Appliances are set to double by 2013. Currently, appliances with VSD account for just 1 in 8 new appliances - mainly room air conditioners and washing machines. However, times are changing quickly. At the heart of the uptake of VSD are government labelling schemes to promote more energy efficient appliances. In October, the US Environmental Protection Agency announced it would be taking control over the popular Energy Star program and would introduce a new top-tier classification called 'Super Star' to create a more rigorous set of criteria for top performing appliances.

"While home appliance shipments have decreased globally, the use of electronics within them has not", commented analyst Jason dePreaux. "One of the main drivers of this trend has been the global emphasis on energy efficiency. Many countries continue to amend minimum performance standards and comparative labelling schemes in an effort to curb electricity consumption. For example, the EU is currently revamping its label of refrigerators despite the fact that it was updated a mere four years ago. The swiftness of appliance efficiency rulemaking means that future appliances must be smarter in the way they use power". In addition to increased efficiency, variable speed motor control, also appeal to MHA makers' desire for more reliable performance and quieter operation. Shipment growth of appliances with variable speed motor drives is forecast to grow rapidly over the next five years.

www.imsresearch.com

Real-Time Comparison of Power Designs

National Semiconductor's newly introduced WEBENCH Visualizer is a powerful comparison and selection tool that enables engineers to rapidly select an optimal power system design.

The Visualizer tool supports a variety of power supply topologies such as buck, boost, buck-boost, SEPIC and flyback. Several alternative circuit configurations are also available to address specific needs like fixed-frequency and constant-on-time architectures, as well as current-mode and voltage-mode control loops. With a power parts library from 110 manufacturers, designers can specify a wide range of parameters such as:

- **V_{IN} from 1 – 100V**
- **V_{OUT} from 0.6 – 300V**
- **Power up to 300W**
- **Efficiency up to 96%**
- **Frequency up to 3MHz**
- **Footprint from 14 by 14mm**

"With WEBENCH Visualizer, we enable analog experts to be superior business decision makers because we've given them all of the tools to produce the best possible design in the shortest time. We've also given non-power experts the ability to do extraordinary things with analog power designs", said Phil Gibson, National's VP of Technical Sales Tools. "The tool creates a graphical snapshot of options across multiple criteria, such as power efficiency, footprint and system bill of materials (BOM) cost. Drawing from 25 different switching power supply architectures and 21,000 components, engineers can navigate through billions of power supply design alternatives in seconds. Design criteria can be modified and the real-time effects observed, allowing for selection of the best DC/DC power supply based on the designers unique needs. So far, 200 thousand registered users, the majority of them located in Europe, have created more than one million DC/DC power supply designs using the WEBENCH toolset".

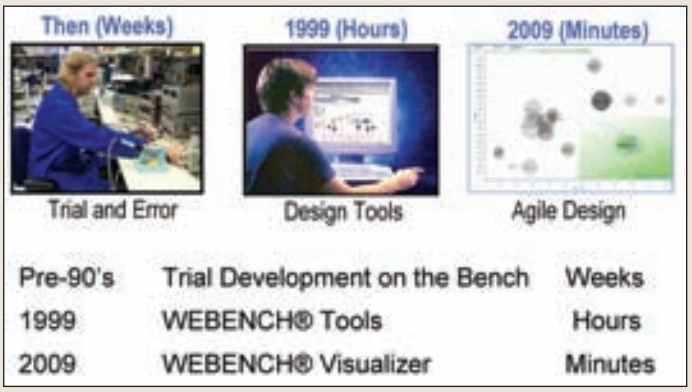
The Visualizer tool features an optimiser dial that enables engineers to 'dial-in' their preference for footprint, system BOM cost and power efficiency. The tool instantly creates 50 to 70 designs from 48 billion possible design options. It then highlights the smallest and most efficient designs, with one recommended as a starting point for further optimisation.

A second visualizer control panel allows engineers to adjust their design options for voltage, current and temperature. In seconds, an updated set of solutions appears, highlighting each design's topology, schematic, footprint, efficiency, operating values and BOM cost/count. The tool's interactive filter allows engineers to further fine-tune the power supply design to meet the target system's requirements.

Once a design is selected, the WEBENCH design environment offers the ability to further tune and optimise that design through additional component options and electrical and thermal simulation. With the 'Build It!' feature, National ships a custom power supply prototype kit within 24 hours.

The WEBENCH Visualizer tool is an extension of National's WEBENCH tools for LEDs and power design. These tools offer instant access to the latest simulation models, parametric data and package information, enabling designers to simultaneously compare the performance of multiple devices in multiple circuit requirements.

www.national.com/visualizer



Online tools such as Webench speed up the power electronics' design cycle
Source: National

Entry point for designing a power supply using WEBENCH Visualizer

PowerWise®

High Performance. Low Power.

Energy-Efficient LED Lighting Solutions

National's new low-side, constant-current LED driver offers integrated thermal control to increase system reliability. The thermal foldback feature of the PowerWise® LM3424 LED driver provides a more robust thermal design to extend the life of the LEDs, making it an ideal solution for a variety of indoor/outdoor lighting and automotive applications.

- ✔ Online design tools
- ✔ Evaluation boards
- ✔ Application notes

Thermal Management

Since thermal design greatly impacts the light output and lifetime of the LEDs, a well-designed thermal system is critical. The LM3424's thermal foldback feature eliminates the need for external thermal management circuitry, allowing for a more robust and reliable thermal system and extending the life of the LEDs.

Easy to Use

With National's WEBENCH® LED Designer online tool, designers can use the LM3424's thermal foldback feature to visualize the design's behavior at user-selected LED temperature breakpoints for easy and quick development of a thermal management system.

Flexible Design

National's LM3424 LED driver, with a wide input voltage range, can be easily configured in buck, boost, buck-boost, and SEPIC topologies with minimal adjustments. Driving a maximum of 18 LEDs in one string, the LM3424 gives designers flexibility while providing up to 96% efficiency and accurate current regulation with less heat and power dissipation.

national.com/led

National Semiconductor

Focusing on Automotive Power

California-based Linear Technology was not hit so much by the financial crisis in the years 2000 and 2008. The company has restructured itself and focuses more on industrial and automotive applications, as CEO Lothar Maier stated on a recent trip to Munich.

Fiscal 2009 was a very challenging year as we managed through difficult economic times while positioning ourselves for growth when the global recession ends. This kind of challenge enables us to distinguish ourselves. Managing through tough times begins with mitigating the impact of reduced sales on both profitability and cash flow from operations. Revenues for fiscal 2009 were $968.5 million. Revenue of $236 million for the first quarter of fiscal year 2010 increased $28 million or 14% compared to the previous quarter's revenue of $208 million and decreased $74 million or 24% from $310 million reported in the first quarter of fiscal year 2009. Net income of $60.7 million increased $9.3 million or 18% over the fourth quarter of fiscal year 2009 and decreased $41.6 million or 41% from the first quarter of fiscal year 2009.

The financial effects of the global recession are certainly not over and continue to impact many of our customers. Customer orders continue to call for short lead times and turns business, or bookings that are recorded and shipped during the quarter, remains at a high level. While there are some concerns that recent improvements in the overall marketplace are at least partially attributable to a replenishment of inventory stock, we continue to experience bookings improvement. Therefore, based on the strength of our positive book-to-bill ratio and the recovery we appear to be witnessing in automotive and industrial end-markets, we forecasting revenue growth for the second fiscal quarter in the range 2 to 5% over the first quarter.

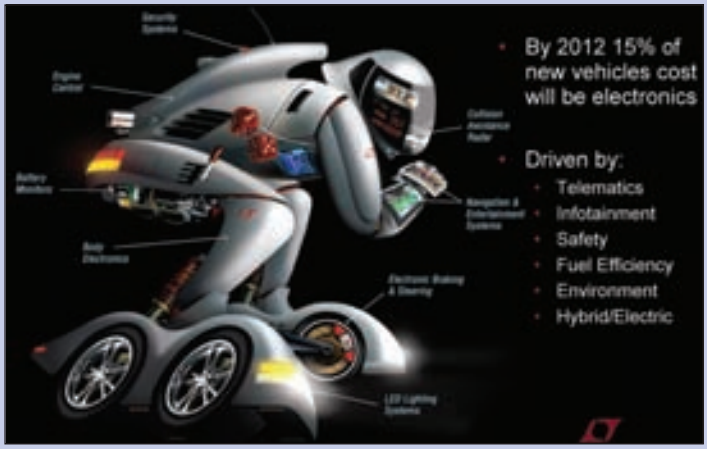
Managing through tough times required careful attention to our variable costs, particularly in the labour area. We reduced our workforce by approximately 10%. In addition, we implemented temporary weekly shutdowns, reduced profit sharing, temporary reductions in base pay, and other cost reductions in many non-labour expense categories. These savings were instrumental in achieving operating margins while maintaining our core of talented employees.

Innovation and technical support remain our most important objectives. Innovation is brought to bear in specific products and on broad industry trends. One such industry trend includes energy harvesting and energy efficiency, not only to achieve environmental objectives, but also to reduce energy costs. Lowering power consumption is an effective response to this trend. The company has introduced several power products that, among other features, deliver higher power while dissipating less heat, and provide high efficiency over a broad range of output currents. New parts designed to charge super-capacitors (energy storage devices) transfer energy from alternative energy sources such as solar, wind or vibration to activate circuitry in long-life remote and unattended applications.

The company continues to put effort into the automotive end-market. The electronic content in automobiles is increasing, particularly in hybrid and all-electric vehicles. During fiscal 2009, we introduced a battery monitoring circuit which has received early acclaim and broad interest (see PEE8-2008 'Monitoring Multicell Li-Ion Battery Stacks'). This circuit has been employed in the first major Lithium-ion battery-powered all-electric vehicle in Japan, the Mitsubishi iMEV. The US carmakers are not of so much interest, since they do not offer the leading edge technology. Here, we are waiting for (H)EVs made by GM such as the Volt, or other models in the future.

µModule products are another area of growth emphasis for us. These products are sold into many end-markets from industrial to automotive to communications and enterprise computers. We expanded our line of µModule products for power supplies and introduced µModule devices for driving LEDs and also in analog signal chain areas for employment in communications infrastructure. These are complex analog-intensive subsystem products housed in an IC package. These bring value to customers by shortening design lead times, while also taking up less printed circuit board space.

"We are focusing on automotive applications in Europe and Japan, particularly on hybrid and full electric vehicles", stated Linear's CEO Lothar Maier



The (power) electronic content of a car is increasing and can reach 15% of the car's total cost in 2012 Source: Linear Technology

Our strategy of serving diverse end-markets continues to be critical to our success. This year, 74% of our business was in the traditional analog end-markets of industrial, communications infrastructure/networking, automotive, and military and aerospace. The remaining 26% was in the computer, cell phone and portable handheld product end-markets. In summary, we have managed through a difficult year and remained financially healthy. We have done this before during the dot-com bust and are doing it again during this global recession.

Linear Technology, headquartered in Milpitas, California, employs 3,800 people worldwide and has technical sales and support locations throughout North America, Europe and Asia. In addition to manufacturing, assembly and test facilities in California, Washington, Singapore and Malaysia, the company has 12 design centers in the US, Singapore, and Munich/Germany.
www.linear.com

29 Palms

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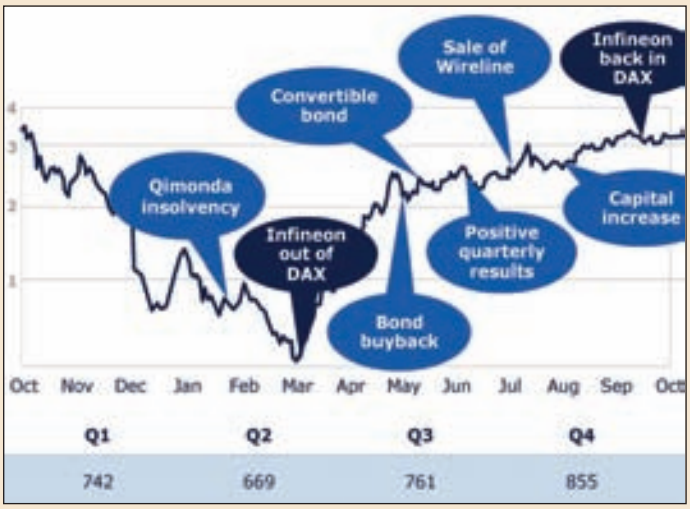
Back on Track

Fiscal year 2009 ended September was an extremely challenging year also for Infineon. Revenues were Euro 3,027 million, down 22% compared to the 2008 fiscal year, reflecting the strong contraction of the semiconductor market in all of the company's target markets such as automotive, industrial or communication. But the company is hopeful of turning the situation back round.



Infineon's share pice (Euro) and revenue development (Euro million) throughout fiscal year 2009

"Amidst the global economic crisis, we had to resolve our refinancing and cope with Qimonda's insolvency. Many didn't believe we'd be able to master the task. To cap the dubious honour of penny stock status, we were thrown out of the German stock index DAX. We took decisive action and turned the tables. The refinancing was successfully resolved. The share price increased more than ten-fold from its all-time low of 35 euro cents in April to today. We returned to the DAX in record time. How was that possible? Well, it called for a show of strength on everyone's part to overcome these exceptional challenges, involving all cost items and requiring painful staff cutbacks. For the staff remaining after the headcount reduction, the last twelve months meant burdens and financial losses. We made good progress over the last financial year, but there's still a long way to go", Infineon's CEO Peter Bauer looks back.

"The first half of the year saw a sharp fall in revenues. Fortunately, the downslide did not continue in the second half of the year. As the global economy recovered slightly, so our business picked up in the second half of fiscal year 2009 – even though it was still distinctly below the previous year's level. A major milestone was the refinancing of the bonds falling due in the 2010 financial year. We successfully placed new convertible bonds which were several times over-subscribed. Yet the greatest contribution by far to the refinancing was made by the capital increase. Almost all the subscription rights were exercised, which we regard as a strong sign of confidence", Bauer said.

Energy efficiency and renewable energy sources are becoming more and more important also for Infineon. Energy efficiency remains a perennial hot topic, despite the economic crisis. A good part of the economic stimulus packages from governments around the globe is earmarked for green technologies. The prospect of a long-term rise in energy prices is making consumers rethink. Semiconductors are indispensable for implementing these energy policy objectives. Particularly high growth rates are to be expected in renewable energies, but also in more efficient motor drives. In the automotive industry, the call for fuel-efficient and low-emission vehicles is also spurring a growth in long-term demand for semiconductors. Automakers are working on raising the efficiency of internal combustion engines to meet CO_2 targets. High-performance semiconductors are needed for the purpose. The same applies to alternative drive technologies in hybrid and electric vehicles, whose importance is gaining in momentum. "The first commercial offshore wind park being built in the Northern Sea near Borkum i.e. will operate with power modules from Infineon. The importance of energy efficiency is also gathering pace in household appliances such as washing machines, refrigerators or air-conditioning systems. These white goods are designed and produced primarily in Asia. To better penetrate this market, we have established a joint venture with LS Industrial Systems in Korea. We have also widened our collaboration with Bosch, making us Bosch's preferred supplier of power semiconductors. We are working together on optimising the energy efficiency of electronic components in the automotive sector. Here, we intend to grow faster than the automotive industry as a whole, since the semiconductor content in the car is continously increasing. And, we have again been confirmed by IMS as the world market leader for power semiconductors", Bauer pointed out.

