ISSN: 1863-5598

ZKZ 64717
05-16

Bodo´s Power Systems®

Electronics in Motion and Conversion

May 2016

No need for external sensors with new power electronics

All information from page 24 on

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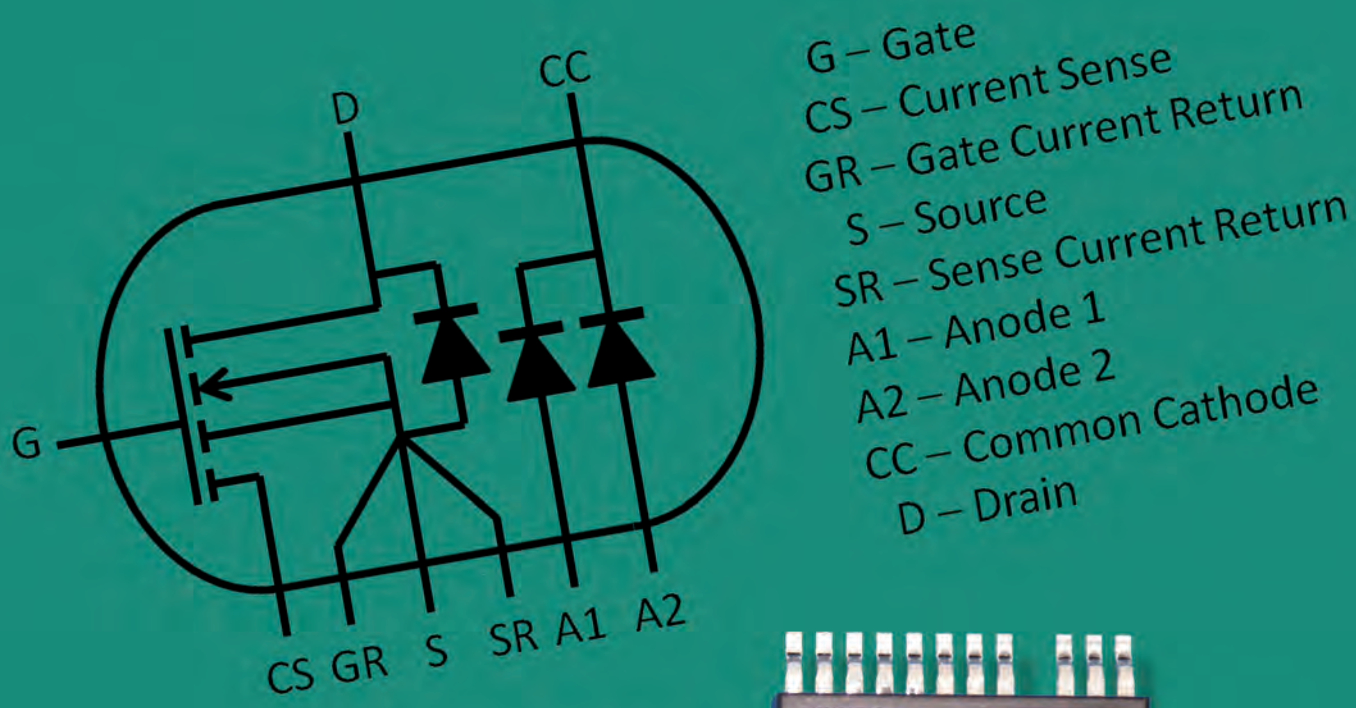
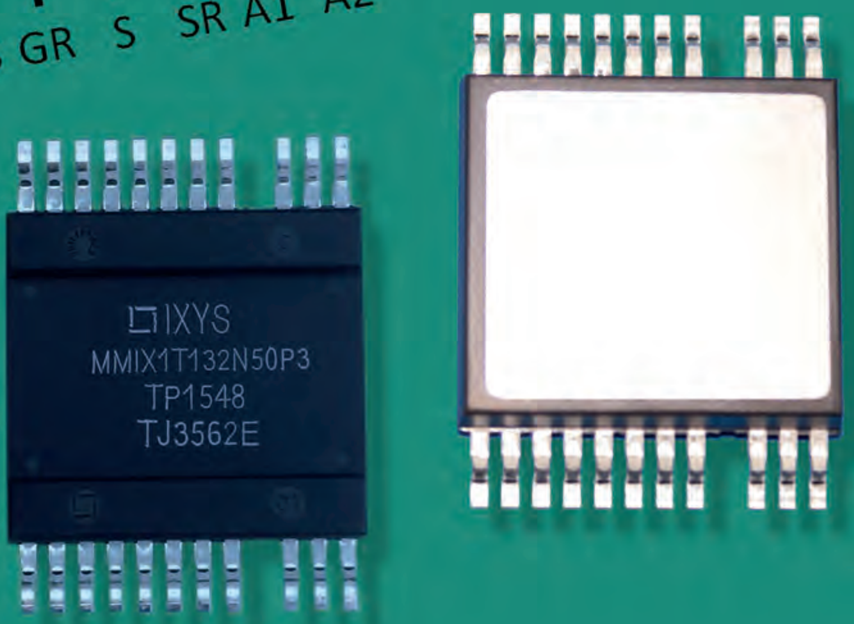
Electronics in Motion and Conversion

May 2016





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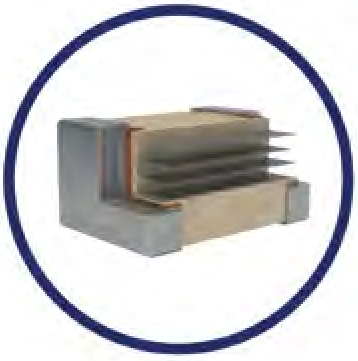
May 2016



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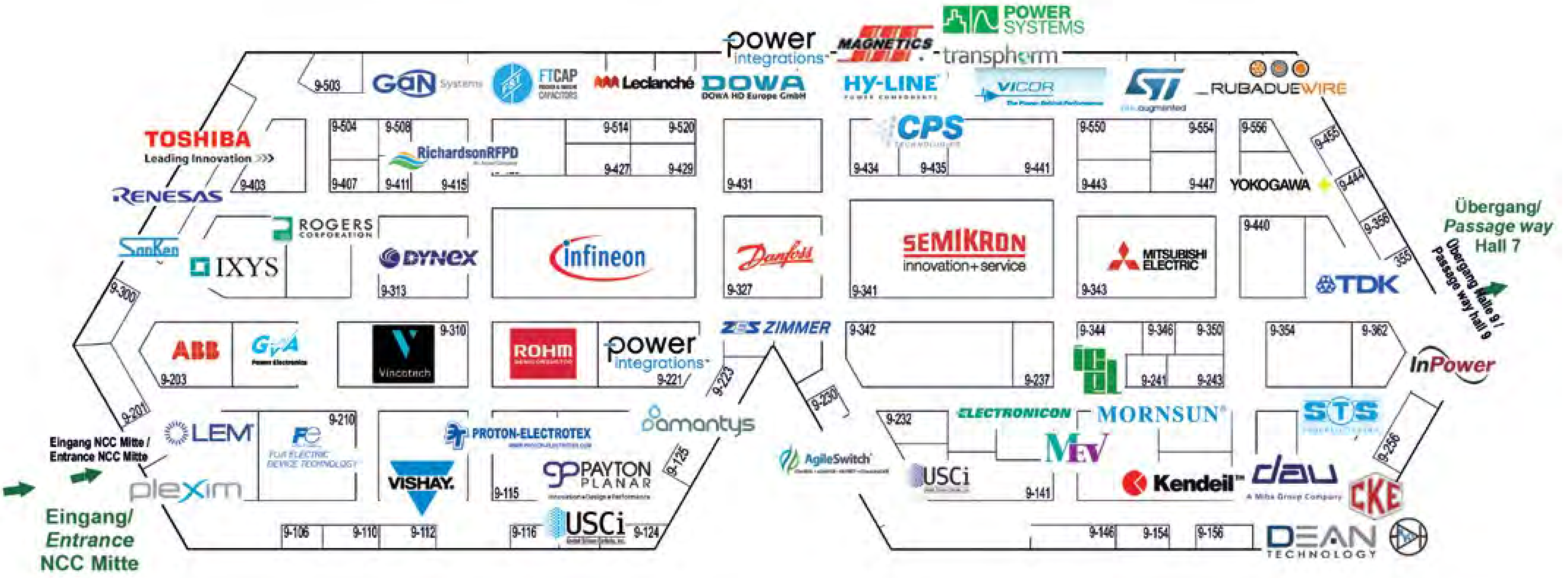
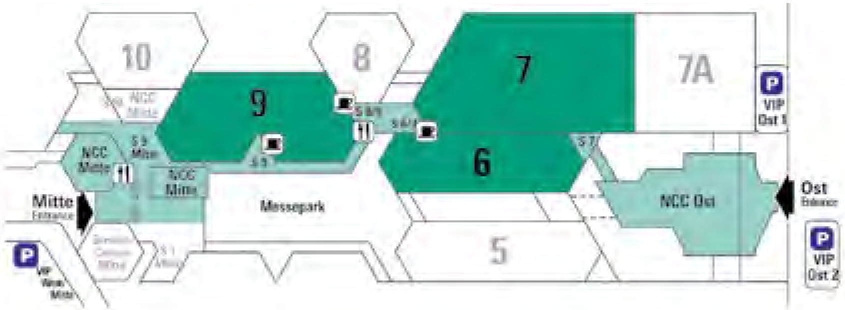
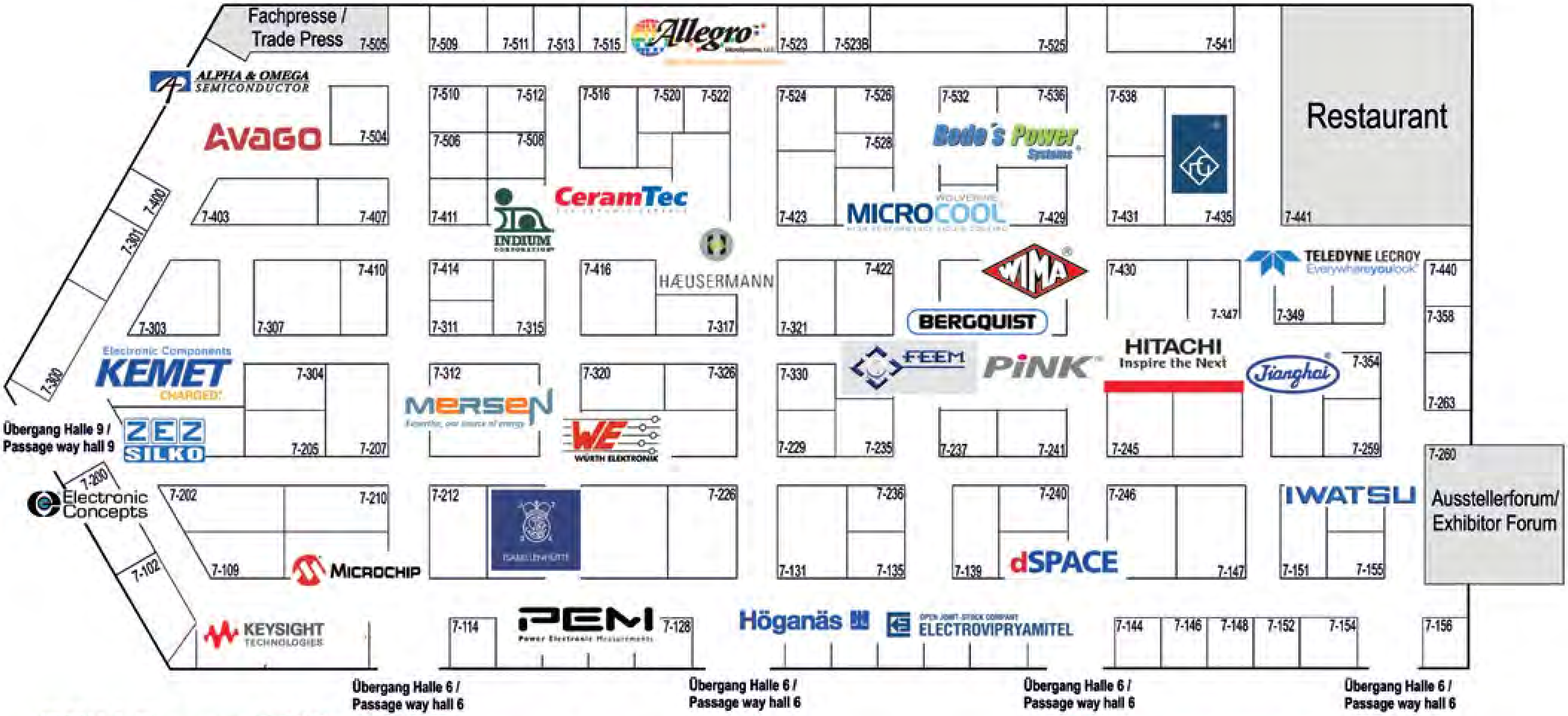
PCIM EUROPE

PCIM Europe 2016 - Hall 9



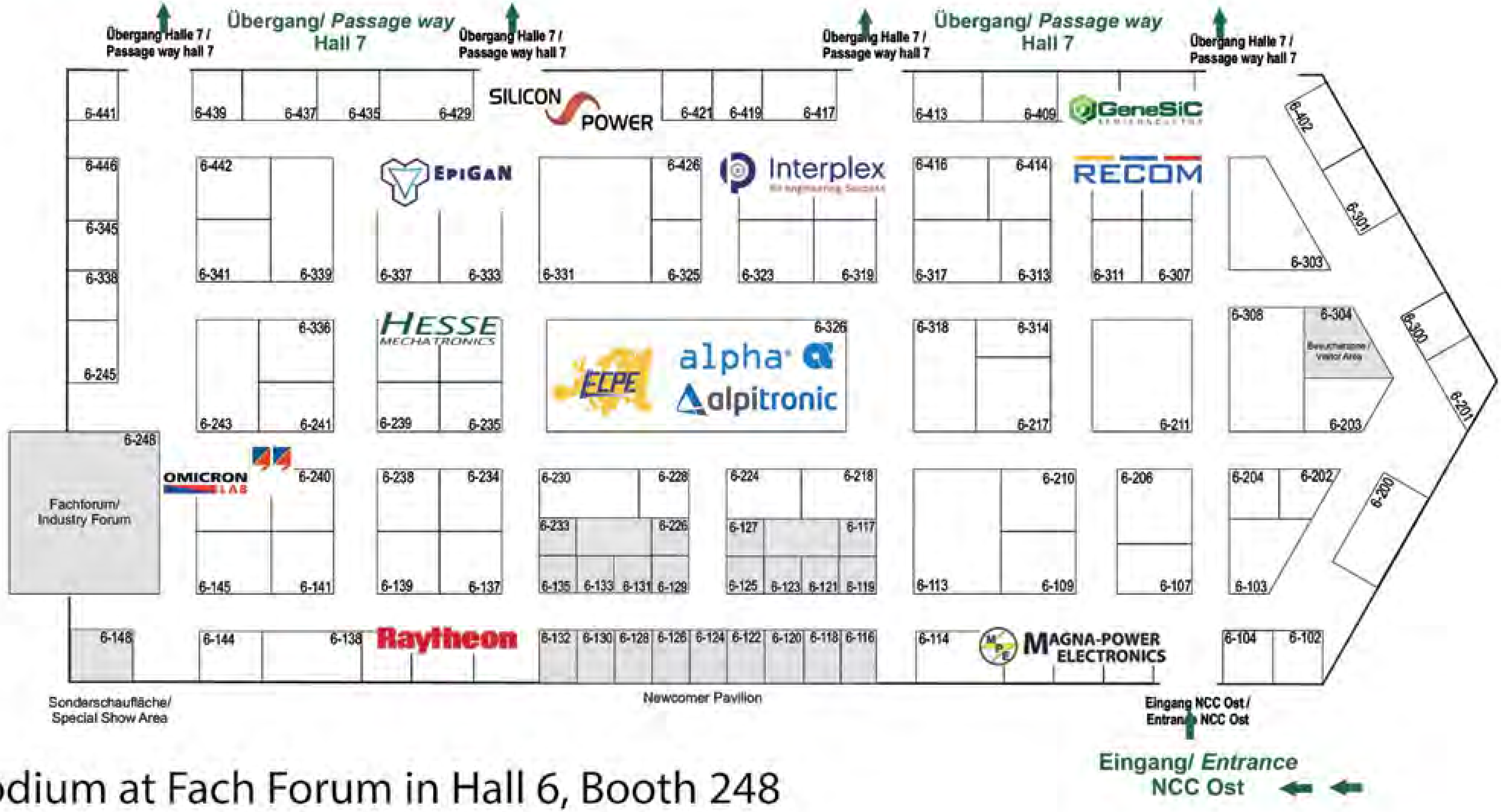
PCIM
EUROPE





PCIM Europe 2016 - Hall 7

PCIM Europe 2016 - Hall 6



Podium at Fach Forum in Hall 6, Booth 248

Wednesday the 11th of May

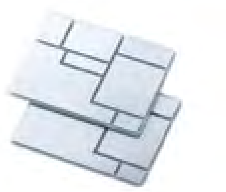
From 12:00 to 13:00 "SIC – Volume, Production and Cost"

From 13:00 to 14:00 „GaN – Volume, Production and Cost"

The Gallery

PCIM
Europe
Halle 9
Stand 529

One Source Solutions for your Power Modules



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Events

PCIM Europe 2016,
Nuremberg, Germany, May 10-12
http://www.mesago.de/en/PCIM/home.htm
http://www.mesago.de/download/PCIM/2016/PCIM2016_Konferenzflyer_WEB.pdf

Sensor + Test 2016,
Nuremberg, Germany, May 10-12
http://www.sensor-test.com/press

ISiCPEAW 2016,
Stockholm, Sweden, May 18-20
http://www.swerea.se/kimab

ISPSD'16 Conference,
Prague, Czech Rep. June 12-16
http://www.ispsd2016.com

Intersolar 2016,
Munich, Germany, June 22-24
http://www.intersolar.de/de/intersolar-europe.html

PCIM Asia 2016,
Shanghai, China, June 28-30
http://www.mesago.de/en/PCC/home.htm

Big Toys in Nuremberg

Nuremberg has always been an innovator of toys. It is always fascinating to visit the Toy Museum in the old town, or to visit the Industry Museum, or the nearby Train and Street Car Museum. For us as engineers, May is a world of big toys here in Nuremberg. PCIM is our playground and power semiconductors are our toys. I think back to the days in the late 80s while I worked for Harris and joined the advisory board of PCIM. A lot of innovations in power electronics have been achieved in the decades since then.

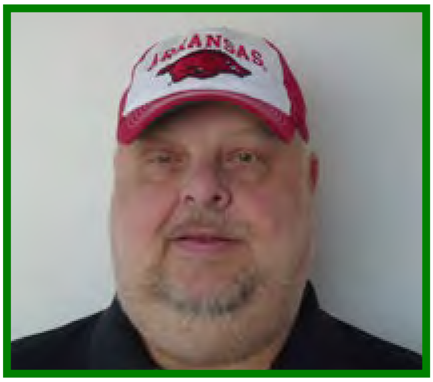
After over a quarter-century, another milestone in semiconductor innovation is upon us – Wide Band Gap technology has come of age. Raytheon produces an amplifier IC in SiC and Navitas introduced a monolithically-integrated, GaN, Power IC, with drive, logic and FET on a single die. Both companies have provided articles about their work for this issue. Several other articles focus on wide band gap devices and their applications. We're seeing more and more of these devices taking over from today's silicon-based semiconductors.

I have been monitoring WBG for years now at the PCIM. This year, the Podiums Discussion will take place at the Fach Forum in Hall 6 Booth 248 on Wednesday May11th. There are two sessions on Wide Band Gap Semiconductors:

12:00 to 13:00
"SiC – Volume, Production and Cost"

13:00 to 14:00
"GaN – Volume, Production and Cost"

I am looking forward to seeing you and hearing your questions for the panel of experts.



These are today's toys for power electronic engineers to make designs more efficient and reduce power consumption for a greener world with less pollution. The PCIM has much to offer with extensive technical paper sessions, poster presentations that allow conversation with the researcher, and a Come-Together party for an evening of relaxed dialog. Nuremberg in May is where power electronics experts simply have to be.

This is issue Number five for 2016. All technical articles are archived on my website. Bodo's Power Systems reaches readers across the globe. If you are using any kind of tablet or smart phone, you will now find all content available on the new web-site www.eepower.com. If you speak the language, or just want to have a look, don't miss our Chinese version: www.bodoschina.com

My Green Power Tip for May:
Get your kids some toys without batteries. They can make noise, blink their eyes, wave their arms, and develop imagination while helping the environment.

See you at the PCIM in Nuremberg!