The Asian economies are recovering from the economic crisis much faster than anticipated, with China and India especially playing the role of economic locomotive. "We already generate almost half our revenues in Asia and will systematically expand our business there. The Chinese Government is currently investing a lot of money in the infrastructure. Renewable energies – water, solar and wind – and expansion of the rail network are just two examples of the growth potential we address there. This might offset the weak market conditions for automation and automotive in other regions", Bauer stated. "What awaits us in the current business year 2010? At the moment, we are seeing a small upswing. It is difficult to tell how strong it will be and how long it will last. We are benefiting from warehouses being replenished in the value-added chain, but the fundamental demand is also picking up. It has to be said though, that our customers' ordering practices are not following normal patterns at present. Another element of uncertainty is the movement of the Euro/US Dollar exchange rate. Were the Euro to continue its climb versus the Dollar, it would have a negative impact on revenues and profit. Our plans are based on an assumed Euro to Dollar exchange rate of 1.50. Assuming the global economy will continue to stabilise or grow, we expect revenues to be up at least 10% for the year as a whole", Bauer concluded.

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E-Mobility Gains Acceptance

Electric vehicles first came into existence in the mid-19th century, when electricity was among the preferred methods for automobile propulsion, providing a level of comfort and ease of operation that could not be achieved by the gasoline cars of the time. Increased concern over the environmental impact of the petroleum-based transportation infrastructure, along with the spectre of peak oil, led to renewed interest in electric (hybrid) vehicles. A special fair in Munich and a strategic European research program highlights this trend, which is also an interesting opportunity for power electronics.

"The recession has hit the automotive industry especially hard. Our industry has been plagued by oil prices which remained too high for too long, the climate debate has a tendency to bring forth easy remedies which cannot be put on the road overnight, the resulting technical and political uncertainties weighing upon potential car buyers, and, finally, the worldwide plunge in demand as a consequence of the financial crisis. For 2009, we expect worldwide automobile production to fall by some 15 to 20%. But we currently see signs of recovery, and not only because of government economic stimulus packages. After all, the various cash incentives to trade in older vehicles have had the desired effect, especially in Germany. As a supplier to the industry, Bosch has also benefited from these programs, even if only to a low degree. This is because these buyer incentive programs have stimulated demand above all for smaller cars. And these cars are not as often equipped with advanced safety systems and diesel drive technologies. This is how the share of diesel, for example, among newly registered cars in Western Europe, which in 2008 lay at a full 53%, has sunk to only 44% this year. This is still, of course, a high value, and one that is set to rise yet again. After the incentive programs have largely sparked premature sales for smaller cars, new opportunities for vehicles in the upper and premium segments will open up in 2010 – against the background of further economic recovery. What is more, these upper and premium segments have some catching up to do, since in the meantime, we have a lot of upper-class cars on our roads that are simply too old. This situation coincides with an increased offering of fuel-efficient and eco-friendly drive systems. So some things will set themselves straight again, but there is no mistaking that the crisis has led to shifts in market structures", commented Franz Fehrenbach, Chairman of the Board at Bosch, on the current situation of the automotive industry.

"The electrification of the powertrain in the car won't come tomorrow because of high cost for the Lithium-ion battery", said Franz Fehrenbach, Chairman of the Board at Bosch

RWE presented electric filling stations and Tesla Roadsters at ECarTec in Munich

Alternative drive technologies are becoming increasingly important, even if the internal-combustion engine is set to dominate the automotive market for the next 20 years. Bosch i.e. is working intensively on the development of alternative drive systems, which will make the automobiles of the future even more energy-efficient and will further reduce emissions. In doing so, the company is responding not only to legislative demands to further reduce fuel consumption and CO_2 emissions, but also to stricter emissions legislation worldwide and to the risks resulting from the finite supply of fossil fuels.

First fair on electric vehicles

Nevertheless, a new trade fair for electric mobility has been

"The Chinese gouvernment is funding electric vehicles, that's why European automakers have to take this upcoming market seriously", stated ESG Automotive VP Robert

established in Munich and was running successfully (195 exhibitors, 10,600 visitors) from October 13-15. "With ECarTec, we are establishing a new Expo in Germany's trade fair landscape that exclusively deals with the topic of electric mobility. An event of this kind is unique", said Robert Metzger, Managing Director and organiser of eCarTec. "Driving fun is a key purchasing motive for end consumers and has today become reality as a result of considerable progress made in battery development. The Tesla Roadster, a battery-driven electric car, features improved power and handling and does 0 to 100 km per hour in just 4s. It has a top speed of 200km/hr and can cover a distance of 400km. And, it does not produce any exhaust fumes. Only those who are at the cutting edge of this trend can benefit from this promising market. And the sales potential is incredibly high", Metzger commented.

At this fair, German utility RWE presented charging stations equipped with already standardised plugs from German connector manufacturer Mennekes. "We wanted to show that electromobility is not only environmentally friendly, but also has a lot of fun", said Carolin Reichert, Business Division Manager for electric mobility. "Today, many people cannot yet imagine that the electric motor will become a solution to the mobile future. As a matter of fact, developments surrounding this topic are already in full swing. Battery manufacturers are working on the latest generation of high-performance Lithium-ion batteries with significantly increased ranges. Vehicle manufacturers are poised to begin series production. Politicians are currently defining the legislative framework required to get the market up and running. And RWE is also making an important contribution towards the breakthrough of electric cars by establishing a universal network of charging stations in Germany". At this fair, RWE also demonstrated with six Tesla Roadsters the fun of driving outside the exhibition hall.

ESG Automotive, a Munich-based subsidary of ESG systems, showed its own design of an electric city car equipped with solar cells for charging purposes. The company has also designed a battery management system incorporating charging with solar cells and monitoring of individual battery cells. VP Robert Morgner is confident that e-mobility has a bright future. "The Chinese gouvernment is funding this technology, that's why European automakers have to take this upcoming market seriously". Indeed, many electric car companies are looking to China as the leader of future electric car implementation

around the world. In April 2009, Chinese officials announced their plan to make China the world's largest producer of electric cars. The Renault-Nissan Alliance will work with China's Ministry of Industry and Information Technology (MITI) to help set up battery recharging networks throughout the city of Wuhan, the pilot city in the country's electrical vehicle pilot program.

Hybrid drives as a bridge to the electric car

Hybrid drives allow fuel consumption and emissions to be further reduced in conventional drive concepts. The mild hybrid achieves this by providing a comfortable start-stop function, by supporting acceleration with a power boost, and by recovering electrical energy during braking operations. This makes a smaller and more economical internal-combustion engine feasible. In the New European Driving Cycle (NEDC), this mild hybrid approach results in fuel savings of up to 15%, as compared with a modern gasoline engine. A strong hybrid approach, on the other hand, has the additional advantage of making purely electric driving over short distances possible. For this, the car needs a more powerful electric motor and a larger battery. Here, fuel savings amount to as much as 25%. The plug-in hybrid goes a step further. This system can be recharged from the power grid and makes purely electric driving over longer distances possible.

The electric car with a range extender, which is a small, highly efficient internal-combustion engine, goes even further. When the battery reaches a low charge level after a longer drive with the electric motor alone, the range extender kicks in to recharge the battery. The range extender always runs at the ideal operating point, meaning that it consumes less fuel. The next step is an electric vehicle which runs solely on a larger battery that is recharged exclusively from the power grid. If a renewable resource has been used to generate this energy, then we can speak of almost zero-emission driving. Both hybrid and electric vehicles are especially suited for inner-city driving.

The essential element of Bosch's portfolio is the power electronics - with an integrated DC/DC converter - that controls energy flow in hybrid and electric drive systems. For recovering the energy expended during braking, Bosch is developing a new electronic stability system that electronically coordinates the braking power of electric motor and friction brakes. In addition, alternative drive technologies call for electric and highly efficient auxiliary systems, such as the electric support of power steering. The first series-produced vehicles with Bosch hybrid technology, the Porsche Cayenne and the VW Touareg, are set to roll off the line in 2010. Bosch has also signed an agreement with PSA Peugeot Citroën to create a strategic partnership for diesel hybrid vehicles. Apart from drive electronics, Bosch will also develop and deliver the electric motors for the electric final drive at the rear axle of these four-wheel drive vehicles. A special business unit has been set up to advance electric drive technology, where some 500 engineers will be working by the end of 2009.

Energy store of the future

As the energy store, the lithium-ion battery will play a decisive role in the advent of the electric drive. In their SB LiMotive joint venture, Bosch and Samsung SDI have pooled their know-how to further develop this technology for automotive applications. "The main aim of this joint venture is to improve the energy density of this battery three-fold, and to cut costs by two-thirds. The battery must have high cycle durability and a long service life. Our investment budget for this project shows how serious we are about it: namely, some 500 million dollars by 2013. In the meantime, we have gained our first customer for this venture with BMW's Megacity Vehicle project, and in September, we broke ground for a new plant in Korea which will make lithium-ion battery cells for cars. The first phase of construction is due to be completed by the end of 2012. Then, we shall be in a position to manufacture battery cells for a minimum of 125,000 hybrid and electric vehicles per year. So even if the electric car will take some time in coming, we have reached initial milestones along this road. This, then, is our contribution to achieving the ambitious goals of electromobility", Bosch's Fehrenbach stated.

The electrification of the powertrain in the car won't come tomorrow, and it won't come all at once. "The reason is that, even years

from today, a lithium-ion battery which enables a car to travel a minimum distance of 200km will still cost between 8 and 12 thousand Euros, or as much as a small car. So both on the technical and the economic fronts, we have our work cut out for us. But over the longterm, the electric drive is a must, since we have no choice but to mitigate climate change and to find an alternative to oil, the supplies of which are ever scarcer. By 2020, we expect to see three million electric cars and plug-in hybrids on the world's roads. This development will also give rise to new business models in the area of mobility, above all for the financing, provision, and charging of the battery. We see such models as part and parcel of a new technology, and as things which are therefore very much part of our future agenda", Fehrenbach said. Of 100 million newly manufactured cars in the year 2020, 6 million will by then be hybrid vehicles and 3 million plug-in hybrids and electric cars.

Lithium-ion (and similar lithium polymer) batteries dominate in the development of elctrical storage for (H)EVs. The Lithium-ion chemistry involves a lithium cobalt oxide cathode and a graphite anode. This yields cells with a 200+Wh/kg energy density and 80 to 90% charge/discharge efficiency. The downsides of traditional lithium-ion batteries include short cycle lives (hundreds to a few thousand charge cycles) and significant degradation with age. The cathode is also somewhat toxic. Also, traditional lithium-ion batteries can pose a fire safety risk if punctured or charged improperly. The maturity of this technology is moderate. The Tesla Roadster uses 'blades' of traditional lithium-ion cells that can be replaced individually as needed. New variants (phosphates, titanates, spinels) have been shown to have a much longer lifetime, with A123 expecting their lithium iron phosphate batteries to last for at least 10+ years and 7000+ charge cycles, and LG Chem expecting their lithium-manganese spinel batteries to last up to 40 years.

"In my opinion, a real revolution is needed for the development of the next generation. We need new storage materials for Lithium-ion batteries", explains battery researcher Stefan Koller, who is involved in the 'NanoPoliBat' EU project at Graz University of Technology (Austria) and Varta Microbattery (Germany). In a newly developed process, Koller utilise a silicon-containing gel and apply it to the graphite substrate material. "In this way the graphite works as a buffer, cushioning the big changes in volume of the silicon during the uptake and transfer of lithium ions", he explains. Silicon has a lithium-ion storage capacity some ten times higher than the up-to-now commercially used graphite. The new material can thus store more than double the quantity of lithium ions without changes to the battery lifetime. This method is far cheaper than the previous ones in which silicon is separated in the gas phase. "The challenge lies in the poor storage density of materials in the counter electrode in the whole battery, something which we have been doing intensive research on", Koller comments.

European E3Car research project

"Besides semiconductor devices for hybrids, we also concentrate our efforts on electric vehicles. In the medium-term, this will be a niche market, but has a great perspective in the long-term", said Infineon's CEO Peter Bauer at ECarTec. Thus, Europe's largest research project to advance the development of electric vehicles has been launched under the leadership of Infineon Technologies.

The E3Car (Energy Efficient Electrical Car) project brings together 33 automotive companies, key suppliers, and research facilities from a total of 11 countries to collaborate on boosting the efficiency of electrically-driven vehicles by more than one-third. The goal of the project is to extend the travel range of electric vehicles by up to 35%, with a battery unit of the same size as a current baseline. Alternatively, this means battery units up to 35% lighter and more compact, while providing the same travel range as a current baseline, will be possible.

As part of the E3Car project and by the end of 2011, Europe is targeting research on innovative electronic components that play a key role in electric vehicle power consumption. Research will focus primarily on semiconductor components and power modules

"In the medium-term electric vehicles will be a niche market, but this has a great perspective in the long-term", said Infineon's CEO Peter Bauer

that control the supply and distribution of power in electric vehicles. These are used in the powertrain, which consumes most of the car's energy, as well as in power converters and Lithium-ion batteries. Project efforts are concentrated on extending the travel range per battery charge, on integrating components to make the battery, charge unit and power distribution network lighter and more compact, and on increasing the efficiency of the power converter so that as much battery charge as possible is used to drive the vehicle and is not lost through heat dissipation. Infineon's contribution is the further development of power semiconductors and modules.

The E3Car project objective is the development of nanoelectronics technologies, devices, circuits architectures and modules for electrical and hybrid vehicles and demonstration of these modules in final systems with a focus on component design, circuit architecture concepts and semiconductor technology developments. The project aims at creating a breakthrough in the development of nanoelectronics technologies, devices, miniaturised sub-systems for the next generation electric vehicles and acceleration of commercialisation of the electric vehicles segment.

The total budget for the three year E3Car project is around Euro 44 million, half of which is funded by the 33 industry and research partners. The other half is provided by the ENIAC (European Nanoelectronics Initiative Advisory Council) organisation and 11 funding organisations in Austria, Belgium, the Czech Republic, Germany, Finland, France, Ireland, Italy, the Netherlands, Norway and Spain. One of the largest sponsors is the German Federal Ministry of Education and Research (BMBF).

The German Federal Government is pursuing a holistic strategy. The 'National Development Plan on Electric-Drive Vehicles', approved by the German Federal Cabinet on August 19, 2009, harmonises and coordinates for the first time all relevant measures – from education and competence building at universities and colleges, through battery development, network integration and power management, to market preparation. The plan is designed to ensure that the whole concept of electric mobility – ranging from basic research to new business models – is adopted in Germany, so that value added is generated in Germany and new future-proof jobs are created. The goal is to have one million electric vehicles on German roads by 2020. In total, the Federal Government is funding electric mobility to the tune of Euro 700 million, Euro 500 million of which come from the government's second economic stimulus package.

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Charging Systems for Electric Vehicles

Decisive for the mass acceptance of electric cars is the development of a corresponding charging infrastructure to be able to recharge the electric cars. The most important prerequisite for this is, above all, a uniform charge socket and the corresponding plug.

Recently, the largest European energy supply companies and vehicle manufacturers agreed on the basic parameters for the charging connection for electric cars. The basis for this agreement is a standard draft developed by German plug specialist Mennekes (800 employees, 100 million Euros annual turnover).

The tasks of the charging plugs are much more complex in this context than one would think at first glance, as they have to cover a large variety of functions. The Mennekes connector is no larger than a common 16A plug and suited for both single-phase 230V connection as well as three-phase 400V connection up to a charging current of 63A.

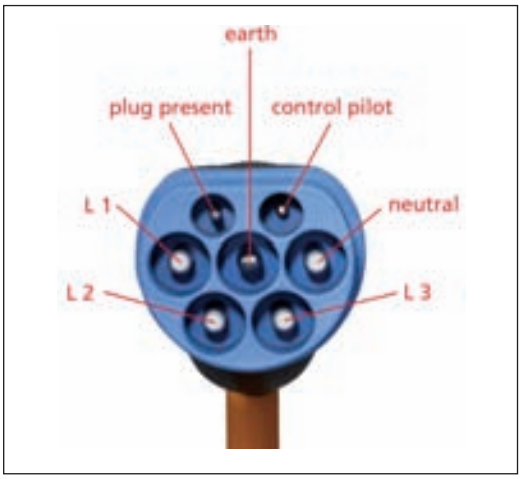
It also features the required communication interfaces between the charging station and the vehicle. A 'plug present' contact for example ensures the activation of the immobiliser and a 'control pilot' contact enables communication, meaning data exchange.

In addition, the company is working on system solutions for charging stations in the commercial and the public sector. Demand-conform charging capacities with different charging currents are offered depending on the application field. Time-saving charging stations with charging currents of up to 63A will be available for the commercial and public sector, e.g. on parking places and in parking garages, which reduce the charging times to less than 10% compared to charging at home. For the domestic sector, solutions will be developed that allow the recharging of electric cars via common 230V household outlets with earthing contact.

High demands

"We have been cooperating intensely with the research and development departments of the large vehicle manufacturers and energy suppliers", comments Volker Lazzaro, Managing Director of Technology and Project Manager e-mobility at Mennekes.

High demands are made on the charging connector, because charging an electric car is supposed to become easier and more comfortable than today. Here is where the company profits from its almost 75 years of experience in the field of industrial plug-type connectors. The safety of the charging technology takes top priority here. For example, the plugs have to be latched during charging, so that they cannot be pulled out arbitrarily or unintentionally during the charging process. In addition, the vehicle and the charging station must be able to communicate with each other via the charging technology to exchange data. For this purpose, the charging cable for the connection between the vehicle socket and the charging station has identical plugs at each end with protection against accidental contact, so that the user does not have to wonder which end to plug in where. In addition, Mennekes will also offer the corresponding charging cable for electric cars at home on a normal 230V household outlet with earthing contact.



The charge plug by Mennekes is no larger than a common 16A plug, and is suited for charging currents of up to 63A

Charging station and cable plugged onto a Smart EV
Source: Mennekes

Mennekes is a partner of the vehicle manufacturer and utility companies such as RWE for the practical field tests of mobility concepts with electric drive. The development of products and systems for vehicle charging has reached an advanced status and concrete shapes on this base. This also shows the current pilot projects in model regions in Germany (Berlin or Aachen).

The agreement of the leading European vehicle manufacturers and energy supply companies on one uniform standard for the charging plug system is an essential step towards enabling mobility with electric drives throughout Europe. The basis for this agreement is the standard draft for the charging plugs. "Even if the integration into binding norms will still take some time, we are already in a close dialogue with the vehicle manufacturers and energy supply companies concerning the practice-conform advanced development of the components and system solutions. Our aim is to make the start into an electro mobile future as easy as possible for the consumers", commented Andreas Sprecker, managing director at Mennekes.

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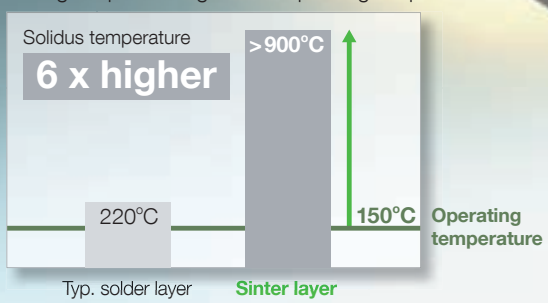

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Power Semiconductor Solutions for Micro-Hybrid Systems

Current CO_2 discussion and the need for the higher efficiency lead to the highly growing market share of the hybrid automotive systems. One of the significant agenda points is so-called micro-hybrid cars. In those cars, the alternator is used also as a starter and the braking energy, or at least some part of it, is recuperated by the battery. The belt-driven micro-hybrid systems operating on a 14V board net are easy to integrate into the existing cars, both mechanically and electrically. The most important task in the alternator mode of operation is to maximise the efficiency of the electrical energy generation. Modern generators have typical efficiency of around 70%. Diodes in the classical rectifier bridge cause 38% of generator losses. **Dr. Ing. Dušan Graovac (Senior Staff Engineer, Automotive), Benno Köppl (Principal Engineer, Powertrain Systems), Frank Auer (Director, Powertrain Systems), and Michael Scheffer (System Expert Powertrain Systems), Infineon Technologies, Neubiberg, Germany**

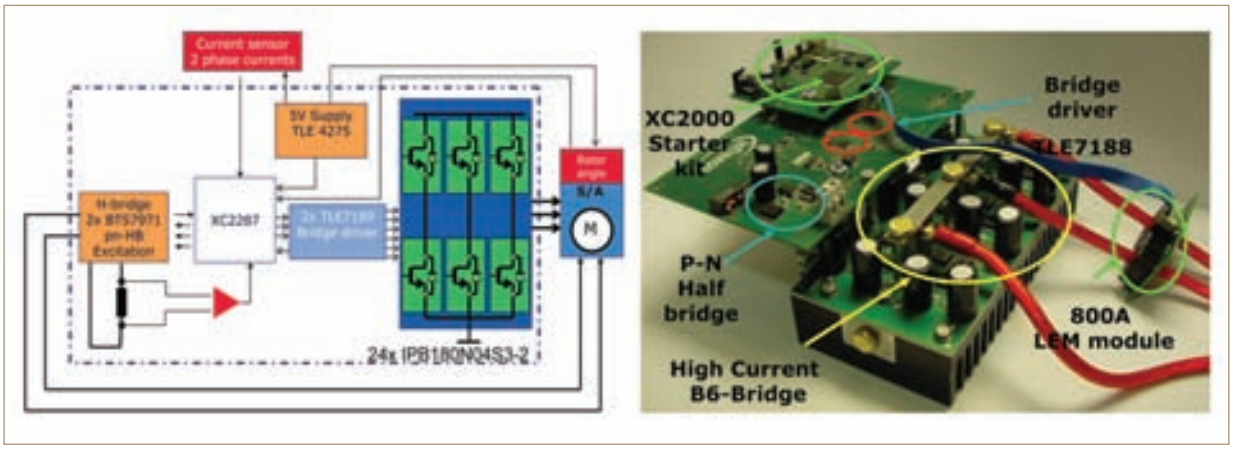


Figure 1: **Infineon's solution for a micro-hybrid ECU**

A simplified block diagram of a belt driven starter-alternator electronic control unit (ECU) and the appropriate system demonstrator are shown in Figure 1. It consists of the Lundell alternator, three- or six-phase inverter with power MOSFETs and a bridge driver, micro-controller for motor control during both starting and generation mode, H-Bridge for excitation control and different sensors.

Compared to a classical alternator with diode rectification, the efficiency of the complete system, including generator, is improved for at least 6%. With alternator modifications efficiency improvements of more than 10% are realistic. Another significant advantage is the increase of the available generator current at low speed of around 40%.

Figure 2 illustrates a load dump behaviour of the proposed alternator control in a so-called 'loss of battery' situation. It can be seen that when dumping the 100A load, the over-voltage peak remains below 25V and has a very short duration of below 5ms. Compared with classical load dump condition, which vary between 32 and 45V for 400ms, this concept brings significant advantages.

Application requirements on power semiconductors

The hardest requirements in a micro-

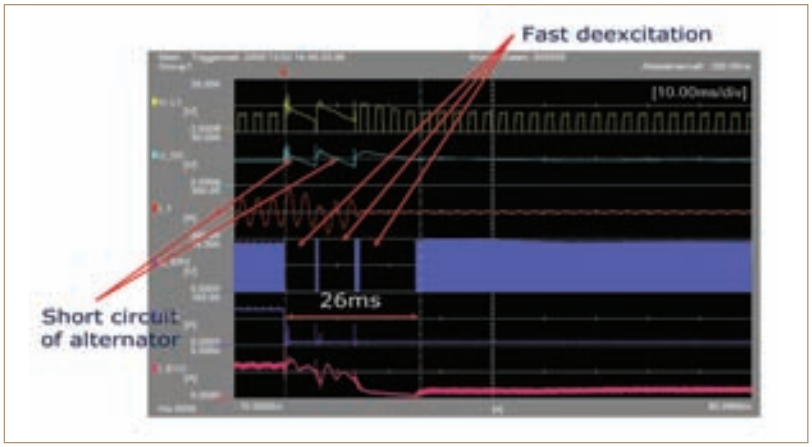


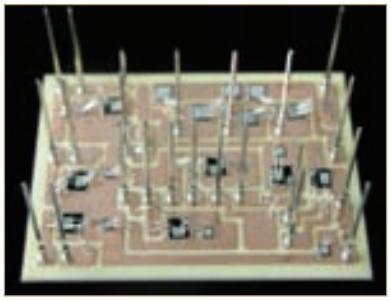
Figure 2: **Load dump minimisation**

hybrid system are set for power MOSFETs and modules. Very high currents (600A) and the need for low voltage drop and high efficiency require very low R_{dson} value and also low values of both the gate-charge (important for the bridge driver current capability) and gate-to-drain charge (important for the minimisation of the switching losses). Modern low voltage MOSFETs are based on trench cells. The Infineon trench concept, compared to the classical trench, enables further reduction in R_{dson}, gate-to-drain charges, gate resistance and is more robust against the parasitic turn-on which could be triggered with high du/dt transients. New 40V generation introduces first sub milli-ohm MOSFET (R_{dson}_max<1mΩ). In order to achieve high currents using standard 7pin D²PAK, a PowerBond bonding technology is used. This approach enabled achieving of a true 180A DC current capability of a D²PAK with the package resistance reduced to 0.3mΩ only.

Semiconductor devices in the micro-hybrid application are placed in the engine compartment with an additional goal of integrating both the power electronics part, as well as the control circuitry into the alternator. Thus, they have to deal with both severe temperature cycles and high junction temperatures. An ECU has to withstand 600,000 internal combustion engine (ICE) starts over 17 years without failure, together with additional thousands of operating hours in generator mode.

Although it is possible to design an ECU based on discrete MOSFETs mounted on insulated metal substrate (IMS), as done previously with the system demonstrator, very high current and power densities, integration in the generator housing and reliability/lifetime requirements can be achieved only by using the power module with a ceramic substrate (DCB – direct copper bonding). Compared to IMS, DCB offers lower thermal resistance (R_{th}) by the factor of 2 to 4.

Figure 3: Cost savings through modules without a baseplate



The classical build-up of a power module with a copper baseplate, from automotive point of view, is bulky and expensive for micro hybrid vehicles. For that reason, power modules without a baseplate are often used in automotive applications. One module of this type is shown in Figure 3. To withstand high electrical and thermo-mechanical stress, interconnections inside the power module have to be as strong as possible. The failure mechanisms for standard modules due to thermal load changes are bond wire lift-off, delamination of the upper side copper layer, and solder cracks.

The main cause of these failures is different heating of the individual areas/layers and the different thermal expansion coefficients of the materials used in the inside the power module. This also shows the importance of the proper material choice for the module lifetime.

The driver IC is the interface between the microcontroller and the MOSFETs. As the microcontroller delivers the control signals, the driver IC level-shifts, amplifies, and buffers the control signals to provide the necessary gate charge for the power stage. In addition, the driver IC incorporates protection functions and functions to reduce the external part count and cost. It also allows operation at very low battery voltages during ICE starting. In addition to that it should be noted that over-current, shoot-through, under-voltage and over-voltage protections are necessary.

Future outlook

In the power MOSFET technology, further minimisation of both R_{dson} and gate charges is expected, together with the increase in temperature capability. Changing the maximum allowable junction temperature of the power semiconductor will directly change the thermal stress on the interconnection of the chip surface. A typical wear-out effect at the chip surface is the wire bond lift off. To test this interconnection, power cycling tests are performed. The number of cycles that a device survives is related to the temperature swing, the maximum temperature and the slopes. The wire bonding process for power modules has already been improved from standard wire bonding to the Infineon new generation wire bonding (Figure 4). For future designs results of the low temperature joining process (LTJT) are very promising. Further innovation comes from the field of drivers, microcontrollers and sensors. In the development, there is a rotor position sensor based on iGMR (integrated giant magneto resistance) technology.

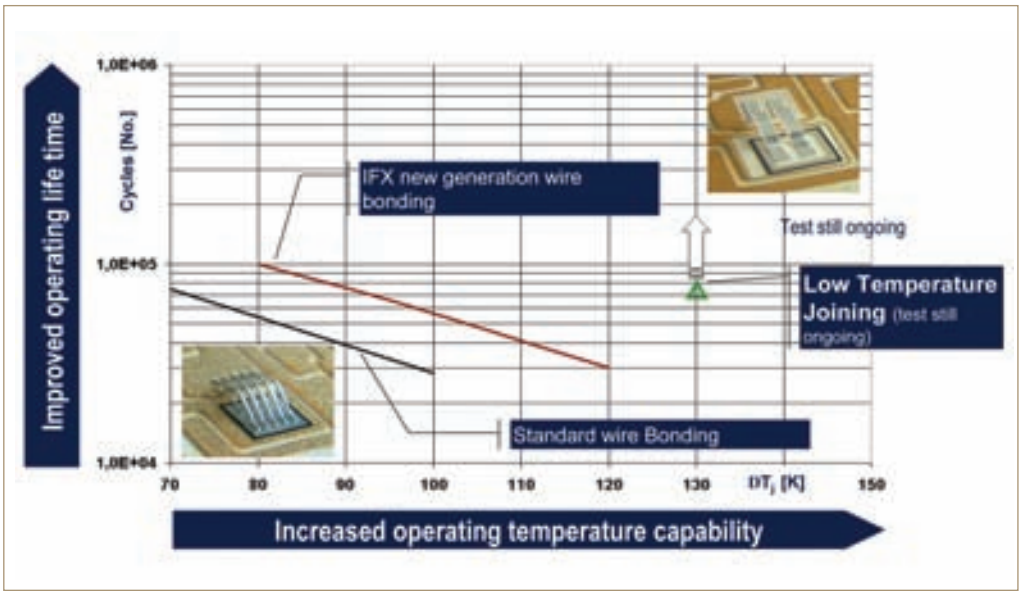


Figure 4: Improvement of power cycling capability as a result of new interconnection technologies (LTJT)

Driving Improvements in Motor Control Design

Electrically actuated automotive systems offer greater convenience for users, as well as enabling car makers to reduce the size, weight and cost of the equipment fitted to modern vehicles. Cars today use numerous electric motors in areas such as HVAC, seat and mirror adjusters, headlamp positioning mechanisms, various washer pumps, and larger systems such as electric power steering. New driver and power stage technologies for automotive BLDC motors can enhance performance, shorten time to market, and reduce costs for vehicle comfort and convenience features. **Dr Georges Tchouangue and Wolf Jetschin, Power Semiconductors Division, Toshiba Electronics Europe**

Electrically actuated automotive systems offer greater convenience for users, as well as enabling car makers to reduce the size, weight and cost of the equipment fitted to modern vehicles. Cars today use numerous electric motors in areas such as HVAC (heating, ventilation and air conditioning), seat and mirror adjusters, headlamp positioning mechanisms, various washer pumps, and larger systems such as electric power steering.