Best Regards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First GaN Power ICs Leave Silicon Behind

Navitas Semiconductor announced the world's first Gallium Nitride (GaN) Power ICs, using its proprietary AllGaN™ monolithically-integrated 650V platform. Combining GaN power FETs with GaN logic and drive circuits enables 10x-100x higher switching frequency than existing silicon circuits, making power electronics smaller, lighter and lower cost.
A new generation of high frequency, energy efficient converters is being enabled for smartphone and laptop chargers, OLED TVs, LED lighting, solar inverters, wireless charging devices and datacenters.
"Breaking Speed Limits with GaN Power ICs"
"GaN has tremendous potential to displace silicon in the power electronics market given its inherent high-speed, high-efficiency capabilities as a power FET," says Dan Kinzer, Navitas CTO & COO. "Previously, that potential was limited by the lack of equally high performance circuits to drive the GaN FETs quickly and cost effectively. Navitas has solved this remaining challenge to unlock the full potential of the power GaN market. With monolithic integration of GaN drive and logic circuits with GaN power FETs, the industry now has a path to cost-effective, easy-to-use, high-frequency power system designs."
CEO Gene Sheridan added, "The last time power electronics experienced a dramatic improvement in density, efficiency and cost was in the late 70s when silicon MOSFETs replaced bipolar transistors, enabling a transition from linear regulators to switching regulators. A 10x improvement in density, 3x reduction in power losses and 3x lower cost resulted a short time thereafter. A similar market disruption is about to occur in which GaN power ICs will enable low-frequency, silicon-based power systems to be replaced by high-frequency GaN with dramatic improvements in density, efficiency and cost. This is an exciting time for the industry."

www.navitassemi.com

Minister Visit to Danfoss Silicon Power

Schleswig-Holstein's Minister for Economic Affairs, Labour, Transport and Technology, Reinhard Meyer, visited Danfoss Silicon Power March 4th, where he learned about the company's successful partnership with Kiel University of Applied Sciences (FH Kiel).
This relationship centers on the development of power electronics, especially technology for turning power semiconductors into power modules and for cooling power components effectively.

Meyer said that a successful technology transfer of this kind between universities and businesses fosters innovation and competitiveness, both within the region and beyond. He added that it also plays an important part in the transition to sustainable energy systems.
Dr. Frank Osterwald, Head of Technology at DSP (Danfoss Silicon Power), praised the close and effective cooperation with the university. He emphasized the fact that, besides the technical expertise involved, the project owed its success in large part to the outstanding work of FH Kiel's technology transfer and the university R&D center's project management. Since the partnership began, around twenty graduates of the university have found employment at Danfoss Silicon Power. He noted that the company has also invested millions in a specially developed production facility, which means it's now possible to provide outstanding, customer-specific products to the energy and automotive industries.
Prof. Dr. Udo Beer, President of the FH Kiel, highlighted the fundamental importance of cooperation with industry for the university, and expressed a hope that there would be more opportunities to support such partnerships in the future. These partnerships are particularly important as a basis for practically-oriented education, said Beer, and help ensure a reliable supply of qualified, skilled workers for the regional economy.
A number of international customers have shown an interest in the new technologies, and this interest has already resulted in specific project enquiries. These enquiries have prompted DSP to recruit 25 additional highly-qualified employees this year, mainly in the area of Development. This really demonstrates how DSP and FH Kiel are leading the way in partnerships between the public and private sectors.

www.danfoss.com

Imaging at SEMICON Europa 2016

The SEMICON Europa program agenda will feature the Imaging Conference 2016, an event highlighting the latest developments and applications in this fast-growing market. The conference will provide information on current and next-generation products, processes, and solutions driving the success of imaging applications forward.
New Imaging Pavillion: The new SEMICON Europa Imaging Pavilion will feature exhibitors being active in the fields of electronic imaging. A dedicated joined booth area on the SEMICON show floor offers excellent networking and speaking opportunities amongst your peers, customers, and suppliers. Cost efficient showcase options allow every company to make the best use of this new platform.
The smartphone "must have" feature is now propagating into fields as wide as automotive, industrial, medical, and agricultural thanks to the fantastic and speedy progress made in imaging technologies.
The conference will highlight progress from imaging giants and innovative start-ups across all application domains.
From silicon to system, SEMICON Europa has got semiconductors covered--and more. SEMICON Europa is the premier annual event for the European semiconductor and microelectronics industry, AND it is also a showcase for growing and emerging technology segments including:

http://www.semiconeuropa.org/

Halfday Seminar "Fundamentals of Power in the Data Center"

PowerRox's Brian Zahnstecher to Present at Both PCIM Europe & PCIM Asia This Year.

Power electronics in data center hardware can make or break the ability to enable an implementation for success or not. A common industry practice is to use simplified assumptions for loading and power conversion efficiency to provide approximate calculations of power utilization. Unfortunately, implementers find huge errors and variability between predicted and actual power consumption, which yield very costly (in CAPEX, OPEX, and time) headaches for many stakeholders. This is due to oversimplification of the highly convoluted and transient nature of power loading in the data center.

This entry to intermediate level tutorial will provide an in depth investigation into what drives power requirements in data center equipment. The first part will focus on key attributes of data center hardware system power budgets including major loads and their power profiles, correlation between such attributes and how they impact overall power demand (i.e. – how redundancy impacts budget), and specific examples (i.e. – blade server, white box, highend network switch). The second part will focus on rollingup what was learned about power budgets at the systemlevel into the rack, aisle, and complete data center levels to provide the full picture of the data center power solution all the way from the load to the building inputs. This will include many applicationspecific examples (i.e. – virtualization, dynamic power allocation, etc.) representative of solutions for today and tomorrow (i.e. – IoT, Cloud Computing, etc.).

Who should attend? Engineers involved in enterprise power solutions, Program Managers, Data Center Managers, enterprise/networking system designers, SW/FW Engineers, Mechanical Engineers, Technical Sales & Marketing Personnel, and anyone involved with OEM market penetration in the enterprise/networking space.

More details can be found on the PCIM websites (EU: https://www.mesago.de/en/PCIM/ or by contacting Brian Zahnstecher: bz@powerrox.com / +1 508-847-5747

https://www.mesago.de/en/PCIM/

Digi-Key Electronics Now Global Distributor for Syfer Technology

Products from Syfer Technology, a brand of Knowles, will now be available globally from Minnesota based, Digi-Key Electronics. Digi-Key are a worldwide full-service provider of both design and production quantities of electronic components from a range of quality name-brand manufacturers.

Commenting on the appointment, Knowles Capacitors Vice President of Sales and Marketing Steve Butcher, said, "We are delighted to be working with Digi-Key to bring the Knowles (Syfer) product range to an expanded audience of designers and users. The combination of Digi-Key service and Knowles products offers a terrific combination for our customers."

Tom Busher, VP of Global I P & E at Digi-Key added, "We are pleased to have the opportunity to add Knowles (Syfer) innovative application-specific capacitors to our diverse line card. Now engineers and customers anywhere can create designs and products with high-quality components suitable for their demanding applications."

Knowles (Syfer) products are of the highest quality, utilizing superior materials that span from volume products to high reliability, and from mil spec to space level. The company has led the industry over the years with leading technical advances like FlexiCap™ and StackiCap™ and have also developed a successful Planar Capacitor Array and EMI filter product line. With a history traceable back to Erie Electronics in the 1960s, Syfer is a global leader in Capacitor products, EMI filters and EMC solutions. The company was later acquired by the Dover Corporation and is now part of The Knowles Corporation, a recent spin-off from Dover. The brand is a constituent part of Knowles along with DLI, Novacap and Voltronics.

www.knowlescapacitors.com

Rebuilding Plant in Record Time

Würth Elektronik Ultramodern PCB production facility in Niedernhall is already up and running again

Just one year after the destruction of the plant in Niedernhall, the PCB specialist Würth Elektronik has rebuilt the production facility. And it was more than a matter of a mere replacement: All available modernisation options were utilized in the process. The result is one of the most advanced PCB plants in Europe.

A disastrous fire destroyed large parts of Würth Elektronik's PCB produc-tion in Niedernhall back in December of 2014. Since then, a specialist team has been working feverishly on the reconstruction. A modern build-ing at the same location is now home to attractively modern workstations and state of the art machinery and equipment. Double-sided and multilayer circuit boards are already being manufactured. The next step will be the production of more complex boards such as HDI and rigid-flex PCBs.

The PCB plant in Niedernhall is focusing on complex rigid-flex boards with its sights on the leading position in European technology. The high level of automation and standardisation enables economical production with high-er flexibility and short lead times – also in Germany. The aim is to maxim-ise the process reliability and reproducibility of all production steps as a quality advantage for the customer. This is not only achieved by using cleanroom technology (ISO classes 4 and 5), but also by utilizing laser direct imaging in the "photo printing" and "solder resist" processes. Through investments in new production machinery and equipment Würth Elektronik also considered the growing trend towards miniaturisation - for example, by integrating the spray coating technique.

http://www.we-online.com

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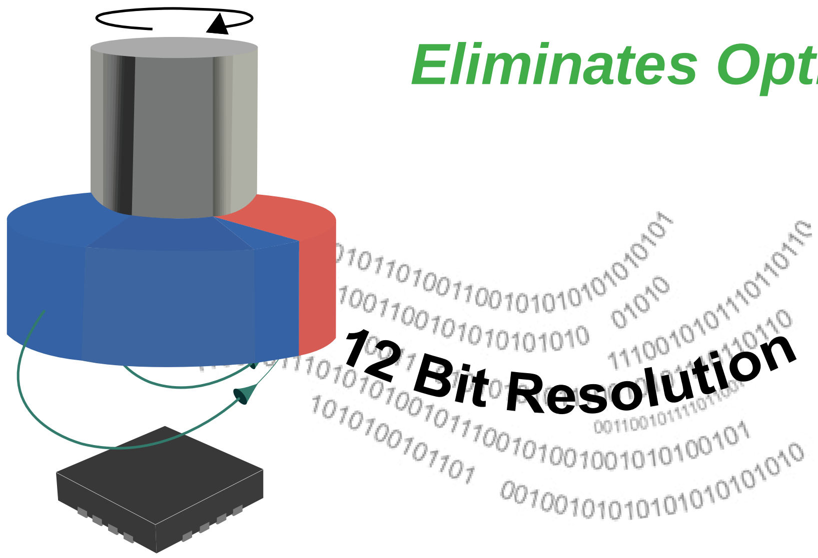
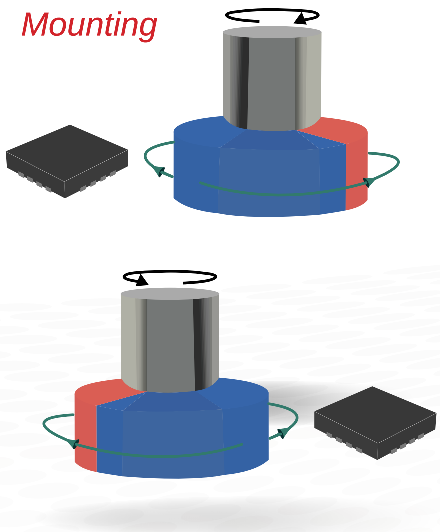


Flexible Mounting



MagAlpha MA300 Features

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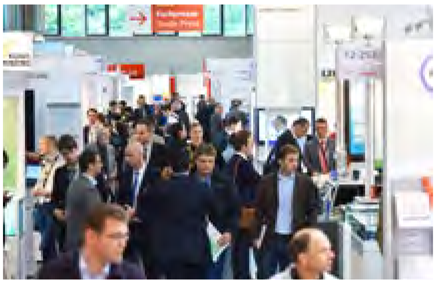
SENSOR+TEST 2016: First-Rate Conferences and Attractive Action Program

The SENSOR+TEST 2016 from the 10th to the 12th of May in Nürnberg will once again be the worldwide leading forum for sensors, measuring, and testing technology. Visitors will have the opportunity to obtain comprehensive information on the state of the art in sensors and measurement. They can study the stands of approximately 580 exhibitors from all over the world, take advantage of the parallel conferences, and take part in a wide-ranging action program.

The spotlight is on two first-rate conferences: The 18. GMA/ITG-Fachtagung "Sensoren und Messsysteme" is to be held this year concurrently to the SENSOR+TEST. This most eminent German-language congress on sensor and measuring technology is jointly supported by the VDI/VDE-Gesellschaft



Mess- und Automatisierungstechnik (GMA) and the Informationstechnischen Gesellschaft im VDE (ITG) and is to be hosted by the GMA this year.

For the second time the European Society of Telemetry will organize the European Telemetry and Test Conference – etc2016 in cooperation with the SENSOR+TEST in Nürnberg. The etc2016 and its exhibition provides a platform for telemetry, telecontrol, test instrumentation, and data processing. It is also the meeting point of the "3rd Advanced In-Flight Measurement Techniques Symposium AIM2016" and the "27th Symposium of the Society of Flight Test Engineers SFTE – European Chapter."

Suited to this year's special topic of the SENSOR+TEST – Measuring in the Cloud – is the international Internet of Things Conference. This distinctive topic is also at the focus of a special stand in Hall 5, and will also be elucidated in a dedicated session on the lecture forum on the first day of the fair.

www.sensor-test.com

The International Conference Dedicated to Lighting Innovations

The 6th International LED professional Symposium +Expo (LpS 2016) in Bregenz from September 20th to 22nd reinforces creativity, innovations and new lighting solutions. The outstanding conference program will focus on "Smart Technologies for Lighting Innovations."

The lighting sector is facing enormous challenges. The LEDification process is ongoing while Intelligent Lighting and Human Centric Lighting strongly affect future lighting developments. New stakeholders, market players and organizations play important roles in future businesses and technology opportunities. State-of-the art knowledge, trend views and collaborations are vital for success in the highly dynamic market. In this environment the annual 3-day LpS event builds a platform to follow the latest trends, predict next generation lighting solutions, enforce collaborations and trigger lighting innovations.

The conference program will concentrate on Future Trends, Intelligent Light, Internet of Things, Light Quality, Light Sources, Intelligent Lighting, Optics, Thermal Management, Reliability, Testing, and Applications, in four parallel tracks. More than 70 international speakers from key organizations such as IBM, Johnson Controls, Bartenbach, Lumileds, Tridonic, Philips, Holst Center, Infineon, NXP, and several renowned universities, will present their findings in the opera house and James Bond film location, the Festspielhaus Bregenz, on beautiful Lake Constance.

The LpS 2016 will be opened by Nobel Prize Laureate Professor Shuji Nakamura from the University of California Santa Barbara (the inventor of the blue and white LEDs), who will present the latest develop-

ments in LED and Laser-Diode technologies. The opening will also give insights into the strategic goals of the European Commission and LightingEurope, the voice of the European lighting industry. Secretary General, Diederik de Stoppelaar will highlight their strategic lighting roadmap 2025 in the field of intelligent lighting.

Online registration is open now with Early Bird tickets available until July 1st at the official event website:

www.led-professional-symposium.com/

International SiC Power Electronics Applications Workshop 2016

ISiCPEAW 2016 is a three-day event, consisting of two workshop days (May 18 - 19), followed by one tutorial day (May 20). The event will cover the latest results and innovations in power electronics applications of silicon carbide technology.

From May 18 to 20, international experts will meet in Stockholm to share their expertise, recent developments and visions of SiC electronics applications. More than an overview on SiC industry, ISiCPEAW proposes a focus on power electronics applications.

The workshop takes place May 18 - 19 at the Marriott Courtyard Stockholm Kungsholmen Hotel. It has the overall aim to promote the use of the latest silicon carbide research and development results, by bringing together the foremost experts from both academia and industry. The focus lies on the use of SiC technology in power electronics applications, components, modules, packaging, reliability and benchmarking versus silicon power electronics. The program is defined by SiC experts and reflects the status of SiC from an industry point of view. Specialists from all over the world will present their views on current status, ongoing development and the opportunities of applications in the power electronic area. They will also present the latest products and solutions, and will be available for detailed technical discussions.

http://www.swerea.se/en/calendar/isicpeaw-2016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MagnaLOAD DC Electronic Loads 1.25 kW to 120 kW+ Released

Magna-Power Electronics, a worldwide leader in programmable DC power products, released its MagnaLOAD product line of DC electronic loads spanning 1.25 kW to 120 kW+. The new product line includes 3 product series, ALx Series, ARx Series, and WRx Series spanning 39 air- and water-cooled models from 1.25 kW to 120 kW+ with voltage ranges up to 0-1,000 Vdc and current ranges up to 0-1,200 Adc. The MagnaLOAD product line launches with Magna-Power's all new distributed DSP architecture, MagnaLINK™, featuring digital control loops and an internally developed high-speed product-to-product communication protocol. The MagnaLOAD product line is designed to dissipate DC power during development, manufacturing, and validation of DC sources, including: power supplies, DC-DC converters, batteries, solar panels, fuel cells, motors, and electromagnets.

The ALx Series MagnaLOAD, 1.25 kW and 2.5 kW, utilizes conventional linear MOSFET-based dissipative elements, allowing the series to achieve a very wide voltage-current operating range within a model's maximum power rating. Using the same heat management innovations developed for Magna-Power's high density programmable DC power supplies, the ALx Series' conservative cooling ensures long product life in environments up to 50 C ambient operating temperature.

The ARx Series MagnaLOAD, 7.5 kW to 45 kW+, introduces Magna-Power's patent-pending Active Resistance Technology, combining a binary switched resistor network in series with linear elements. Used in conjunction with the new MagnaLINK™ DSP controller, the ARx Series achieves 16-bit programming and measurement resolution and, as a result of the Active Resistance Technology, at a fraction of the price of traditional electronic loads. In addition to typical voltage, current, power, and resistance control modes, the Active Resistance Technology enables the product's Rheostat control mode, providing direct on-the-fly control of internal binary resistor network, avoiding control bandwidth constraints typically experienced with resistance control modes.

The WRx Series MagnaLOAD, 15 kW to 120 kW+, also utilizes Magna-Power's new Active Resistance Technology in combination with the company's newly developed internally manufactured microchannel water-cooled heatsinks. Designed for high-power applications where heat-flow control is essential, the WRx Series greatly increases power density compared air-cooled alternatives. An integrated solenoid controls the flow of water to avoid condensation. Full power can be achieved using conventional water with water inlet temperatures up to 25 C.

MagnaLINK™, Magna-Power's next generation control architecture, provides a distributed network of DSPs across the major assemblies in its programmable DC products. Beyond Magna-Power's standard fast transient response and high accuracy programming and measurement, MagnaLINK™ adds: fully digital control loops, adjustable control gains, programmable slew rates, arbitrary waveform generation, among many new advanced control technologies. Expandability is at the forefront with MagnaLINK™, providing buffered digital master-slaving MagnaLINK™ ports, allowing many units to be added in parallel or series with uncompromised performance and aggregated DC input measurements.

All MagnaLOAD products come standard with front and rear full control (host) USB ports, RS485, dual MagnaLINK™ ports for digital master-slaving, and a 25-pin D-Sub external user I/O connector with configurable pin mappings; LXI TCP/IP Ethernet and IEEE-488 GPIB interfaces are also available. Many different programming environments are supported via Standard Commands for Programmable Instrumentation (SCPI), and provided National Instruments LabVIEW™ and IVI drivers.

Some features may not be available at launch, but will be available at a future date through a firmware update. Consult a local Magna-Power sales partner for more information.

All Magna-Power products are designed and manufactured at the company's vertically integrated headquarters in Flemington, New Jersey USA. MagnaLOAD products are now available directly from Magna-Power in the USA, through Magna-Power sales offices in the United Kingdom and Germany, or from a network of distributors in over 40 countries worldwide.

About Magna-Power Electronics

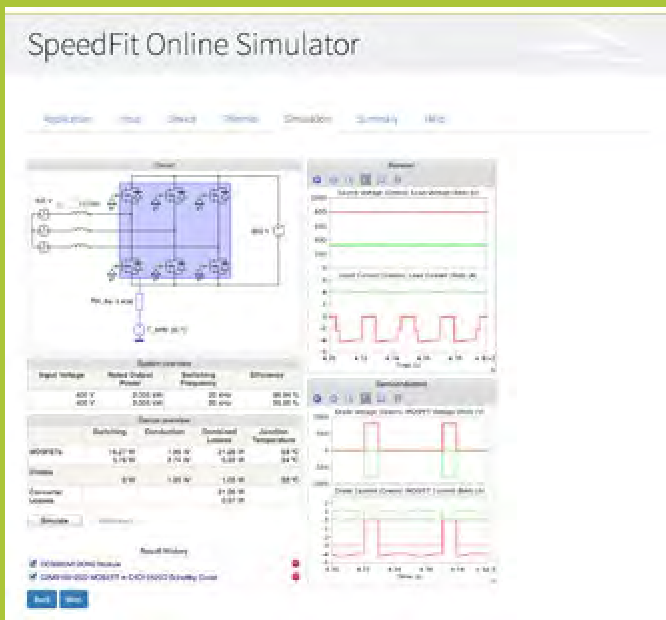
Magna-Power Electronics designs, and manufactures robust programmable DC power products in the USA that set industry standards for quality, size, and control. Its products can be found around the world feeding power to national laboratories, universities, and a wide range of industrial sites. The company's experience in power electronics is reflected in its 1.25 kW to 2000 kW+ product line, quality service, and reputation for excellence.

http://magna-power.com

Industry's First Web-Based Circuit Simulator Dedicated to Evaluating Silicon Carbide Devices

By Kristofer Eberle, Plexim and John Mookken, Wolfspeed, A Cree Company

On May 3, Wolfspeed, a Cree Company, will launch the SpeedFit™ simulation tool, a free and powerful online circuit-simulation tool for power design engineers. It is the only online circuit simulation tool solely dedicated to simulating and evaluating the performance of silicon carbide (SiC) power devices.



In just seconds, the SpeedFit simulation tool allows a design engineer to determine the benefits and advantages of an all SiC-based power converter and select the right devices for their application. The user can tailor the simulation to the exact application parameters of interest using a set of tools to analyze SiC device performance, key voltage, and current waveforms.

The SpeedFit user interface is simple and intuitive with topologies broadly categorized into DC/DC, AC/DC, or DC/AC applications. A set of tabs guides the user toward determining the right SiC component(s) for a design. It provides performance data including average switching and conduction losses and estimated junction temperatures for the selected SiC devices for a specific operating condition.

After choosing a topology, the user specifies system-level circuit parameters, chooses a recommended device, and defines thermal interface parameters and cooling. The SpeedFit simulation tool even allows users to specify external gate resistance values and major passive component values in the circuit. Users can also compare results for different circuit configurations and devices. The tool summarizes the system parameters, device part number and simulation results in one concise report.