In most instances, a brushless DC (BLDC) motor is preferred for its high reliability, low friction, small size and relatively low cost. However, drives and controls for BLDCs are more complex than for conventional brushed motors. As a result, they have always challenged system designers to achieve attributes such as accurate speed or position control, high efficiency with low heat generation, and low audible noise. Moreover, in many cases such challenges must be delivered within a short development timeframe and at a highly competitive price.

Motor control challenges

Key challenges when building BLDC applications lie in designing the control electronics, as well as minimising losses in the power bridge delivering current to the motor windings.

Designing and programming a sensorless BLDC controller requires specialist expertise and can be time-consuming and expensive in terms of both circuit implementation and software development. Because of this, using an application-optimised controller IC that integrates much of the key functionality in hardware is often preferable, and is a solution that is increasingly employed in many industrial and home appliance applications. However, devices that deliver the requisite functionality in the automotive arena and that are also qualified to the required automotive standards have, conventionally, been much more difficult to identify.

Figure 1: Driver IC and Power MOSFET solution for automotive applications

It is for this reason that Toshiba is investing in the development of controller/pre-driver ICs and power MOSFETs (Figure 1) that are optimised to driving the power stage of an automotive motor application, while also meeting the stringent requirements of the AEC-Q100 and TS16949 standards. Such devices will make the implementation of BLDC motors much more commercially viable in the cost-sensitive automotive arena.

Automotive qualified driver ICs

A family of these dedicated automotive ICs is due to be launched in the second quarter of 2010. Among the devices planned, the TB9061FNG will be suitable for applications such as driving fans and pumps, where fast load regulation or minutely controlled rotor angles are not required.

Figure 2 shows a block diagram of the planned device, which will be supplied in a 24pin SSOP package and capable of operating with temperatures from -40 to 125ºC.

Billed as a three-phase sensorless/brushless motor pre-driver, this IC will accept both PWM and DC control inputs and will incorporate six pre-driver (P channel/N Channel MOS) outputs for three-phase motor control.

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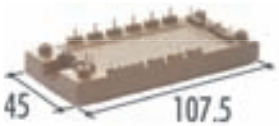
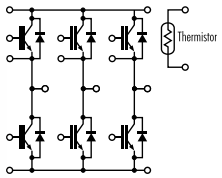
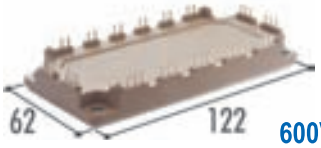
6-Pack IGBT



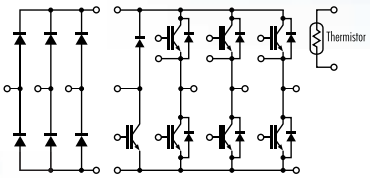


600V: 50A , 75A , 100A
1200V: 35A , 50A , 75A , 100A



600V: 100A , 150A
1200V: 75A , 100A , 150A , 180A

PIM IGBT

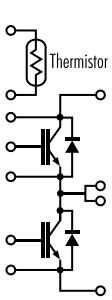


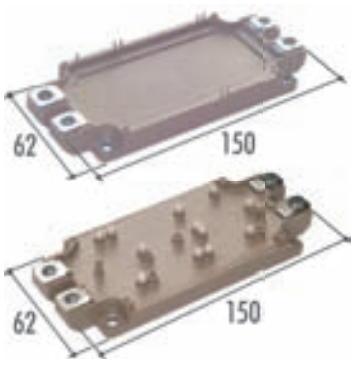
600V: 50A , 75A , 100A
1200V: 25A , 35A , 50A

600V: 100A , 150A
1200V: 50A , 75A , 100A , 150A

2-Pack IGBT

1200V: 225A , 300A , 450A , 600A





6-Pack & PIM with PressFit Contacts

		25A	35A	50A	75A	100A	150A	180A
6-Pack	600V			●	●	●	●	
	1200V			●	●	●	●	●
PIM	600V			●	●	●	●	
	1200V	●	●	●	●	●	●	

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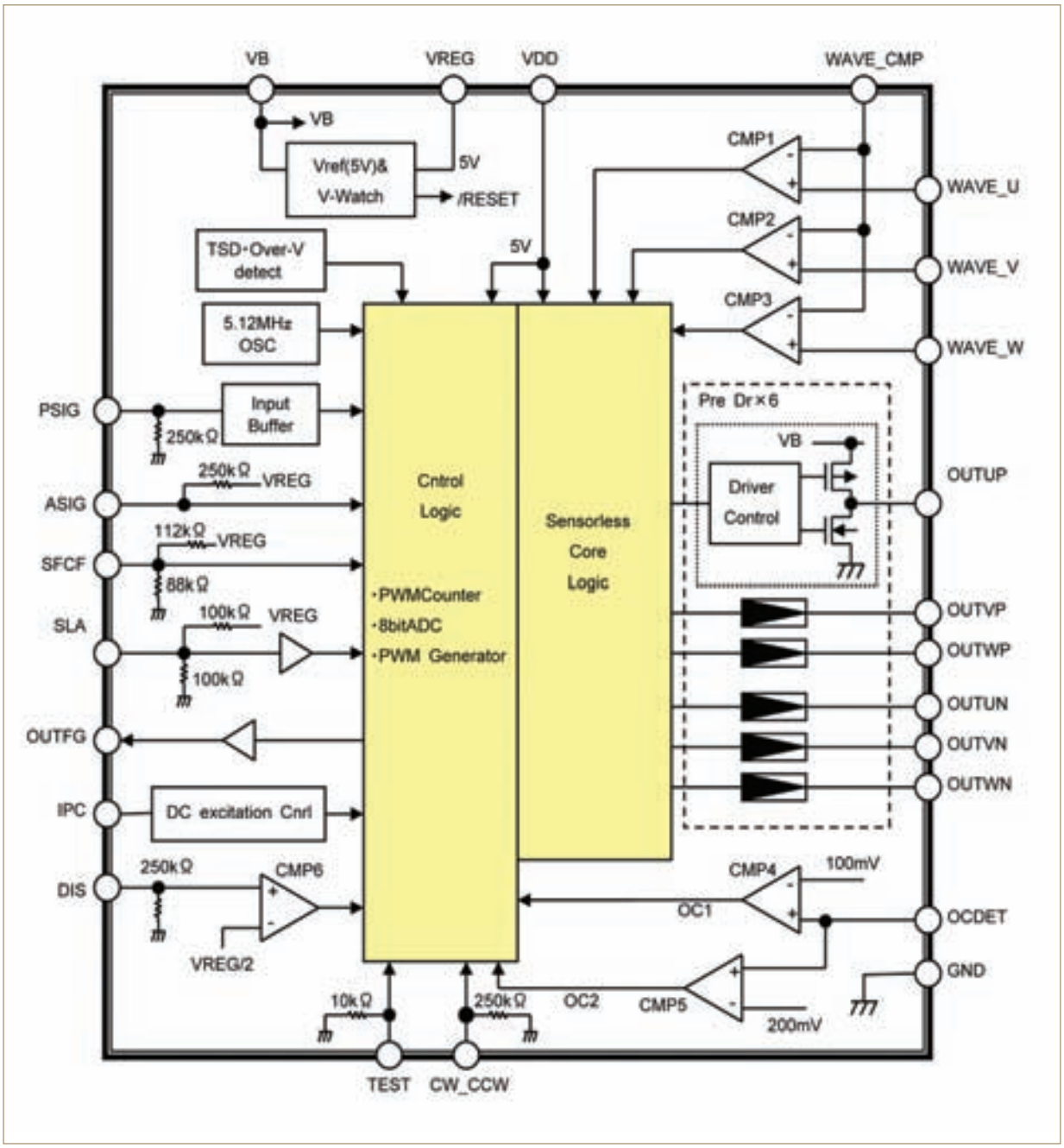

Figure 2: **BLDC Driver TB9061FNG block diagram**

The design significantly reduces the need for additional software programming by implementing sensorless core logic for motor control in hardware alongside control logic that includes a PWM counter, an 8bit ADC and a PWM generator. Input PWM frequencies ranging from 10Hz to 1kHz can be accommodated with valid duty cycles from approximately 5% to 95%. The input PWM signal is measured and calculated in the on-board logic circuit. The IC then generates a corresponding 20kHz PWM three-phase signal at the outputs.

Motor direction can be controlled clockwise and anti-clockwise using a single external pin, while built-in three-channel comparators minimise the need for additional components for the detection of the motor's induced voltage. Furthermore, built-in stall mode detection and automatic recovery control ensure robust and reliable operation, as do other safety mechanisms including over-current detection and over-voltage detection. The over-current detector can be triggered by two different current conditions (limited and over-current).

Power semiconductors

Of course, the driver is only one part of the total motor drive solution. It is also important to implement an optimised power stage, and it is here that the latest advances in power MOSFET technology can make things easier for the automotive designer.

MOSFETs used in automotive motor control designs are typically required to be small in size yet capable of handling high currents and many thousands of power cycles. At the same time, they must exhibit high reliability in the often harsh automotive environment and meet the AECQ101 and TS16949 standards requirements.

The key to developing MOSFETs that are small, reliable and able to handle high currents and many thousands of power cycles lies in low loss device design at both the silicon and the packaging level. Indeed, low-loss device design is

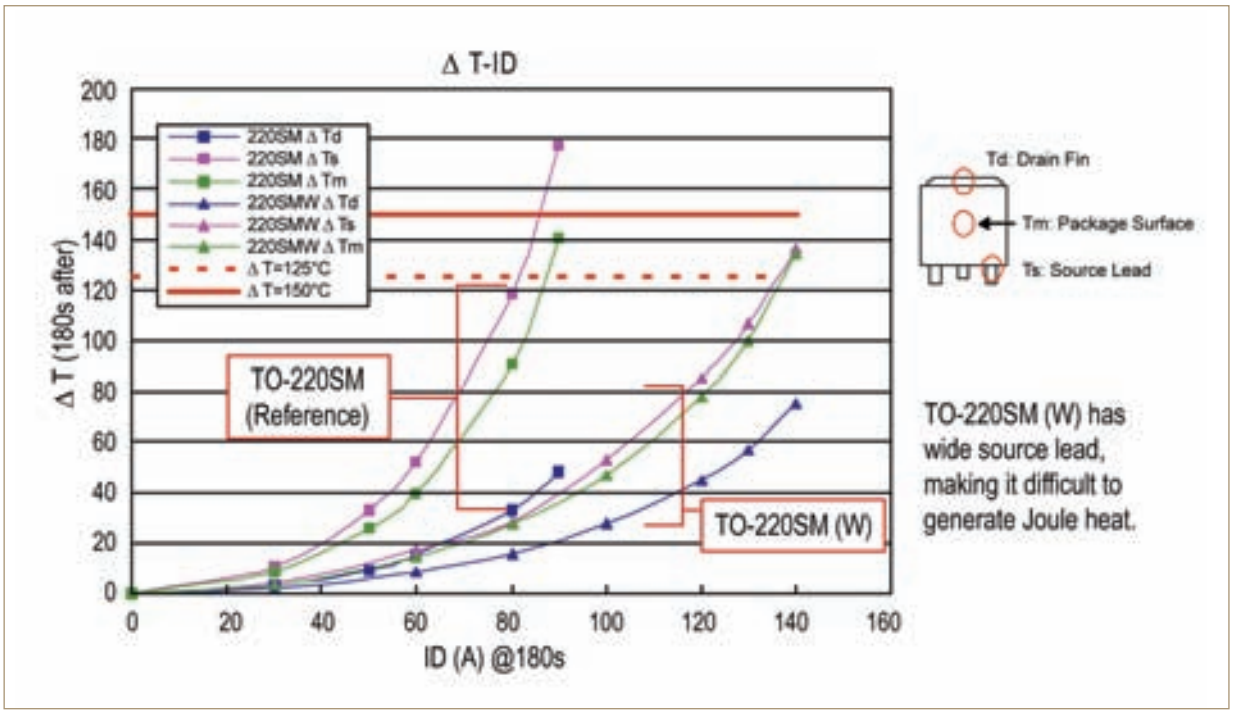

Figure 3: MOSFET temperature comparisons

imperative to maximising reliability by minimising the heating effects of continuous and pulse currents to which the device may be exposed. Because of this, reducing on resistance ($R_{DS(ON)}$) and other factors influencing the creation of I^2R losses is clearly important. However, at the same time, switching performance demands consideration of factors such as gate charge (Q_g) and input capacitance (C_{iss}).

As far as package design is concerned, optimising the characteristics of the device leads and internal ohmic connections can help to minimise I^2R heating by reducing electrical resistance. Low thermal resistance throughout the leads, connections and overmold is also necessary, to help the device dissipate internally generated heat as efficiently as possible.

At the silicon level, reducing the typical on-resistance also helps to minimise I^2R heating within the die. A low C_{iss} is highly desirable for automotive MOSFETs as this reduces turn-on energy and allows fast response to control signals. For use in an H-bridge, MOSFET turn-off behaviour is not an issue. For three-phase BLDC, the dead time has to be controlled, which means the turn-off time has to be fast enough to prevent short-circuit conditions damaging high- and low-side MOSFETs.

Toshiba's own solution to these challenges has been to develop a family of MOSFETs that combine package advances with advanced U-MOS IV trench technology. The trench architecture delivers

Opportunities in Automotive Market for Electric Motors

The automobile market has crashed, and whilst this has affected component suppliers, there still remain areas where the electrical motor market is growing, according to a new report from IMS Research.

With light vehicle sales having experienced the largest drop in living memory in most western economies, one would expect a reduction in the number of electrical motors used in automotive applications. However, 'The World Market for Electrical Motors in Automotive Applications' report shows that the continued growth in vehicle sales in regions such as China and South America, the continued penetration of actuated systems into a greater number of vehicles and the innovation of new technologies requiring motors, has helped soften the drop in demand to some degree.

Demand for some types of electrical motors is holding up better than for others. The brushless DC motor market, for example, is performing relatively well. To quantify this, worldwide sales of motors used in automotive applications are estimated to have dropped by almost 20%, from 2.3 billion units, over the period 2007 to 2009. In contrast, sales of brushless DC motors are estimated to decrease by only 6% over the same period. Nevertheless, the market for brushless DC motors in automotive is still small, accounting for only around 5% of motors used in automotive applications. Also, many high volume applications, such as seat adjustment or window actuation, only require intermittent operation. So while brushless DC motors may be used in some top-end vehicles, primarily to benefit from the reduced noise levels of the motor, this is not true for the 'mass market'.

"In spite of the higher cost of these products, the greater reliability and energy efficiency as well as longer lifetimes of brushless DC motors, make them popular in applications with high duty cycles. Already, many of the fuel pump applications have switched from brushed to brushless. This replacement trend is expected to continue in water pump applications, such as in cooling systems", comments IMS analyst Alex West. "Other applications also using this technology include dual clutch and automated manual transmission, as well as HVAC and power steering systems. Also, as the market for electric and hybrid vehicles increases, this is expected to spur demand for the more efficient brushless DC motors".

www.imsresearch.com

the low $R_{DS(ON)}$, low input capacitance, low gate charge and high current-handling capability.