The SpeedFit simulation tool will be available on wolfspeed.com and uses the PLECS® WBS web-based simulation tool developed by Plexim. Files containing the loss models and thermal impedance information are also available for download at wolfspeed.com for offline use in the PLECS tool, so existing PLECS users can now access models for Wolfspeed's parts. PLECS Standalone can be obtained from Plexim's website and has a free demo mode allowing access to a collection of prebuilt designs. Free PLECS trial licenses for PLECS can also be requested on Plexim's website.

Wolfspeed will be showcasing the SpeedFit simulation tool on their stand (9-242) at PCIM May 10-12. To try the SpeedFit simulation tool, visit www.wolfspeed.com/speedfit on or after May 3.

http://www.wolfspeed.com/

http://www.plexim.com/

2020 Vision: Key Trends in Power and Energy Management

By Dave Heacock, Senior Vice President and Manager, Texas Instruments Silicon Valley Analog

Over the next four years, our industry will continue to face significant energy management challenges, such as the burden of delivering and storing more power. The world's population consumes about 17 terawatts of power from various energy sources, with the highest consumption happening in developed countries like the U.S.(1) The problem is finding ways to deliver this massive amount of power more efficiently. The solution: breakthroughs in power electronics. We are working hand in hand with our technology partners to develop energy innovations designed to solve some of these complex challenges through advancements in semiconductor technology and power topologies. High-voltage analog and mixed-signal semiconductor solutions will deliver greater power efficiencies in the coming years. By uniquely combining high-voltage manufacturing processes with power management integrated circuits that can support higher input voltages, more efficient power solutions can enable a variety of markets. (Read more about high-voltage innovation in our new white paper: Redefining power management through high-voltage innovation). Let's look at three trends where power management innovation will make the greatest impact in the next four years.

Megatrend No. 1: Power density

Power density is the rate of energy flow per unit volume, area or mass. Design engineers strive to deliver more power, more efficiently and in smaller footprints. They require the best possible power density in products like server power supplies and batteries for electric vehicles. So it is no surprise that each year, we see many new techniques and approaches to improving power density.

At TI, we continue to look for a more holistic approach to the power and energy problem. By focusing on the total power chain and not just one piece of it, we are able to suggest innovative approaches to traditional problems. For example, how do I take off-line energy and convert it so it's appropriate for a server farm? Our customers are interested in the total energy costs (power and cooling) and how quickly they can get a return on their investments. They are very willing to evaluate and try different technologies and approaches to find new ways that will fundamentally help them lower costs and improve efficiency.

Manufacturers including TI are turning toward new materials, such as gallium-nitride (GaN) on a silicon substrate, to enable faster switching frequencies and even greater efficiencies from input voltages up to 700 volts. In addition to developing these HEMT (High-Electron Mobility Transistor) devices, we are developing several gate drivers uniquely suitable for GaN FETs and introducing advanced multichip modules (MCMs) that include both gate drivers and the GaN power FETs in a single package.

Megatrend No. 2: Energy efficiency

In the next four years, we will also see smarter management of the energy grid. Techniques such as "peak shaving" – basically taking power from the grid at night when energy usage and cost is low and delivering the energy back to the load during the daytime peaks will become more prevalent. This keeps the energy requirements from the grid for a home or building below a certain level during peak usage, easing the daytime energy demands.

Alternative energy generation further complicates the equation in that alternative energy sources typical vary throughout a 24-hour period. Unlike gas power plants, wind and solar vary greatly during a day. Using a similar technique to peak shaving, co-generating plants will become more cost-effective. The plants can maximize the use of alternative energy when available, and supplement the output with a natural gas steam plant. Cost-effective energy storage combined with efficient power conversion is necessary to make this type of arrangement commonplace in the future. Without the improved power conversion, the losses of moving energy into and out of the storage medium would be too large to be practical.

I think the time is near when many of us have energy storage systems in our homes for use with our electric vehicles and to limit our home's energy demand on the central energy grid. This will allow us to use those power-hungry products while not burdening the electric infrastructure. Consumers will win with lower costs (recharge at night with lower rates; discharge during the day during peak demand) and by being more conscious about their overall energy usage than they were in the past.

Megatrend No. 3: Storing, delivering big data

Big data has to do with data creation, storage, retrieval and analysis that are astonishing in terms of volume, velocity and variety. Data volume of global consumer Web usage, e-mails and data traffic totals 6,706 petabytes per month(2), and industry analysts expect as much as 35 zetabytes of data(3) to be generated annually by 2020.

Can we afford the power it takes to store and deliver this amount of data to millions of users every day? Clearly, we need to look at ways for power management technology to help drive more cost-effective and energy-efficient data storage.

Consumers want constant access to their information, but most do not need access 24/7. However, once the computing power is in place to deliver this access, the costs do not vary across the day. Since companies can't charge for this "maintenance," they are searching for novel ways to scale their power usage while maintaining peak capacity, all while still making a profit. Improvements in our approach to data centers are needed to address this.

Making a greater impact for tomorrow

We live in an exciting time where innovation in power electronics is helping to solve the challenge of delivering and storing more power – and delivering that power more efficiently. We need to be open to novel ways of addressing traditional problems with advancements in semiconductor technology and power topologies building a more sustainable impactful future for everyone.

www.ti.com/power

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Successful 10th Battery Experts Forum

An even more comprehensive program impressed the participants of the 10th Battery Experts Forum – formerly called „Development Forum Accumulator Technologies“ – organized by Batteryuniversity in Aschaffenburg, Germany, from 5 through 7 April 2016. More than 40 top-class speakers informed around 600 experts about state-of-the-art technology trends, who attended to discover trends and to find solutions.

By Roland R. Ackermann, editor Bodo's Power Systems

For the first time, the congress with accompanying exhibition (40 companies) successfully organized five additional parallel sessions, too – all of them totally sold out. And also booked to the last seat with 120 participants was the preceding Training Day on Tuesday, 5 April, with fundamental courses in German and in English on battery technologies, management, safety and chargers.

After the welcoming address by Dr. Jochen Maehliss of Batteryuniversity the most interesting paper of the first forum day was the profound and in-depth keynote „The world market 2016“ held by Sven Bauer, CEO of BMZ – The Innovation Group, in strong words with in parts amazing findings and open-hearted comments. Following actual data and trends he sees the year 2020 as the breakpoint for a new market structure.

Presently he confronts the fact, that 90% of the existing worldwide market (around 425,000 MWh) is lead acid with the discussions in the European Union to ban lead, which is no longer state of the art and is number one in the failure rate. NiCd batteries are almost out, NiMH still shows some growth, but everything points in the direction of Li-ion. Other solutions like flow batteries or NAS. In Y20 the total battery capacity will reach 221 GWh while lithium batteries (LIB) take 80 GWh – their penetration is then especially expanded in the motive sector (2 milliosn e-bikes sold last year, or golf cars) – it´s then almost doubled (from 33 to 63%), in tools (from 23 to 33%) and in storage (59 to 68%). In the SLI application (Start, Light, Indication for cars, truck, moto, boat etc.) of 4 wheel and 2 wheel vehicles though the LIB penetration will still be as low as 1%.

Four big manufacturers cover 80% of the market, with Sanyo-Panasonic and Sony two Japanese and with Samsung and LG Chem two Korean, whereas China tries to catch up, heavily supported by the government to promote electric vehicles: Half of the EV price is paid by the state, and buying petrol-driven cars costs a „fine“ of 15,000 USD.

The battery market presently represents about 62 billion USD. The included segment of other applications (rather than SLI, automotive and portables) will increase from 20 to 28 billion USD in Y20; it is dominated by forklifts, e-bikes and the telecom market, followed by UPS and medical devices.

Li-ion cell shipment volumes by cell type: cylindrical (predominantly 18650) is followed by prismatic (both slightly above 2 billion cells) and laminates/pouch at around 1 billion, coming up strongly (more details see below). Key success factor is production speed, performance and customer access.

Performance and Safety of PV-Li-Storage Batteries

Harry Doering described the activities of ZSW, center of solar energy and hydrogen research, in materials research including beyond lithium, cell design, validation of new chemistries and ageing mechanisms and post mortem analysis. He gave an overview on the safety hazards of Li-ion batteries, of materials and of electrolytes. His resume: Li-ion is an available technology, with no intrinsic safe cell technology, suitably controllable by BMS.

Maritime Batteries

Torqueedo´s speaker Marc Hartmeyer of Starnberg, Germany, described the application, the safety, influences of the environment and of the voltage plus the demands of mixed systems. Modern maritime applications use Li-ion, whereas low-cost applications and displacers (rental) still employ lead-acid. The problem is, that there is no single standard for the maritime sector, for instance ISO 10133 for small craft, IEC 60092-508 for electrical installations in ships or ISO 16315 small craft – electric propulsion systems.

The Institute of Electrical Energy Systems (IfES) of the Leibniz University Hanover demonstrated CP (Constant Power) charge/discharge experiments as a new approach to characterize, select and optimize cells. The method allows comparison and selection in context with a real application, optimization of the cell usage and analysis and optimization of the pack. Details of the adjustment of the initial state and of definition of the efficiency are still open.

Mareike Wolter of Fraunhofer IKTS presented interesting approaches to increase the energy density in Lithium batteries. As compared with today, energy density on battery, cell, electrode and material level can almost be doubled until 2015. On cell level this needs active materials with improved storage density, reduction of „inactive“ components and increase of packaging density; on system level the cell size must be increased, component number reduced and efficient cooling must be provided. High capacity electrodes are characterized by active materials with high specific storage capacity, maximum packaging density, increased electrode thickness and reduced separator thickness.

Battery and Cryptology

Ineltek´s Andreas Riedenauer answered the question „Why Cryptology“: It´s safety, anti-cloning and know-how hiding plus additional customer and manufacturer value. Immediate financial losses by plagiarism amount to about 300 billion Euro, which is 4% of the world trade volume, and with a growing rate of more than 35% per year. This can result in image damage for the brand, life danger and boost for organized crime. The technologies employed are cryptology in hard and software, NFC (near-field communication) and USB-C. As solution for luxury goods a secure tag hidden under the device guarantees genuineness and a contactless reader or an NFC phone can check the authenticity.

Dr. Jens Peters of Helmholtz Institut Ulm highlighted the relevance of performance parameters of Li-ion batteries and their environmental influence with an in-depth view into a unique life cycle assessment (LCA) process, the influence of battery key parameters and he gave eco-design recommendations.

Parallel Sessions

The parallel sessions 1 to 5, also totally booked, covered topics such as cell design and new materials; cell and battery tests; lifetime and security; high-voltage systems and electro mobility in several successive experts lectures.

Most interesting were „Electrolytes for Li-ion Cells based on Polymers and Ceramic Particles“ presented by KIT, „New Anode Materials“ presented by Varta and „Cathode Materials for Li-ion batteries: Trends per Application“ by Umicore Battery Recycling in Session 1, and „Ageing Research on Li-Ion Cells“, „Chemical Analytics for Prognosis of Cell Ageing and Risk Assessment“ and „The Influence of Vibration and Shock on the Lifetime of Li-Ion Battery Packs“ (Fraunhofer ISE, ICT and ISC respectively) and „Abuse Testing for Identifying Weaknesses in Production and Construction of Li-ion Batteries“ (RWTH Aachen) in Session 2, plus „Modern Test Methods and Analysis of Batteries“ (Keysight Technologies), „Prevention of Installation of Polarity-Reversed Cells“ (BMZ) and „500 kW, 500km and 15 min – Batteries for Long-Distance EVs“ (Voltavision).

Second Experts Day

First highlight of the second day was the lecture „Pouch cells, prices and materials“ of Shmuel De-Leon, who introduced „Lithium Rechargeable Pouch Cells – The Hidden Secret“. History: In 1998 Sony launched mass production of Li-polymer cells using aluminum film as pouch case. Conductive foil tabs are welded to the electrodes. Since then Li Pouch cells are used for more and more applications. Advantages are its thin format, reduced weight, high volume density and high surface area (good thermal characteristics) plus flexible sizes: No standardized pouch cells exist. Each manufacturer designs its owns – NRE for a new size mold is in the 1 to 2 kUSD cost range.

The second key speaker, Dr. Michael Buser from Risk Experts indicated fire hazards and safety risks in storage, production and transport of Li-batteries and informed about means and rules of conduct to avoid them. He classified potential hazards, ingredients of primary and secondary batteries, their temperature behavior and he showed a comprehensive list of dangerous substances and decomposition products. Dr. Buser indicated organizational protection measures, safety systems and rules, disposal and recycling. Interesting was his finding, that uncontrolled and sudden delivery of the stored energy normally occurs not as electrical, but as thermal energy.

At the vivid panel discussion “Quo vadis 18650” in the beginning of the afternoon leading manufacturers from the cell producers Samsung and Panasonic, the battery manufacturer BMZ and the OEMs Kaercher and Fein formulated a position on the future of 18650 cells, which continue to dominate the market. They are of special interest in connection with the autonomous vehicle and e-bikes.

During the second day, the participants also learned about Li-ion capacitors (JSR Micro NV), the Panasonic Li-ion product roadmap, Major architectures of ESS (TI), Lifetime, environmental influence and need for action of Li-Packs (Umweltbundesamt, Federal Environmental Agency), Li-ion cells with customized electrodes for specific applications (Litarion), Impedance-based battery management for lithium-oxygen systems (Lithium Balance AS), Next cell generation (Samsung), Self Control Protector: a surface-mounted fuse for LIB (Dexerials) and extinguishing systems for transport and storage of LIB (Salgromatic Fire Systems).

The parallel sessions of the second day covered high-voltage systems and electro mobility (three lessons each, e.g. about innovations in the e-bike industry by Inside eBike).

http://www.batteryuniversity.eu/

CIPS 2016 - Power Electronics in Challenging Little Boxes and More

More than 300 engineers and scientists attended the conference. Attendees came from 21 countries in Europe, America and Asia with 22 participants alone from Japan. The 9th International Conference on Integrated Power Electronics Systems (CIPS 2016) was held on March 8-10, 2016, in Nuremberg as part of the ECPE Annual Event. The Conference was organized by ETG, the Power Engineering Society within VDE, and by ECPE, the European Center of Power Electronics. IEEE PELS and ZVEI were technical co-sponsors.

By Prof. Eckhard Wolfgang, ECPE, Prof. Andreas Lindemann, Univ. Magdeburg and Prof. Dieter Silber, Univ. Bremen, Technical Program Chairs CIPS 2016, and Prof. Johann Kolar/ ETH Zurich

The program of this year's conference included 100 papers (80 in 2014): Four keynotes, 9 invited, 54 oral and 33 poster papers. A good balance of contributions was achieved between industry and academia.

Prof. Johann Kolar/ETH Zurich and Prof. Eckart Hoene/Fraunhofer IZM explained in the 1st keynote speech "The Google/IEEE PELS Little-Box Challenge". Here is a brief summary:

The intention of Google was to start an open competition to build the worldwide smallest single-phase power inverter, with a $1,000,000 prize. This would make power electronics systems more compact, and cheaper. The prize was given on February 28, 2016, to the team "Red Electrical Devils" of the Belgian company CE+T. The use of GaN technology and soft-switching enabled a power density of 143 W/in³ of the 2 kVA inverter which had to be realized in this project. The dimensions are 2.5 x 1.615 x 3.41 in³ resulting in a volume of 13.77 in³. This volume is significantly smaller than the smallest existing inverter on the market. However, the lower efficiency also has to be considered. Besides the GaN devices, MLC capacitors and ferrite magnetic components were used; for details see https://www.littleboxchallenge.com/. Furthermore, instead of electrolytic capacitors a low-volume active DC-side power pulsation buffer was used for buffering the power fluctuation with twice the AC output frequency intrinsic to single-phase DC/AC converter systems.

Prof. Kolar analyzed the concepts of the 15 finalists – the presented power densities were mainly in the range of 120…220 W/ in³ (10 out of 15 teams) – and showed details of the approach used by the

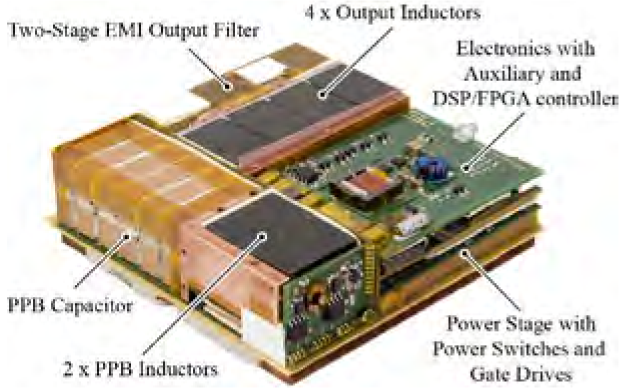

Figure 1: Converter system of ETH Zurich/FhG-IZM/Fraza (135 W/in³) presented at the finals of the Google/IEEE Little-Box Challenge

team of ETH Zurich, Fraunhofer IZM and Fraza d.o.o. (cf. Fig.1 and https://www.pes.ee.ethz.ch–Publications–Conferences). As a main conclusion, power densities of 200 W/in³ could be achieved even with moderately high switching frequencies and SiC instead of GaN power devices, and advanced high-frequency magnetics, careful thermal management and 3D-packaging/integration are key enablers for a further power density improvement.

Schneider Electric achieved the 2nd place and presented their concept (100 W/in³) and results in the CIPS 2016 special Little-Box dialog session together with the team of ETH Zurich, Fraunhofer IZM, and Fraza (135 W/in³).

Figure 1 shows a Converter system of ETH Zurich/FH-IZM/Fraza (135 W/in³) presented at the finals of the Google/IEEE Little-Box Challenge. The system employs two interleaved bridge legs per phase which are operated in triangular current mode to achieve ZVS of the GaN GIT power switches (CoolGaN, Infineon, 200 kHz….1 MHz). Moreover, a new gate drive with 500 kV/µs dv/dt-immunity and only 20 ns delay time, innovative foil winding inductors with multiple airgaps and low high-frequency losses (Fraza d.o.o.), as well as an active buck-type power pulsation buffer (PPB) equipped with high energy density ceramic capacitors (CeraLink), and advanced air cooling, i.e. a top- and bottom-side heat sink (top-side heatsink not shown in Fig.1) are used.

Dr. Engel/ CeraCap Technology & Innovation Consulting presented an invited paper "Design and Materials of Antiferroelectric Capacitors for High Density Power Electronic Applications". Based on the specific solutions for power electronics and high temperature environment, the MLCCs based on anti-ferroelectric ceramics and copper inner electrodes are recommended for use in power electronics. They combine small size, low ESR, low ESL, high current handling capability, high isolation resistance at elevated temperatures, and potentially low cost, even comparable to film caps. CeraLink MLCCs can be used at high frequencies too which is necessary for GaN based circuits.

In the Keynote "Prospects for advances in power magnetics" given by Prof. Charles Sullivan/ Thayer School of Engineering at Dartmouth, Hanover NH, USA, the use and limitations for magnetic components in high frequency circuits were discussed. Inductors and transformers are critical for advances in power conversion. Increased frequency can, in principle, reduce their size and power losses, but high-frequency losses make this hard to realize in practice. In windings, proximity effect is the most severe challenge. It can be addressed either by using many winding layers sufficiently thin compared to δ

Advanced and Broad Power Management Portfolio

Microchip Technology has an expansive offering of power management solutions to fit virtually every type of design criteria. From the smallest form factor needed for mobile devices to complex industrial power management designs to automotive standards, you are sure to find a highly integrated solution to meet your needs. If you are looking for greater flexibility in your design, Microchip's digitally enhanced power analog devices integrate a microcontroller (MCU) or digital signal controller (DSC) for a fully programmable and flexible solution.

Applications:

- LDO and switching regulators
- Charge pump DC/DC converters
- Power MOSFET drivers
- Digitally enhanced and PWM controllers
- System supervisors
- Voltage detectors
- Voltage references
- Li-Ion/Li-Polymer battery chargers
- Power MOSFETs

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or by using a single layer. Design errors can result in large increases in loss relative to lower-cost designs, so design calculations are essential. Other strategies and considerations include interleaving, positioning of the winding relative to the gap, parallel windings, and aluminum conductors. Research in windings includes effective utilization parallel thin foil layers, as well as current balancing in very large litz-wire bundles. Evaluation of magnetic materials using performance factor assumes ideal windings, but can be modified to account for high-frequency winding loss. Results show opportunities for continued miniaturization of power converters using frequencies above 2 MHz.
The introduction of GaN devices has encouraged power electronics designers to develop advanced power device integration concepts towards monolithic integration. The respective Keynote paper was "100 MHz GaN Power Conversion" presented by Dr. Dragan Maksimovich. He demonstrated this technology for VHF D – mode converters using a GaN-on-Si Process. The presented application was a radio frequency transmitter with much improved efficiency by tracking the signal envelope. Such types of amplifiers are well-known from audio frequency amplifiers, and their basic approach is the principle of pulse width modulated dc-dc-converters. Previous developments had been based on Silicon LDMOS devices but GaN devices enable much higher frequencies. In the presented example the AC envelope frequency is >20 MHz. PWM switching frequency can be as high as 200 MHz. A half bridge including gate drivers is monolithically integrated. Output Power is 7 W at 91% peak power efficiency. The developments of GaN devices encourages the author to scale the principle to much higher power in future. Therefore in the outlook a 3 MHz ZVS switching at 380 V, 500W was shown using a recently developed monolithic 600 V GaN-on-Si half bridge (from IAF, Freiburg) with integrated Schottky diodes. It described the potential of post-silicon power electronics.