So far, automotive MOSFETs have used conventional package architectures and materials. This has effectively restricted performance, but Toshiba WARP packages now introduce a number of innovations aimed at simultaneously reducing internal heat generation, increasing heat dissipation, and improving overall durability.

Conventional aluminium bondwires are replaced with a copper clamp, for example, and the clamping mechanism is optimised to maintain a reliable mechanical bond, so as to withstand repeated power cycling as well as exposure to shock and vibration. The clamp has a larger cross-sectional area than a multi-bondwire interconnect, and this combines with the higher electrical conductivity of the copper material for a drastic reduction of I^2R heating due to package losses. Furthermore, because the copper clamp lowers package inductance, not only is heat generation further reduced but improved noise performance and faster switching times are possible. Finally, an enlarged source terminal creates a low-resistance pathway for current entering the device. Combining the direct copper clamping structure and wide source lead has been shown to improve package thermal resistance by around 20%.

These package technology advances and the U-MOS IV channel architecture have come together in the Toshiba WARP-FET automotive MOSFET family offering current-handling capability up to 150A and maximum voltage of 75V_{DSS}. The trench technology contributes to typical $R_{DS(ON)}$ as low as 1.7mΩ and typical C_{iss} down to 4500pF.

The improvements in performance throughout the package and the die have enabled a valuable reduction in electrical losses combined with improved heat dissipation. As a result, the average MOSFET operating temperature is appreciably lower than for a comparable device using conventional packaging and trench architecture. Figure 3 confirms this by comparing the temperature at the drain, package surface and source lead of automotive trench MOSFETs in the standard TO-220SM package (also known as D^2PAK) and the TO-220SM(W) WARP package.

The combined effects of the enhancements to silicon performance and low-loss packaging allow these MOSFETs to achieve many thousands of power cycles. This will serve to boost reliability in automotive BLDC motor-control applications.

System solution

Figure 3 shows the planned driver IC and the latest automotive MOSFET technology. Because the TB9061FNG IC is optimised for use with these power devices they can, together, simplify and speed the implementation of a full automotive motor drive system. To accelerate development, further an evaluation board will soon be launched that combines a TB9061FNG driver IC with six WARP-FETs and a sample automotive pump. The pump motor can be controlled using a pulse generator connected to the board's PWM input, or by applying a DC control signal.

By enabling a true system solution for automotive brushless motor control, this driver IC/automotive MOSFET combination will significantly reduce the time engineers need to spend identifying and selecting components and designing circuitry, at the same time as providing an assurance of quality and reliability in the end product.

Advantages of Advanced Active Clamping

Power semiconductor manufacturers are offering IGBT modules with ever greater power densities. The limit is represented by the maximum power loss that can be dissipated; optimisation criteria are the packaging technology as well as the conduction and switching losses of the semiconductor chips. The high current density of the modules together with high switching speeds place increased demands on the driving circuits, both in normal switching operation and under overload conditions. Advanced Active Clamping switching technology offers a solution showing how modern high-power IGBTs can be better utilised. **Heinz Rüedi, Jan Thalheim and Olivier Garcia, CT-Concept Technologie AG, Switzerland**

Parasitic inductances in IGBT modules

and converter circuits cannot be completely eliminated for physical reasons, and their influence on the system behaviour cannot be neglected. Figure 1 (upper part) shows the parasitic inductances contained in a commutation circuit. The current change caused by turning off the IGBT produces voltage transients at its collector, as shown in the lower part of Figure 1.

The commutation speed and thus, the turn-off over-voltage at an IGBT can, in principle, be affected by the turn-off gate resistance $R_{g(off)}$. This technique is used particularly at lower powers. However, $R_{g(off)}$ must then be dimensioned for overload conditions such as turn-off of the double rated current, short circuit and a temporarily increased link circuit voltage. In normal operation, this results in increased switching losses and turn-off delays, which reduces the usability of the modules. So this simple method is unsuitable for modern high-power modules.

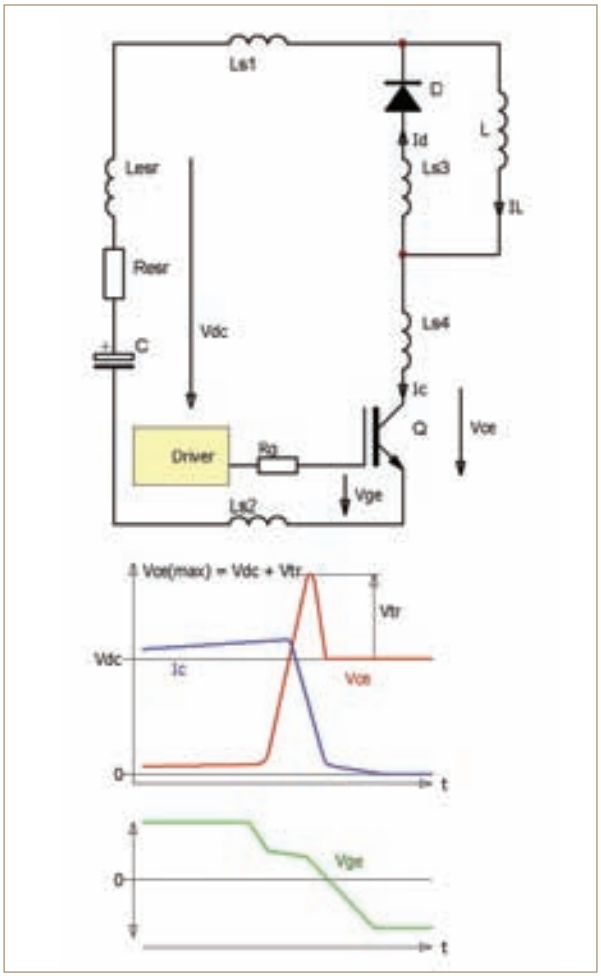

Figure 1: Commutation circuit with parasitic inductances (above) and typical characteristic at IGBT turn-off (below)

Soft Turn-Off

The problems described above have led to the development of two-stage turn-off, soft-switch-off, and slow turn-off driver circuits operating with a reversible gate resistance. In normal operation, a low-ohmic gate resistor is used to turn the IGBT off in order to minimise the switching losses, and a high-ohmic one is used when a short circuit or surge current is detected (see Figure 2).

However, the problem lies in the reliable detection of these conditions: desaturation monitoring always involves a delay known as the response time, usually of 4-10µs, until a fault is detected. When the IGBTs are driven with a pulse that is shorter than the response time in the event of a short circuit, the fault is not detected and the driver turns off too quickly. The IGBT is then destroyed by the resulting over-voltage.

Moreover, coverage of limit cases (between over-current/non-over-current) presents a problem; for instance a higher over-voltage may well occur when the double rated current is turned off than at a short-circuit turn-off.

These kinds of driver circuits must be regarded as dangerous and users must be advised against their use in equipment of higher power and in systems from which high reliability is expected.

Apart from that, a soft turn-off circuit designed for only two operating conditions is clearly unable to ensure optimal driving at all times under changing operating conditions. Consequently, this principle is, at best, a compromise, also with respect to efficiency.

Active Clamping

Simple Active Clamping has already

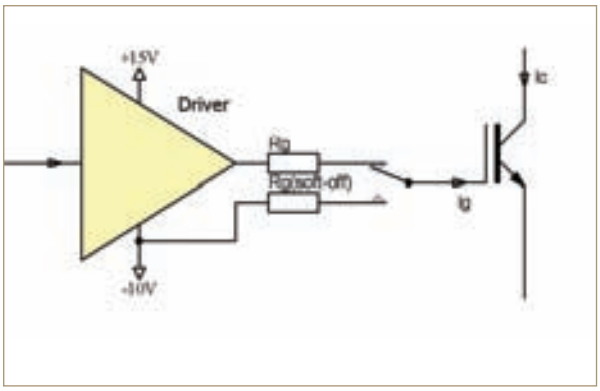

Figure 2: **Principle of an IGBT driver with soft turn-off**

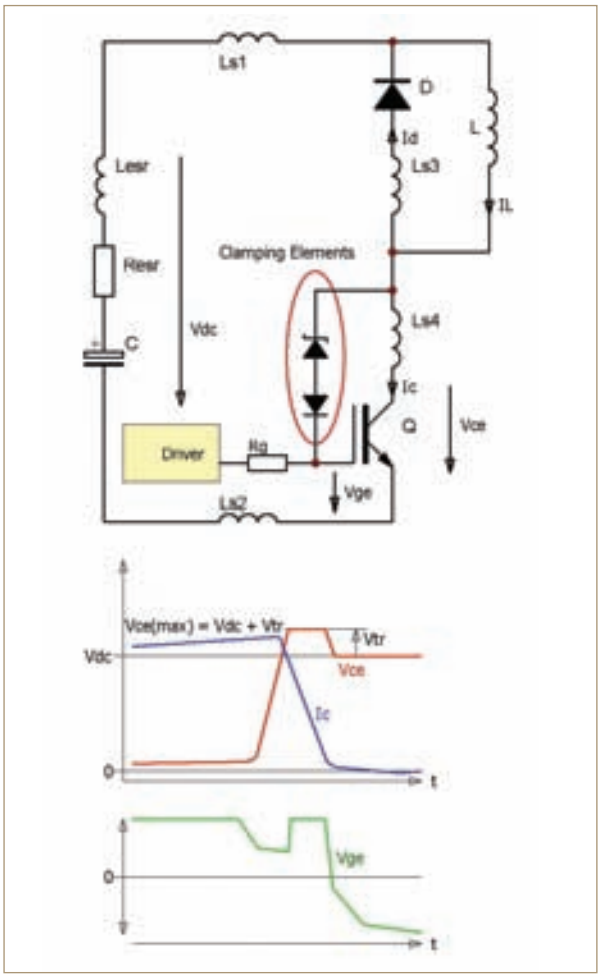

Figure 3: **Principle of an IGBT driver with Active Clamping (above) and typical characteristic at turn-off with Active Clamping (below)**

been used for some time to protect power MOSFETs. Active clamping means the direct feedback of the collector potential to the gate via an element with an avalanche characteristic. Figure 3 (upper part) shows the principle on the basis of an IGBT switch.

The feedback branch consists of a clamping element, as a rule comprising a series of transient voltage suppressors (TVS). If the collector-emitter voltage exceeds the approximate breakdown voltage of the clamping element, a current flows via the feedback to the gate of the IGBT and raises its potential, so that the rate of change of the collector current is reduced and a stable condition results. The voltage across the IGBT is then determined by the design of the clamping element. The IGBT operates in the active range of its output characteristic and converts the energy stored in the stray inductance into heat. The clamping process continues until the stray inductances have been demagnetised. The fundamental relationships involved here on the basis of typical curves are illustrated in the lower part of Figure 3.

Benefits of Active Clamping:

- Self-adapting system, comes into action only when really needed
- Lower switching losses
- Simple circuit configuration
- The IGBT to be protected is itself a major part of the protective circuit
- No additional power components (snubbers) required
- Relatively exact voltage limitation independent of the operating point of the converter
- Conventional drivers can be used

Active Clamping offers more reliable protection of the IGBTs than a soft turn-off circuit, does not require the detection of a fault case, and offers higher efficiency.

Advanced Active Clamping

Simple Active Clamping is traditionally used only to protect the semiconductor in the event of overload. Consequently, the clamping elements are never subjected to recurrent pulse operation.

The problem of repetitive operation takes the following form: modern high-power IGBTs are optimally driven with gate resistors in the range from 0.1 to several ohms. For turn-off, the driver supplies an output voltage of –10V. However, the Active Clamping Circuit must raise the gate voltage temporarily to about +15V, in order to reduce the rate of current change. This produces a voltage drop of 25V across the gate resistor. A high current is absorbed by the driver, which flows through the Active Clamping circuit, where it produces high losses and additional voltage drops. The simple Active Clamping circuit is consequently unsuitable for repetitive operation.

An improved Active Clamping circuit has been presented with a plug-and-play driver for IHM modules [1]. The circuit principle is shown in Figure 4. Here, the base of the chain of clamping diodes is, as usual, connected to the gate of the IGBT, but additionally to the input of a booster stage. The driver voltage is consequently raised as soon as a current flows through the clamping element. The driver stage now no longer draws any current from the clamping element, and the current flowing through the latter is then available exclusively for charging the gate. The voltage drop and power loss in the clamping diodes can thus be dramatically reduced. This circuit has proved its worth in the first generation of SCALE plug-and-play drivers used in a large number of industrial and traction applications.

SCALE-2 Integrated Advanced Active Clamping

The SCALE-2 generation [2] offers Advanced Active Clamping functionality not only in plug-and-play drivers but also in driver cores. Figure 5 illustrates this with the circuit of the SCALE-2 2SC0435T low-cost driver core with the use of the Advanced Active Clamping function.

The base of the clamping elements is

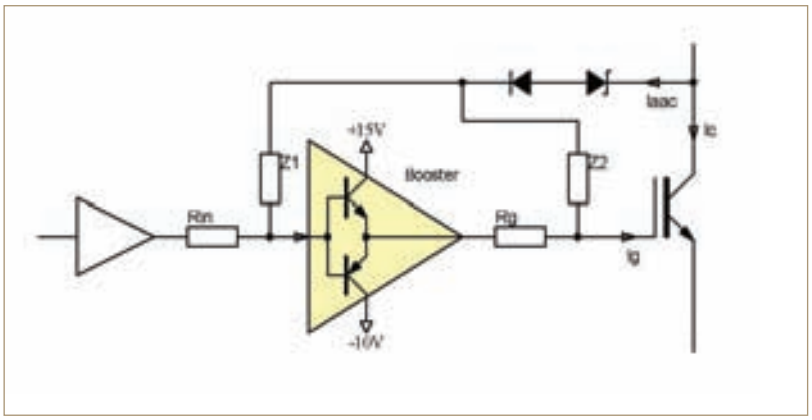

Figure 4: **Principle of an IGBT driver with Advanced Active Clamping**

connected not only to the gate of the IGBT, but also to the ACL input of the SCALE-2 driver ASIC. The gate driver ASICs implemented in sophisticated fast analog CMOS technology continuously raise the output resistance of the turn-off driver stage as the current to the ACL input increases. When the current reaches several 100mA, the output stage has high impedance, so that the driver no longer absorbs any current from the clamping element. This circuit operates more efficiently than the discretely implemented solution shown in Figure 4, uses significantly fewer components and is very simple and safe for the user.

Figure 6 shows the turn-off behaviour of the 2SP0320T plug-and-play driver with an IGBT module FF450R12IE4 using the same SCALE-2 circuit technology with Advanced Active Clamping.

The Advanced Active Clamping integrated in the SCALE-2 chipset has – in addition to all the advantages of the simple Active Clamping solutions – the following benefits:

- Simple scalability in the voltage class
- Low thermal load of the clamping elements
- Very low-ohmic gate resistors possible
- Steep limiting characteristic
- Suitable for all modern high-power IGBT modules
- Periodic operation possible
- Minimum switching losses
- Improved system performance
- Self-adapting system, acts only when really needed
- Can be configured simply and safely
- Very competitive system costs

Conclusion

Advanced Active Clamping is one of the most important features of a modern driver for high-power IGBTs. The circuit not only protects the IGBT in the event of a fault, it is also the precondition for allowing the optimal utilisation of IGBT modules with high power densities. Integration by sophisticated analog or mixed-signal ASIC technologies allows the simple and cost-effective implementation of Advanced Active Clamping with very few components.

Drivers with Advanced Active Clamping are offered as ready adapted plug-and-play drivers and in the form of driver cores. The latter allow the user to adapt the circuitry to his requirements.

Outlook

The benefits of Advanced Active Clamping for direct parallel connection of IGBT modules, as well as in multilevel topologies, will be presented in the January 2010 issue of PEE. The integration of dv/dt feedback will also be covered.

Literature

[1] Heinz Rüedi, Peter Köhli: 'SCALE' Driver for High Voltage IGBTs, PCIM Europe Conference Proceedings Nuremberg, 1999

[2] Jan Thalheim, Heinz Rüedi: Universal Chipset for IGBT and Power-MOSFET Gate Drivers, PCIM Europe Conference Proceedings Nuremberg, 2007

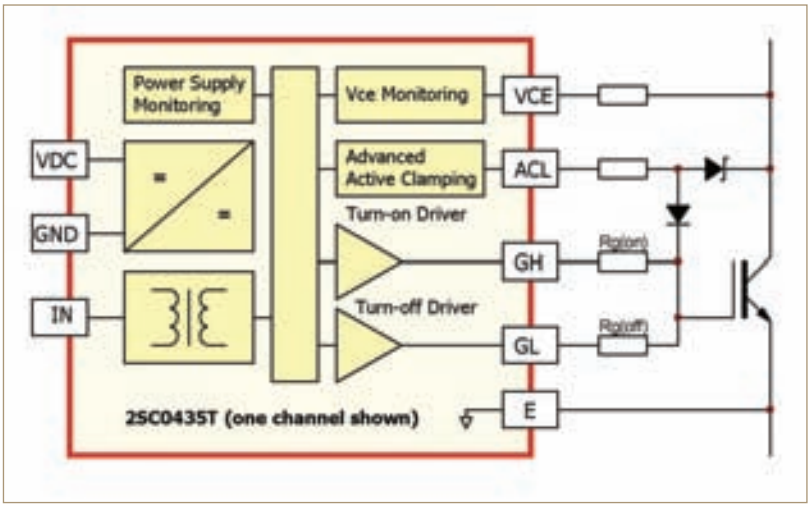

Figure 5: **SCALE-2 Integration of Advanced Active Clamping illustrated by the 2SC0435T driver core**

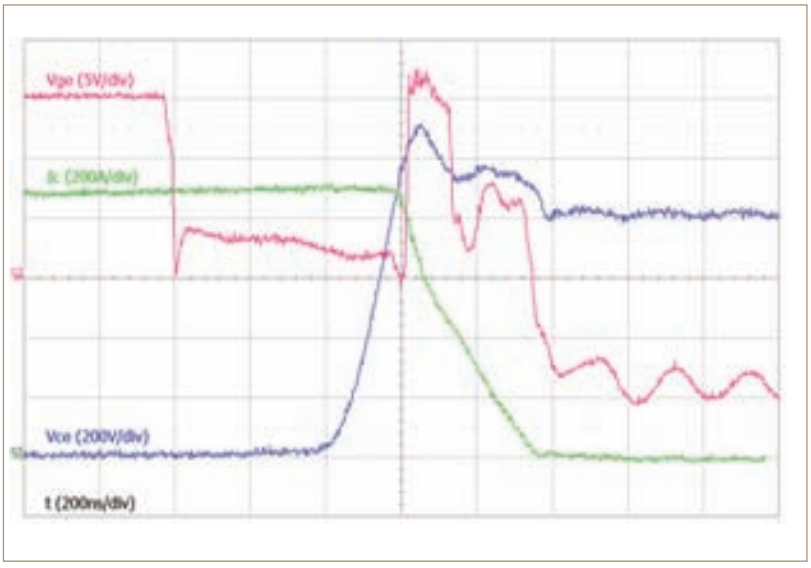

Figure 6: **Switching behaviour of a FF450R12IE4 IGBT with the 2SP0320T (with Advanced Active Clamping) at V_{dc} = 800V and I_c = 900A, L_{stray} = 68nH, Temp = +25°C**

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New 1200V SPT+ IGBT and Diode for High Temperature Applications

The application spectrum for the 1200V voltage class chips and modules is increasing worldwide due to the constant increase of power electronic systems present in various fields like automotive, industrial, regenerative power sources etc. Higher demands for improved electrical performance and reliability due to the increased levels of power and switching speeds in modern applications have resulted in development efforts for more optimised devices capable of withstanding such conditions. Moreover, a common trend of operating the devices under junction temperatures up to 175°C is present. **Bulent Aydin and Marta Cammarata, ABB Switzerland Ltd, Semiconductors, Lenzburg, Switzerland**

The SPT+ Enhanced-Planar technology was introduced in 2005 and covers voltage classes ranging from 1.2 to 6.5kV. During the current development of an improved SPT+ 1200V chipset, the IGBT was further optimised for higher reliability at higher temperatures, while keeping the electrical performance. Furthermore, a newly developed diode is designed for high reliability, soft recovery and low forward voltage drop.

1200V SPT+ IGBT and diode

The SPT+ IGBT design is shown in Figure 1. Its development target was to reduce the on-state losses by introducing an N-enhancement layer surrounding the channel P-well. This improves the plasma concentration at the emitter side and therefore lowers the on-state losses. On the other hand, the newly developed diode is based on a pin-diode design utilising a combined local and uniform lifetime control. A schematic cross-section is also shown in Figure 1. The optimised shape of the stored electron-hole plasma ensures a low forward voltage drop and soft reverse recovery performance.

Additionally, a state-of-the-art passivation design was developed for the new chipset including Silicon-Nitride and Polyimide layers ensuring high mechanical and environmental robustness and reliability, especially important when operating at higher temperatures.

The static and dynamic performances were extensively measured and evaluated to ensure matching the outstanding turn-off ruggedness even at high temperatures. Also the high levels of IGBT short-circuit capability are proven, despite the low on-state and switching losses.

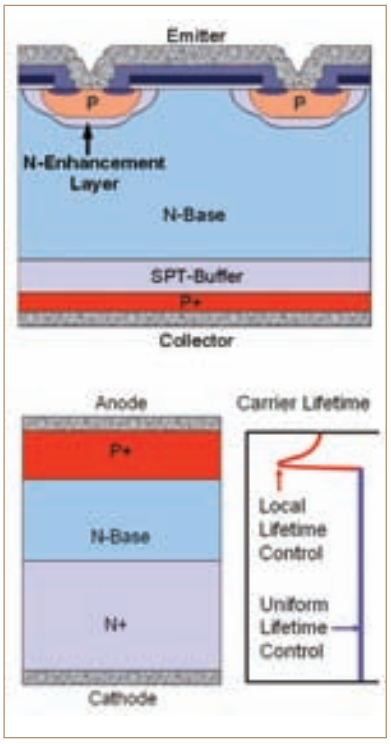


Figure 1: Schematic cross-section of the SPT+ IGBT (top) and diode (bottom)

Static and dynamic performance

The measurements presented here are performed on IGBT and diode chips rated for 100A nominal current, with an active area of 104mm² for the IGBT and 50mm² for the diode.

The IGBT electrical characteristics include low on-state losses with a strong positive temperature coefficient, as shown in Figure 2. This is a very important feature for ensuring safe paralleling when chips are mounted in high current modules. At 125°C the IGBT shows a $V_{CE\,sat}$ value of 2V at 100A. The diode low forward losses with a positive temperature coefficient are also shown in Figure 2. At 125°C the diode VF shows a value of 1.8V at 100A.

Figure 3 shows the turn-off and turn-on switching characteristics under nominal conditions at 125°C for the 100A IGBT chip. In both cases, the current transients during switching are very smooth and soft with short-current tails resulting in low losses, low overshoot voltages and low EMI levels.

Under nominal conditions of I_C = 100A, V_{DC} = 600V and with a stray inductance

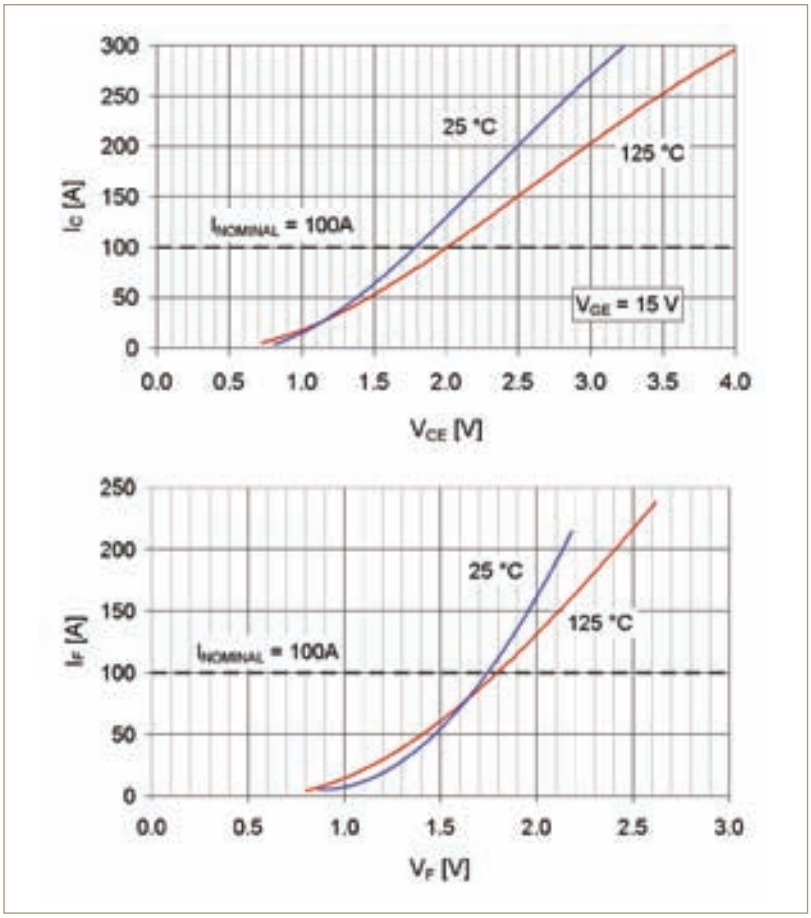


Figure 2: On-state characteristics of the 100A IGBT (top) and diode (bottom)

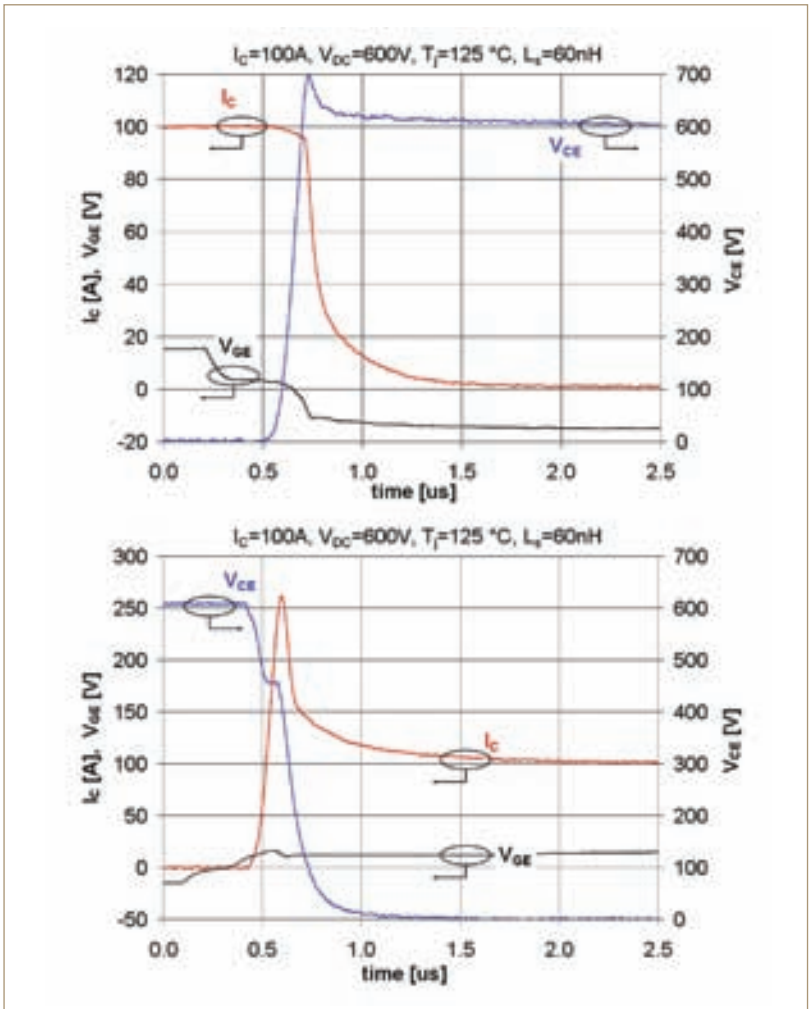


Figure 3: 100A IGBT turn-off (top)and turn-on (bottom) characteristic

L_S = 60nH, the fully integrated switching losses at 125°C are: IGBT turn-off energy E_{OFF} = 11.9mJ and IGBT turn-on energy E_{ON} = 14.7mJ. The diode reverse recovery current behaviour is mirrored in the IGBT turn-on waveform. Also, for the diode the current transients during switching are very smooth and soft. Under nominal conditions of I_F = 100A, V_{DC} = 600V and with a stray inductance L_S = 60nH, the fully integrated reverse recovery energy is E_{REC} = 12.6mJ.

SOA performance

The excellent safe operating Area (SOA) ruggedness of the SPT+ technology is confirmed for the IGBT turn-off in Figure 4. A successful turn-off of 800A i.e. eight times the nominal current with a DC-link voltage of 1000V at 175°C, and a higher than standard stray inductance of 200nH is shown. The peak-power reached in this test was 800kW, while clearly surviving dynamic avalanche conditions and also successfully withstanding Switching Self Clamping Mode (SSCM) of operation. The measurement was done using a gate-emitter voltage of 20V. In the subsequent test-step of 850A, the IGBT went into current saturation and turned off in a short-circuit type mode. This shows that the IGBT has an excellent robustness being able to turn off all currents up to saturation at V_{GE} = 20V.

This test confirms the suitability of the IGBT for operating at higher temperatures since the SOA represents a main limitation towards operating silicon devices under such conditions.

The short-circuit capability of the new 1200V SPT+ chip is shown in Figure 5. The waveform shows how a 16µs short-circuit pulse was withstood at 175°C and with a DC voltage of 900V. The corresponding short circuit current is 400A and the total energy dissipated is 5.9J. The devices were also verified at a wide range of temperatures showing rugged performance under all short-circuit test conditions.

In Figure 6, the SOA ruggedness of the diode is demonstrated. The reverse recovery at 200A i.e. double the nominal current, with a DC-link voltage of 1000V at 175°C and with a switching speed of dI_F/dt=4900A/µs, i.e. twice the nominal switching speed, is shown. The resulting total peak power is 400kW, with the device withstanding clear dynamic avalanche conditions.

The softness reverse recovery test performed at 1/10th of the nominal rated current and at a higher-than-standard stray inductance of L_S = 200nH is shown in Figure 7. It confirms the diode very soft recovery behaviour with small oscillations at a peak overshoot voltage of 1050V.