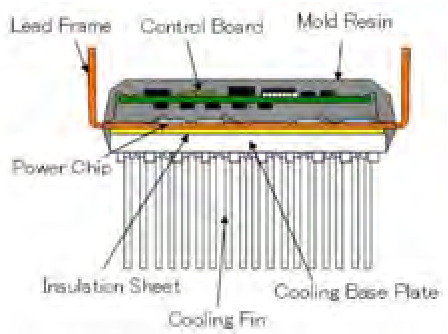


Figure 2: Cross-section of highly-integrated inverter module

Dr. Reinhard Herzer/ Semikron had been invited to give an overview on "New Gate Driver Solutions for Modern Power Devices and Topologies". More and more SiC switches (MOSFET, JFET) with voltage classes between 600V and 1700V are coming on the market with decreasing RDSon and costs as well as sufficient reliability. To use the outstanding performance of SiC devices it is extremely important to improve their application and system environment. From the package side low inductivities and thermal resistances, high temperature operation (≥ 175°C) and higher reliability are demanded. On the driver side fully integrated gate drivers with complex driving and protection functions for higher frequencies (40...200kHz), higher operation temperatures and close and low inductive connections to the switches are necessary.
In the Keynote "Review of Integration Trends in Power Electronics Systems and Devices", Dr. Gourab Majumdar/ Semiconductor & Device Group, Mitsubishi Electric Corporation, Japan showed the path to a highly integrated power module (Figure 2).
Various technological advancements in the areas power chip, circuit concepts and packaging structures made so far have immensely improved power modules' capability leading to realization of a nearly full inverter solution integrated within a smart modular housing. This trend is considered to progress sustainably in the future as well bringing in advanced solutions for power conversion systems and, thus, contributing in global efforts on energy saving.

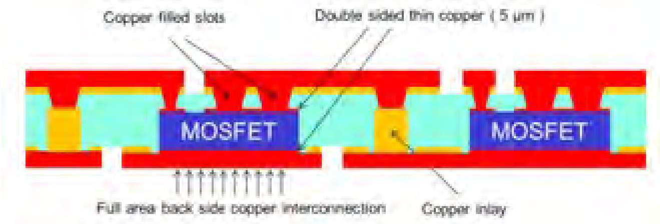


Figure 3: Power Core Half Bridge Packaging Concept

DI Hannes Stahr/ AT&S Austria, presented an "Investigation of a power module with double sided cooling using a new concept for chip embedding" in his invited paper. The embedding technology shows promising potential for power modules in many applications, e. g. in automotive, and due to its advancements with respect to electrical, thermal, reliability performance and space requirements in comparison to conventional SMT solutions. This is demonstrated by an embedded power module for driving a Pedelec, Figure 3. It has been shown that by applying embedding technology the shortest possible interconnections and, therewith, significantly reduced switching losses could be realized.
It can be concluded that 2016 CIPS conference showcased cutting-edge integrated power electronics. Contemporary systems - such as for electromobility, renewable energy and energy efficiency - will benefit from the reported results of intense research and development.

As in the previous CIPS conference there were two awards:
The VDE best poster award of 1000 € in recognition of an outstanding paper presented in the dialogue session. The award committee selected: Sebastian Kremp, Oliver Schilling, Verena Müller, Infineon Technologies AG, Germany – "Empirical study on humidity conditions inside of power modules under varying external conditions"
The ECPE Young Engineers Award promoting young engineers to present papers at CIPS. The award of 1000 € was given to: Daniel Kearney, Slavo Kicin, Enea Bianda, Andrej Krivda and David Bauman ABB Corporate Research Centre, Baden-Dättwil, Switzerland – "PCB Embedded Power Electronics for Low Voltage Applications
Figure 4 shows the members of the organizing/technical program committee.

Figure 4: From left to right: Thomas Harder/ ECPE, Prof. Dieter Silber/ University of Bremen, Prof. Eckhard Wolfgang/ ECPE, Prof. Andreas Lindemann/ University of Magdeburg, Prof. Leo Lorenz/ ECPE.

www.ecpe.org

Fig. 2:Gourab Majumdar, Takeshi Oi, Tomohide Terashima, Shiori Idaka, Dai Nakajima, Yoichi Goto: Review of Integration Trends in Power Electronics Systems and Devices; CIPS 2016
Fig. 3: H.Stahr, m. Morianz, S. Gross, M. Unger, J. Nicolics, L. Böttcher: Investigation of a power module with double sided cooling using a new concept for chip embedding; CIPS 2016
Fig. 4: Tilman Weishart Photography

No Need for External Sensors in New Inverters

When it comes to trends in the power electronics sector, the rate of change is accelerating, with different emphasis being placed on key factors such as power density, performance or reliability depending on the final application. One requirement that remains constant however, irrespective of the application, is reducing costs. In fact, in any new development in the power electronics industry, from transistors to entire inverter solutions, cost savings are of the essence.

By Johannes Krapp, Semikron

One of the main factors affecting costs and performance in converter technology is current sensing. The right solution is a compromise between cost and accuracy, or rather the dynamic characteristics of the measurement process. Many different current sensing techniques exist, with one of the best in terms of bandwidth and accuracy being fluxgate technologies. For cost reasons, these are usually limited to special niche applications. More common in the >100kW range are Hall-effect current sensors which, thanks to new integrated amplification circuits, deliver a high level of accuracy with integrated galvanic isolation. With new packaging technologies for power electronic systems, discrete solutions often tend to conflict with new overall system requirements. Active devices embedded in printed-circuit boards or PCB based AC and DC bus bars open up all sorts of new possibilities for integrating current sensing technology. The substantial market volume and the all-important costs factor have led to the development of a wider range of alternative current sensing methods. The market demand for isolated current sensors will hit the 100 million mark in 2020, which is roughly equivalent to the amount of iPhones produced in 2012.

How to find the right sensor solution for IGBT inverters

With the exception of some individual cases, current measurements are required within most applications, since the load current value serves as a basis for efficient control. The other need is related to providing the right protection under fault conditions. The decision over what current sensor technology to use does not only come down to dynamic characteristics and a reliable, interference-free function. In fact, accuracy and, of course, costs are also crucial to the decision. It goes without saying different applications have different requirements: in electric vehicles for example, the high RPM and large currents mean that bandwidths in the 100 kHz+ range are needed to deliver optimum results in terms of torque and motor efficiency. In other applications such as aviation, an error deviation of 0.5% across a temperature range of -50°C to 125°C is a must. In between is the majority of applications, made up predominantly of industrial, speed-controlled drives, voltage supply systems and regenerative energies. Another requirement is the scope of the insulating properties. Due to technical limits, not all current sensing techniques with reinforced insulation such as Hall-effect sensors can simply be replaced by shunts or IC solutions. In contrast, in the lower output range where basic isolation is sufficient, i.e. <80A and <400V, IC-based solutions are being used more and more frequently. This trend underlines the fact that sensor ICs are also increasingly being used in high-power applications thanks to the cost benefits they provide, and the generally easier integration of current sensing elements.

Current measurements are usually taken using auxiliary parameters: voltage in resistive current sensing methods and magnetic fields in magnetic methods. Other optical or mechanical methods are usually not economically viable in industrial applications today. Pure magnetic methods are based on the principle of the Hall effect, the B-field induces the Lorentz force on moving charge carriers and the magnetic fields of AC and DC currents are detected using Hall elements. Since both the charge carriers and the Hall voltages are dependent on temperature, the biggest challenge with Hall-effect sensors is ensuring that the accuracy requirements are met across the entire temperature range.

With open loop sensors, the magnetic fields are shown directly as voltage without the signals having to be processed in any way. With this type of sensor, developments aim at improving signal amplification by using new ASIC technology. Open loop sensors, which are unbeatable when it comes to size, weight and price, can already be found in many high-volume applications including eMobility.

If the magnetic flux in the magnetic core is balanced to zero, this secondary (compensating) current is the exact representation of the primary current. As a result, these closed loop sensors deliver good overall accuracy across the entire temperature range.

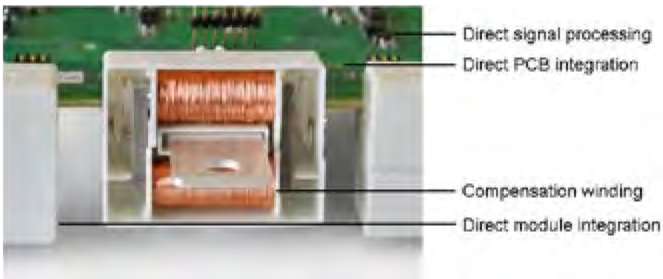


Figure 1: An accurate closed loop sensor in a SKiiP4 IPM with directly connected electronics

By integrating current sensors into the power module, they can be directly connected to the driver electronics and by noise resistance, transmitted to the controller unit. The measurement accuracy of the SKiiP4 IPM module integrated sensors is in the range of 0.5% across

300A FULL SiC POWER MODULE

Higher Voltage | Higher Current | Lower Switching Loss

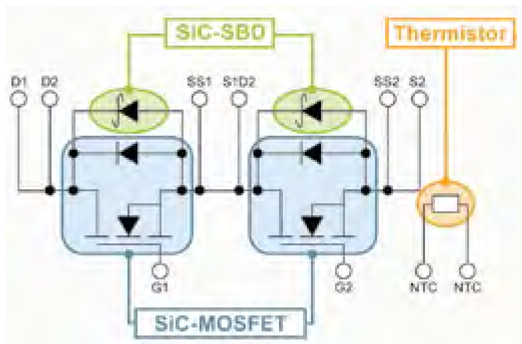
ROHM Semiconductor now offers a 300A full SiC power module, BSM300D12P2E001, that enables support for larger power applications such as power supplies industrial equipment.

High frequency operation through reduced switching loss

- Switching loss is significantly reduced compared with similarly rated IGBT modules

Safer design supports larger currents

- Original design technology reduces inductance by half, enabling the development of 300A rated products.
- Integrated thermistor prevents excessive heat generation.



Device Configuration

- Full H-Bridge SiC module integrates a SiC SBD and SiC MOSFET into a single package
- Equivalent package as standard IGBT modules
- Built-in thermistor
- Tjmax = 175 °C

Full SiC Power Modules Lineup

Part No.	V_{DSS} (V)	I_D (A)	Tjmax (°C)	V_{isol} (V)	Package	Construction
BSM080D12P2C008 *	1200	80	175	2500	C-Type	DMOS+SBD
BSM120D12P2C005	1200	120	150	2500	C-Type	DMOS+SBD
BSM180D12P3C007 *	1200	180	175	2500	C-Type	UMOS+SBD
BSM300D12P2E001	1200	300	175	2500	E-Type	DMOS+SBD+Thermistor

* no online sample ordering possible, please contact ROHM Sales

the entire temperature range with a bandwidth up to 100 kHz. Developments in the area of Hall elements centre on the improvement of the charge carrier mobility and, consequently, on greater accuracy. New materials such as indium antimonide (InSb) or graphene offer a way of doubling the mobility in the sensor element.