The rugged design and improved passivation have enabled the new chipset

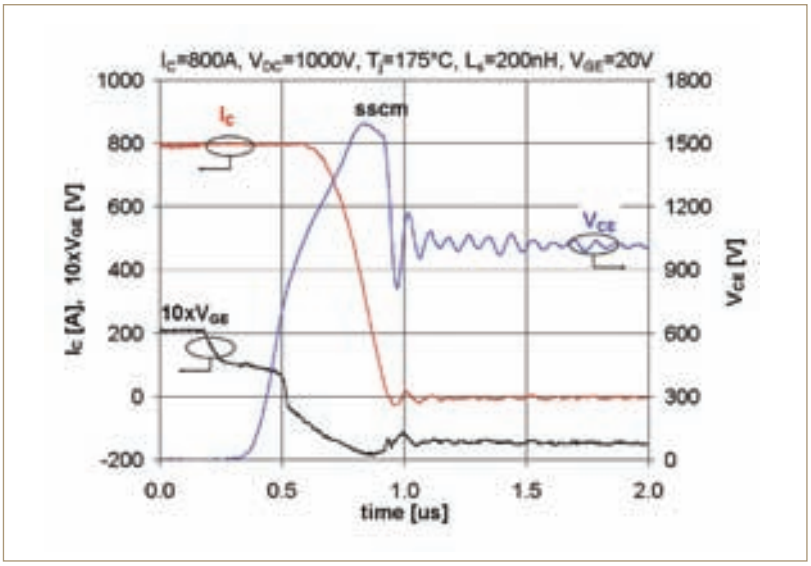


Figure 4: **IGBT turn-off under extreme conditions demonstrating the high ruggedness of the newly developed chip**

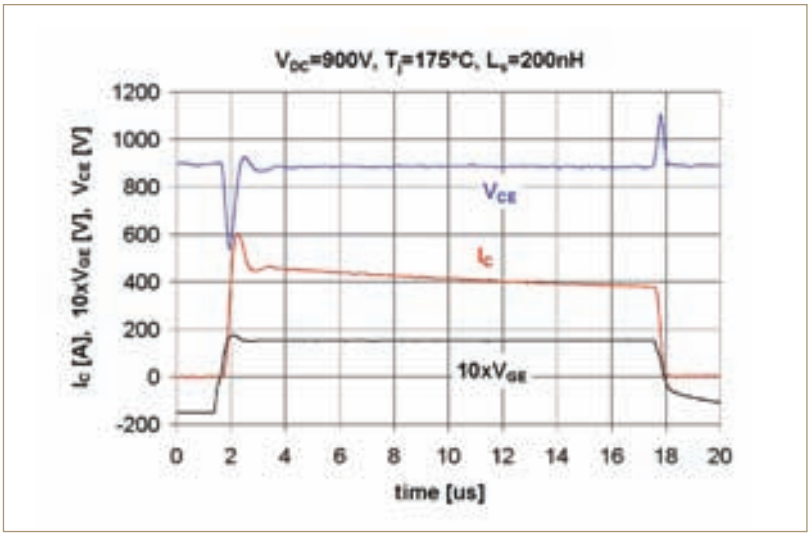


Figure 5: **Short circuit SOA waveform of the 1200V SPT+ IGBT**

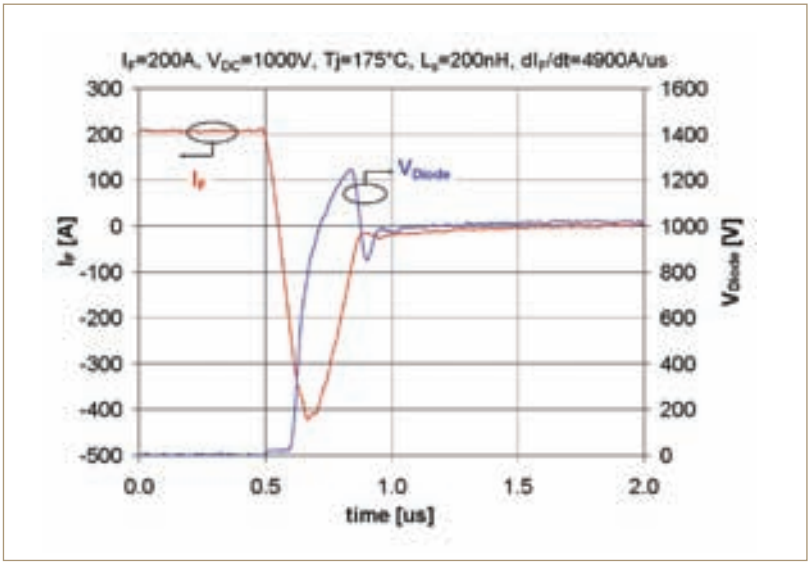


Figure 6: **Diode reverse recovery under SOA conditions**

to be seriously considered for the future applications targeting 175°C as a maximum operation junction temperature.

High reliability performance

The reliability of the new chip-set was qualified using a combination of standard tests including HTRB (High Temperature Reverse Bias), HTGB (High Temperature Gate Bias), THB (Temperature Humidity Bias), Cosmic Ray test and a newly developed test which combines high temperature, high humidity and high voltage.

More precisely, in this new test the IGBTs are switched with a frequency of 1kHz at an ambient temperature T = 85°C with relative humidity RH = 85%. The switched voltage is V_{DC} = 750V with an overshoot at the turn-off transient that reaches a peak value of 900V. The test is carried out at a

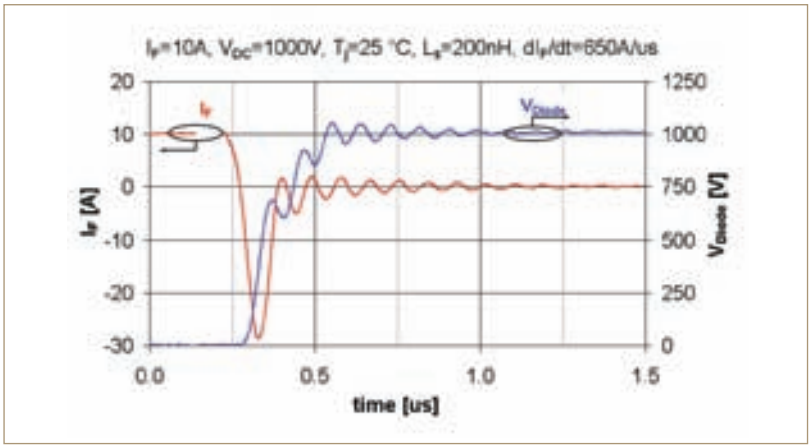
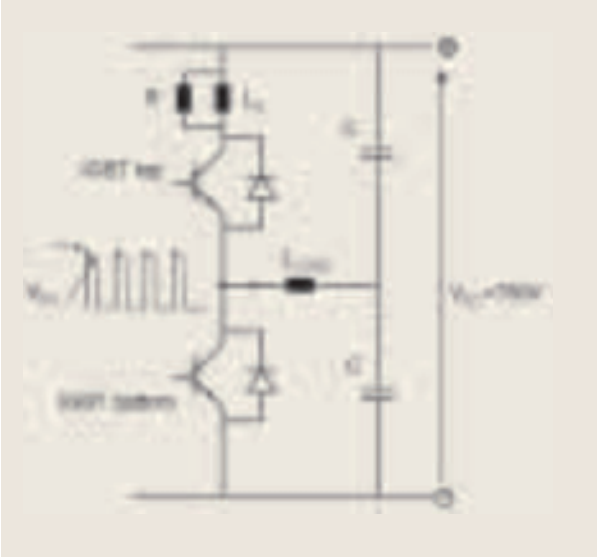


Figure 7: Softness reverse recovery for a 100A rated diode

Figure 8: Circuit scheme used for the THB-V_{DCsw} test



relatively low current level. We called the test THB-V_{DCsw} (Temperature-Humidity-Bias, performed at the DC-link voltage and switched). The test circuit is shown in Figure 8.

It is evident how the switching at the nominal DC-link voltage imitates biasing conditions very close to those the device experiences in real field applications, while the acceleration property of the test is given from the high temperature and high humidity values.

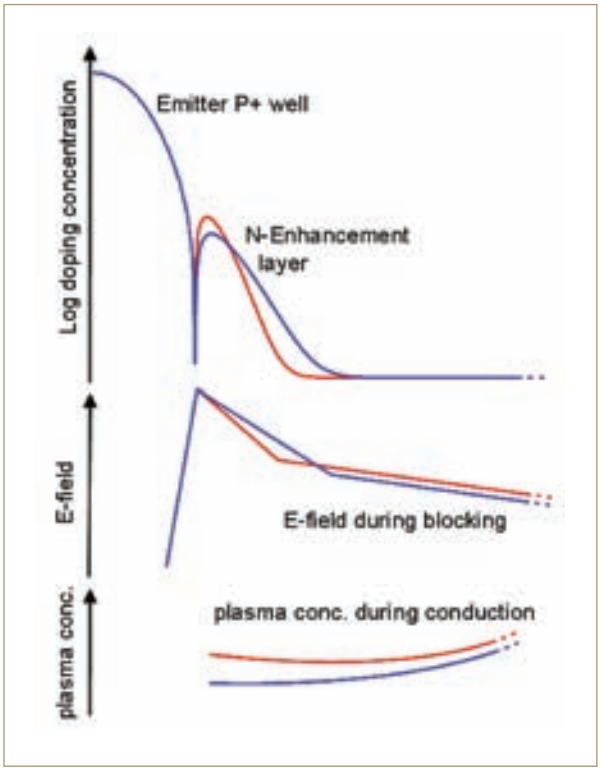
Outstanding performance of the new chip-set was proven by testing over 1000hr without any failure. By comparing the measurements performed after test with the measurements done before test, the chips show very stable electrical characteristics and values. Further investigations are planned to obtain the chips' lifetime limits under nominal conditions, and also to provide a further acceleration factor by increasing the DC-link voltage levels.

Future developments

Current development efforts are targeting design parameters of the N-enhancement layer to exploit its development potentials. This investigation focuses on the presence of the N-enhancement layer which brings forth a reduction in the avalanche blocking capability of the device. Hence, the shape of the enhancement layer doping profile can be optimised, in order to maximise the enhancement feature and minimise the loss of blocking performance.

As shown in Figure 9, this is possible if the layer is narrow but with a higher concentration (red profile in the figure). A narrow N-layer has the advantage of generating a small modification of the electric field shape, and therefore less blocking capability reduction. The higher doping concentration of the N-enhancement layer has the advantage of increasing the enhancement effect and therefore lowering the on-state losses. Experimental results from fine optimisation of the enhancement layer have resulted in an increased enhancement effect and between 5 to 10% lower on-state losses for the same blocking capability.

Figure 9: IGBT cell emitter doping profile and related electric field and plasma concentration for the enhancement layer



Comprehensive Testing with Combination Testers

Increasing quality demands require comprehensive, 100% testing of semiconductors. Static tests are no longer enough. Only supplemental dynamic testing procedures, such as switching unclamped inductive load and a double impulse test can meet the requirements. Inspection of thermal impedance is very important in the process. The simplest approach uses a test system that can perform all these tests.

Günther Dörgeloh, General Manager MRS Electronic, Rottweil, Germany

Since the IGBT die cannot be tested thoroughly before assembly, all parameters have to be tested after the module was assembled. A complete test consists not only of parameter testing, but also the thermal connection of the chip to the heatsink and the dynamic switching behaviour. Thus, a test sequence consists of a pretest measuring the cold parameters, then the stress test dynamic and thermal impedance (Z_{th}) and retest to make sure the part is still functional. To conduct all these test in one station, combination testers are available.

Parameter testing

The static parameters of power semiconductors are the most important parameters that must undergo testing after production. The I_{DSS} (drain off-state current) and $I_{GSSf/r}$ (forward and reverse off-state current of the gate) leakage currents, in particular, provide information on any possible mechanical damage to the chips. Gate threshold voltage and breakdown voltage are important indicators of doping. But is that still enough today?

Static tests are often inadequate to meet the high demands for quality in the manufacture of special-purpose machinery and in the automobile industry. Future requirements in the automotive industry are clearly moving in the direction of robust design and validation. But a robust design of components that are released according to the most modern methods does not help if process problems occur in production and nullify such efforts. To keep the required failure rate <10 ppm, advanced tests must guarantee the quality of production.

Dynamic test

Dynamic tests examine the switching behaviour of the component under load. The component will ultimately be used as an electronic switch in converters and similar units. For IGBTs, at high environmental temperatures RBSOA (reverse bias save operation) is especially critical. Components with avalanche characteristics must pass the switching unclamped inductive load test. This test destroys weak components.

Thermal impedance test

The production of heat in any noteworthy quantity is a very undesirable, yet unavoidable, property of every piece of power electronics. In this context, it is very important that the semiconductors have the ability to dissipate as much of the heat as possible from the place of origin (depletion layer) to the environment (heatsink) via the enclosure (see Figure 1).

The bubbles and voids that appear during soldering of a chip impede the required heat dissipation. The component will work for a limited time but, sooner or later, a thermal failure will occur. Measuring the thermal impedance (Z_{th}) provides information on the thermal connection of the chip. It is unnecessary to examine all of the characteristics; measurements at one or

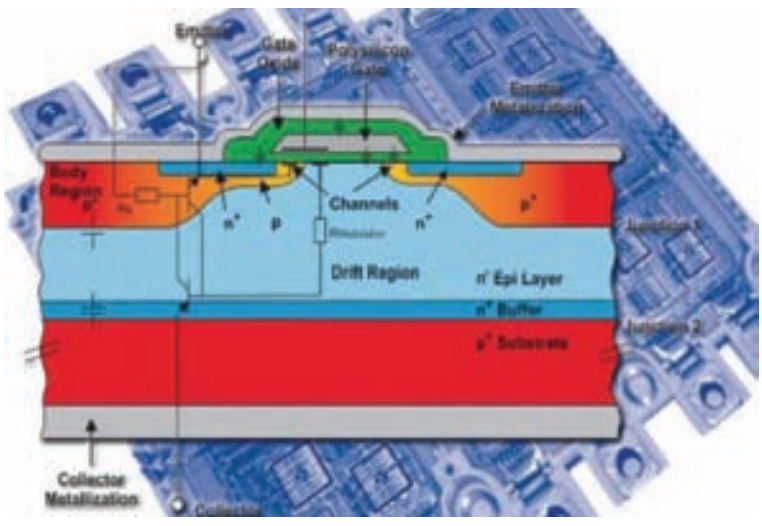


Figure 1: Structure of an N-channel IGBT cell

two informative measurement points are sufficient.

Only one contact

The required quality demands that these tests (switching unclamped inductive load test, RBSAO and Z_{th}) be performed as a 100% test of the components. The simplest solution would be to use specialised testers with independent contacts, possibly even for additional hot and cold tests. It is readily apparent that this approach does not make economic sense, but it is nonetheless possible to combine the tests mentioned above in one tester, despite the different ancillary conditions of each test. This approach saves the effort of multiple contacts and handling time.

And the following is also possible. First, the static parameters can be determined to deduce the processes for chip manufacture and assembly. Second, stress tests can be performed with an increasing load. The static parameters would then be measured again to ensure that the stress tests did not do any damage. And all that can be done with just one contact.

MRS' modular testers enables tailoring of the vertices (maximum test voltage, maximum current, and the required multiplex productions) to the requirements. The tests run in real time on a high-performance digital signal processor (DSP). A commercial PC is used to control the tester.

Measuring the static parameters

For the static parameters, a source instrument adjusts the test voltage or the test current and measures the variables. The measurement module works continuously. Except for the indispensable anti-alias filter, the hardware does not contain any additional filters. The DSP performs each processing of a signal. From a large assortment, the optimal FIR filter can be selected for each test. Short filter times are used for time-critical measurements. Sensitive measurements, such as leakage currents in the lower nA range, require longer filters. Digital signal processing enables very exact, reproducible measurements of leakage current, even in extremely electromagnetic industrial environments.

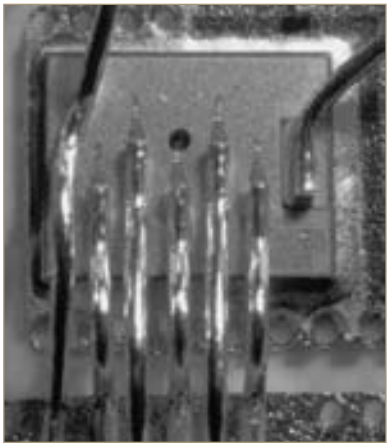


Figure 2: Failure of a transistor in a switching unclamped inductive load test

Measuring dynamic behaviour

The two dynamic tests used most widely are the switching unclamped inductive load test and the double impulse test. Both involved stress tests that destroy problematic components.

The switching unclamped inductive load test links the test to an inductive load without an override (unclamped). The transistor is switched off once the specified cut-off current is reached. Because there is no override path, the current continues to flow through the unit being tested and drives it into the avalanche breakthrough or into linear mode if an active clamp is required over the gate. Within a very short time, a very high rating in the chip is converted into heat.

In cases of inhomogeneous, defective doping or defective source or emitter gate metallisation, hot spots on the silicon develop that can lead to fusion of the crystal (see Figure 2). IGBTs, in particular have an unavoidable parasitic thyristor structure that ignites when the failures noted above occur, and that can lead to a latch-up with the resulting destruction of the component. These kinds of components may not leave production in any circumstances. FETs have only a part of these parasitic structures, so that there is no danger of a latch-up. Nevertheless, these structures are enough to cause comparable failures (a controlled increase of the parasitic bipolar transistor).

The set-up for the double impulse test is comparable to the set-up for the unclamped inductive load test, although an override path exists in this case. If complete converter modules or phase legs are being tested, the existing diode conveniently located on the opposite side of the transistor can be used as an override diode. This approach corresponds to later usage. A complete switching cycle is now run: commutation of the current into the override diode and reserve recovery of the override diode when switching back on. A test tester monitors the ancillary conditions of the test. A rapid digital storage oscilloscope can also be used to perform additional detailed analysis of current and voltage curves online.

The dynamic tests of IGBTs are especially interesting at high environmental temperatures. The current gain of both parasitic transistors increases as the temperature rises, as does the extrinsic base resistance. Both increase the danger of a latch-up. An appropriate choice of test parameters enables testing compliance with the safe operating area of each component. The transformed heat is mostly limited to the chips.

Measuring the thermal impedance

Measuring the thermal impedance can determine the amount of created heat the component can dissipate in long-term operation.

Measuring the thermal impedance occurs in three phases:

- Measurement of a temperature-dependent parameter (diode flow voltage, saturation voltage, and so on),
- application of well-defined (electric) energy,
- second measurement of the temperature-dependent parameter directly (in as short a time as possible) after the power impulse.

Application of well-defined energy means that constant power must be adjusted over a specific time. The time is determined from the thermal time constant of the structure to be tested, usually between 10 and 500ms. The power is selected to enable good measurement of the temperature difference without exceeding the maximum barrier layer temperature. The amount of warming that has occurred can be calculated from the change of the temperature-dependent parameter.

This measurement of Z_{th} corresponds exactly to reality and is clearly superior to other approaches.

Figure 3 illustrates a detailed analysis of a module that was rejected by the tester during the product part approval process (PAPP) phase. Curves ZTH_1 to

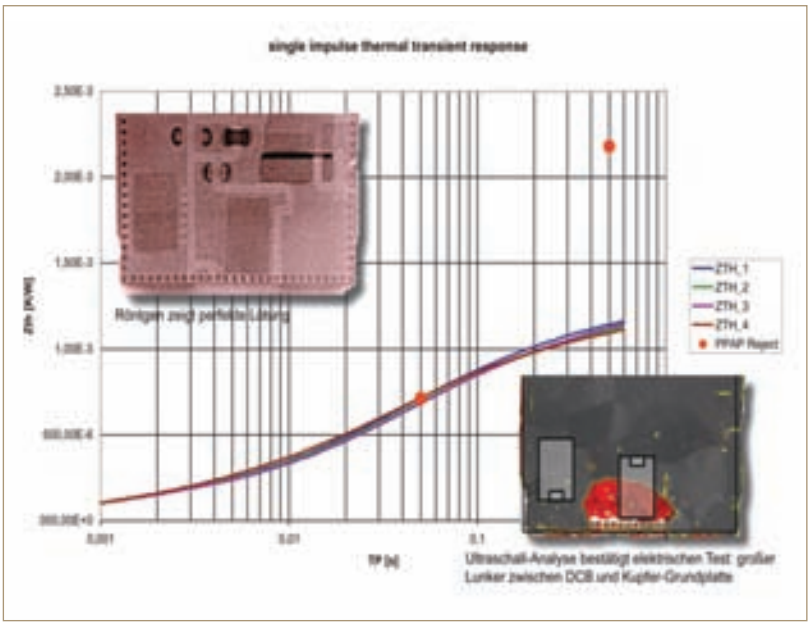


Figure 3: Rejection of a chip with poor thermal fastening

ZTH_4 were determined during the evaluation phase to specify the thermal behaviour of good parts. The routine test uses a power impulse that lasts 500ms. It is briefly interrupted after 50ms for an intermediate measurement of the temperature-dependent parameter. No abnormalities are seen after 50ms, but extreme abnormalities are seen after 500ms. The reason for the difference is that the chip is very well soldered with direct copper bond (DCB) and can dissipate the heat very well to the DCB.

The bubble is located between the DCB and the copper baseplate. That is why the bubble cannot be seen by an X-ray. The solid copper baseplate absorbs so much of the X-rays that the bubble disappears in the noise. Only an expensive ultrasound examination would confirm the results of the tester. Only an analysis of both Z_{th} results that are determined in a sort of inspection impulse contains valuable information for the process engineers.

This component was perfect in terms of the static parameters and passed both dynamic tests without any problems. In the field, however, it failed in a short time because of overheating.

Semi-Regulated Bus Converters

SynQor has launched several new entries in its SQ60 series of isolated semi-regulated DC/DC converters for intermediate bus architecture applications. The SQ60 series accepts the full Telco input range of 36 to 75V and provides a semi-regulated 12V for point-of-load converters. These converters incorporate board-mountable, fixed switching frequency technology, and use synchronous rectification to achieve full load power conversion efficiencies approaching 96%. The SQ60120ETA17 provides 204W in an open-frame, eighth brick package with power dissipation so low that it does not require a heatsink.

The 12V quarter-brick offerings include the 25A/300W SQ60120QEx25 bus converter, available in an open-frame or baseplated package, the SQ60120QPA28 a 28A/336W open-frame bus converter, and the 33A/396W SQ60120QPB33 baseplated converter. The SQ60060QPA55 is a 6V bus converter in an open-frame configuration providing 55A/330W for lower bus voltage requirements. The SQ60120HZA50 is a 12V half-brick bus converter that can provide up to 50A/600W in a baseplated configuration.

The quarter-brick and half-brick converters all feature tightly matched output droop share characteristics. This provides for direct paralleling of devices without any additional external circuitry.

Each of the droop share converters are calibrated at the factory to ensure the output voltage is well matched. In addition to current sharing, a droop characteristic improves load transient response as well as point-of-load converter stability.

www.synqor.com/busqor

IGBT Modules with Fuji V-IGBT Chips

In addition to the existing SEMIKRON modules with IGBT chips from Infineon, SEMITRANS modules are now also available with V-IGBTs from Fuji with a 1200V blocking voltage. The new V-IGBT comes in three different module sizes, a total of eight different power classes, and three switching topologies. The modules are available with a rated current of 150 to 600A. SEMITRANS 3 and 4 modules are very low-inductance modules with a module inductance of just 15nH. The typical IGBT switching speed of 5000A/µs results in a module overvoltage of just 75V.

The modules come in single-switch, half-bridge or chopper topology specifically for inverters in industrial drives or any other given area of application. Standard SEMITRANS modules boast high insulation strength of 4000V/min, which is 60% higher than the global insulation strength norm of 2500V/min.

In addition to the 1200V modules featuring IGBT2, IGBT2 fast, IGBT3 or IGBT4 technology, the modules are also available with a blocking voltage of 600 and 1700V. Three standard SEMITRANS case sizes, 34 mm wide SEMITRANS 2 and 62mm wide SEMITRANS 3 and 4 modules are available. Additional sizes for non-standard customer applications are also offered, for example SEMITRANS 6 with six-pulse inverter bridge circuits, SEMITRANS 5 with circuits for three-level inverters as well as for current monitoring, which is achieved by integrating shunts. SEMITRANS 9 was developed to provide a particularly high insulation strength of 9kV for railway applications. All SEMITRANS modules feature a copper baseplate.

www.semikron.com

350W Half-Brick DC/DC Converter

Power-One has introduced the HBA48T12280, a 350W DC/DC converter for use in cellular infrastructure applications and more specifically to RF amplifier applications. The HBA48T12280 has a smooth efficiency curve that equals or exceeds 90% for loading conditions ranging from 40 to 100%. Its ultra-wide trim range allows it to be configured to operate within a 21 to 33V DC output. Additional features include: 36 to 75V DC input range, -40 to 100°C operating temperature range, capability to withstand a 100V input transient for 100ms, ability to start-up into pre-biased loads, and an on-board input differential LC-filter.

The HBA48T12280 has an industry-standard half-brick footprint (61mm x 57.9mm), a low profile (12.7mm) height, and is RoHS compliant for all six substances.

The open-frame converter module is constructed with a dual-board approach using discrete magnetics.

www.power-one.com

60W DC/DC Switching Regulators

Powersolve's PSR30 and PSR60 series are DC/DC switching regulators designed for battery or distributed power applications.

Available from stock, there are eight models in the series featuring non-isolated outputs up to 60W. With efficiencies as high as 96%, a 250kHz switching frequency and a wide DC input range, the new regulators provide outputs of 5, 12, 15 or 24V. Supplied in a compact open PCB single-in-line (SIL) package, the devices accept inputs from 20 to 53V DC. Operating ambient temperature range is –25 to +65°C and short circuit and overload protection is standard.

Newbury-based Powersolve Electronics Ltd was established in 1987 as both a distributor of power products for many of the industry's leading power supply companies and as a manufacturer in its own right of standard and custom power solutions.

www.powersolve.co.uk

LDOs with 8µA Quiescent Current

Texas Instruments has launched a family (TPS727xx) of 200mA, low dropout regulators (LDOs), which offer an auto low-power mode that combines ultra-low quiescent current of less than 8µA with fast transient response while maintaining low noise and a high power supply rejection ratio (PSRR) of 70dB at 1kHz. With 70% lower quiescent current than existing devices, the new LDOs help increase battery runtime without sacrificing performance in noise-sensitive applications, such as smart phones, MP3 players, RF modules, remote controls, ZigBee network systems and handheld consumer devices. Typical high-performance LDOs require the load quiescent current to be 25µA or less. Auto low-power mode allows the TPS727xx to achieve less than 8µA without an additional mode pin and automatically switches to and from low power depending on load current. In addition, the use of auto low-power mode eliminates the need to modify software drivers to control the mode pin, which speeds and simplifies the design process. It also reduces cost by eliminating the need for a general purpose input/output (GPIO) pin and overhead firmware. It also provides low dropout of 130mV, plus stable and accurate output voltage range of 0.9 to 5V, which increases system reliability.

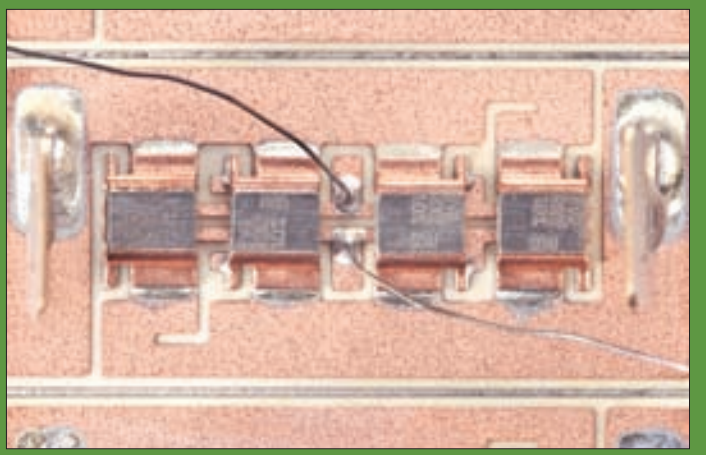
www.ti.com/tps727-preu

Correction (PEE 7-2009, pages 20 - 23)

Shunt Current Measuring up to 800A in the Inverter

In 2005, Siemens Drive Technologies introduced the first large inverter using shunts for phase current measuring and brought it into series production. It wasn't until recently that the power output was extended to 132kW with the new inverter SINAMICS G120 series. Back then, the joint development between Siemens, Semikron and Isabellenhütte laid the foundations for being able to measure currents of up to 800A today.

The shunt modules developed by Semikron (module housing) and Isabellenhütte (shunts) for high currents are optimised in terms of TCE (thermal coefficient of expansion), offset, long-term stability and capacity and therefore meet the above mentioned requirements almost perfectly. They contain a parallel circuit of up to four precision SMD resistors (see Figure 5) for each phase, which are mounted onto a DCB substrate for better heat dissipation. By using optimum resistors and modified geometry for the DCB layout, a TK of 30ppm/K will be maintained for all modules. This figure shows part of a power module not from Semikron. For this reason, here is the correct photograph of Semikron's power module with four BVR current sense resistors from Isabellenhütte.



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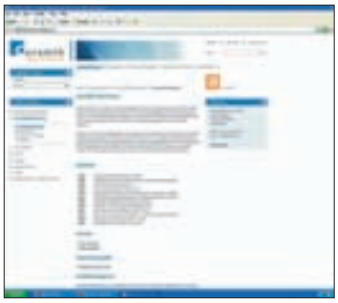

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IRFP4004PBF	40	1.7	195*	220	TO-247AC
IRFB3004PBF	40	1.75	195*	160	TO-220
IRFS3004PBF	40	1.75	195*	160	D2PAK
IRFS3006-7PPBF	60	2.1	240*	200	D²PAK-7
IRFB3006PBF	60	2.5	195*	200	TO-220
IRFS3006PBF	60	2.5	195*	200	D²PAK
IRFS3107-7PPBF	75	1.85	195*	380	TO-247AC
IRFS3107PBF	75	2.6	240*	160	D²PAK-7
IRFP4368PBF	75	3.0	195*	160	D2PAK
IRFB4115PBF	100	2.6	195*	360	TO-247AC
IRFS4010-7PPBF	100	4.0	190	150	D²PAK-7
IRFS4010PBF	100	4.7	180	143	D²PAK
IRFS4127PBF	150	5.9	171	151	TO-247AC
IRFS4115-7PPBF	150	11	104	77	TO-220
IRFB4127PBF	150	11.8	105	73	D²PAK-7
IRFS4115PBF	150	12.1	99	77	D²PAK
IRFP4668PBF	200	9.7	130	161	TO-247AC
IRFP4568PBF	200	20	76	100	TO-220
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