IC integration allows PCB based sensor solutions

New developments in power electronics work by eliminating costly materials and production processes. The use of a single, common carrier material from the power electronic chips to the controller chips might be one way to reduce costs in the future. PCB production involves reliable, automated processes, offering cost and time benefits in converter assembly. Challenges remain with regards to the reliability of different connection processes within, and to the PCB, as well as with regard to suitable cooling concepts. The clear advantages that this technology offers lie in the possibility of integrating control lines, reducing interference and parasitic effects. Semikron's MiniSKiiP GB modules already offer a bus bar alternative for up to 250A and in the low power range, new developments for entirely PCB-based systems already exist, as do Hall-effect sensor ICs which can be directly assembled over the AC copper lines that are integrated into the PCB.

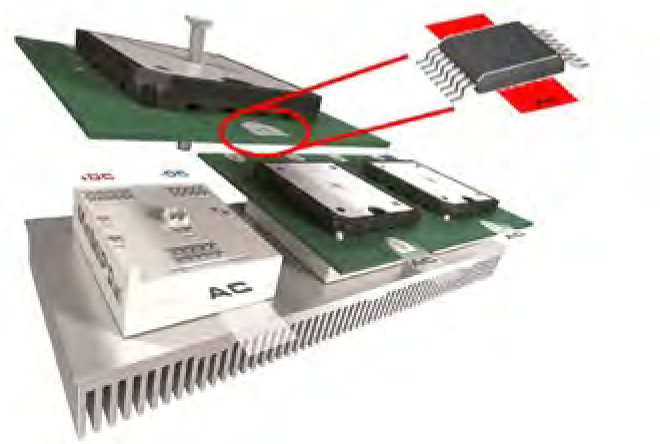


Figure 2: MiniSKiiP GB paves the way for SMD current sense resistors up to 200A

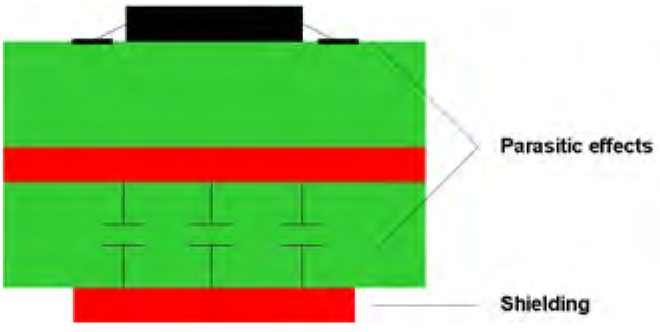


Figure 3: Impact of parasitic effects in the PCB on signal accuracy

These modules allow for bandwidths up to 150 kHz and up to 0.7% accuracy, and existing sensing technology demonstrates verifiable linearity. The biggest challenge when using these solutions is the signal to noise ratio which is highly dependent on layout and converter design. Here, too, signal interference is caused by parasitic capacitance in the PCB traces and pads, just like in "large-scale" converter systems.

A low-pass filter can help reduce noise, but cancels out any dynamic advantage this system has. Additional shielding can improve performance but reduces simplicity and cost benefits of the PCB based solution. So a well-proven PCB layout is a must for such a solution.

In addition to Hall-based current sensing ICs, there are also magnetic resistive methods like AMR sensors that are based on the anisotropic magnetic resistive effect, in which the resistance changes in relation to the external magnetic field. Here, the current measurement is identical to the closed loop principle of differential magnetic field measurement with compensation. The current is fed through a U-shaped bus bar, creating a field gradient between the two sides of the bus bar. The sensor measures this difference and moves to zero by the compensation winding. The current which is required for the compensation determines the measurement signal.

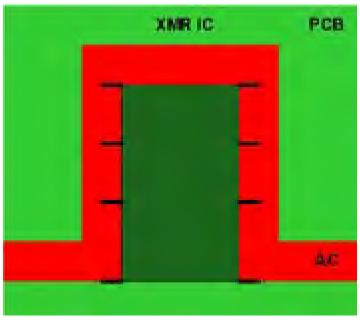


Figure 4: New XMR sensor IC try to get rid of U shape) optional

The advantage of AMR technology is that the sensor exhibits no hysteresis and, thanks to the fast control loops incorporated in the IC, is suitable for bandwidths of up to 500 kHz, i.e. signals with rise times below 2µs. With the right PCB layout, this principle can cover a variety of current ranges. The main shortcoming of this solution remains accuracy, with the latest technology delivering approximately 2% accuracy. The challenge here is interference immunity with regard to external magnetic fields and the rather restricted sensor position possibilities, which makes PCB production especially challenging.

Besides these magnetic current sensing solutions, resistive current sensing is always a good choice due to the cost benefits it offers. Moreover, from technological advances in this area resistive current sensing is becoming increasingly viable for the >100A output ranges too. The basis of resistive current sensing involves measuring the induced voltage drop across the current-carrying conductor to infer the current. The challenges to be overcome here are the low voltage signal, which is in the millivolt range, the power dissipation at the moment the measurement is taking, as well as the need for separate galvanic isolation from the controller.

Nowadays, shunts that are used in challenging applications have to fulfil substantial requirements: 0.5% accuracy, resolution with 16 bits, high linearity and long-term stability up to 170°C, along with reinforced isolation. Integrating shunts into external bus bars outside of the power module is usually contrary to the aim to keep converters compact in size.

The alternative would be to integrate the shunt sensor into the power module directly. Up until now though, one of the main obstacles was the fact that costly IGBT chips potential needed to be used for the integrated shunt sensor. New shunt technologies and intelligent integration concepts open up new possibilities.

Here, SEMIKRON's solution is to replace existing contact bonds with shunt resistors, to efficiently integrate the current sensors into the power module without affecting power density. The module connection and module driving processes have to remain unchanged in order to ensure efficient system upgrades. SEMIKRON is the first in the

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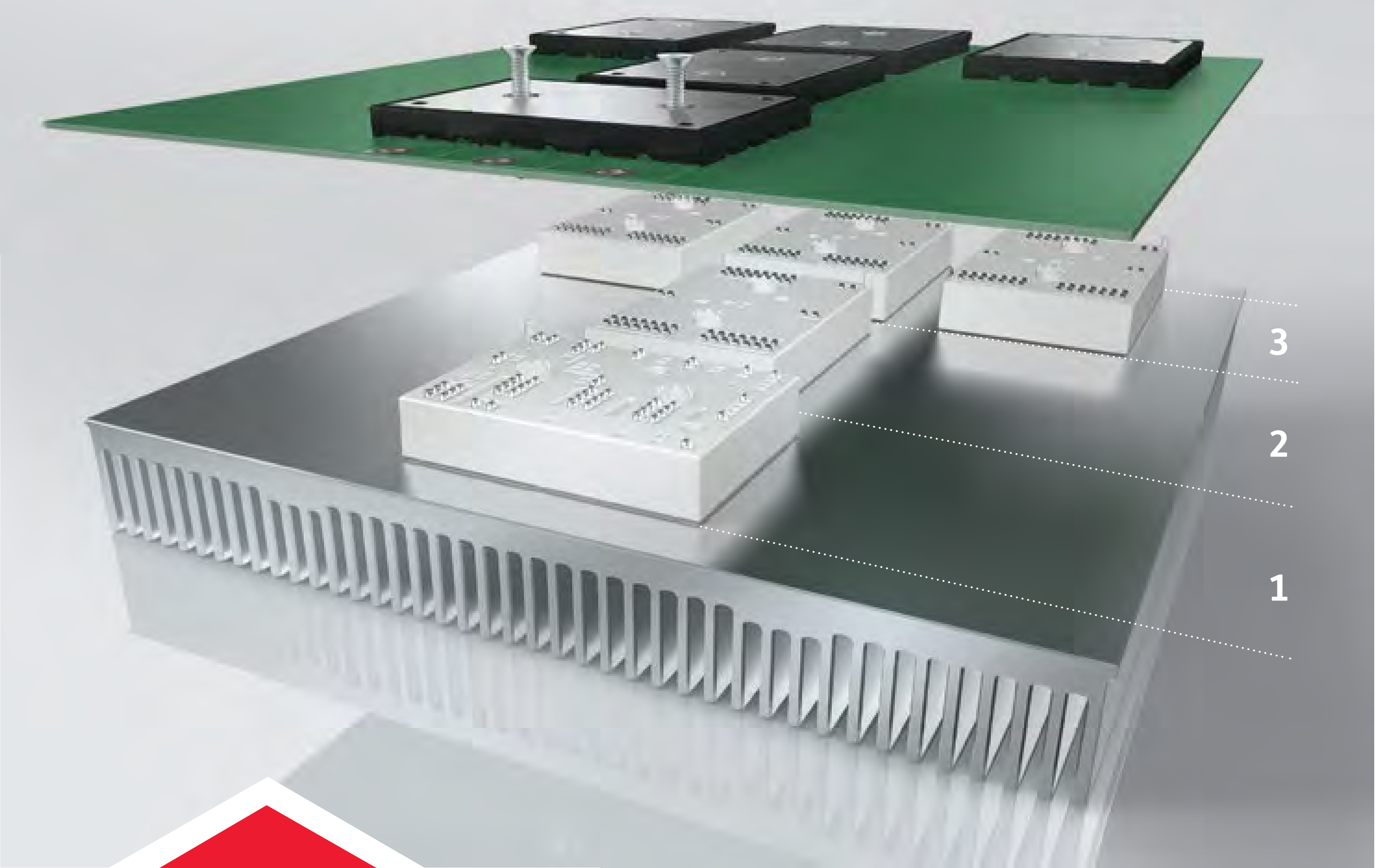
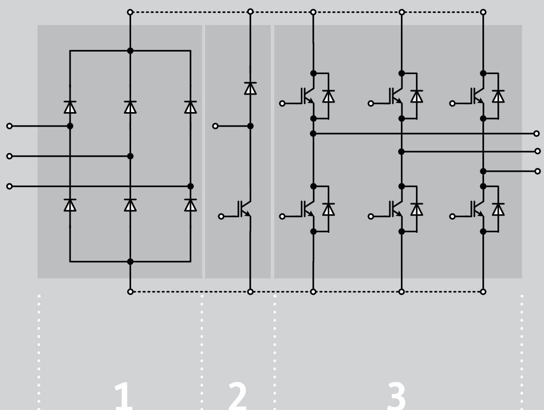
Complete Solution up to 90kW



Scalable without compromise, from input to output

- Major system cost savings with less material used compared to standard baseplate solutions
- Compact inverter design replacing copper bus bars with high power PCBs
- Full drive solution from rectifier to inverter output, including brake chopper
- One PCB concept, scalable from 2kW to 90kW



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industry to produce a standard 17mm module with integrated shunt resistors for up to 600A. The resistors used are based on an alloy that works unimpeded at temperatures of 250°C, and delivers very reliable results thanks to its ultra-low temperature coefficient. By incorporating the current sensing technology into the module, external sensors are no longer needed. Overall size and weight, two crucial factors when it comes to mobile applications are also lowered. The sensors are connected to driver electronics using press-fit connectors, requiring only a single step in the driver assembly process with no additional sensor mounting or connections. The high linearity of the shunts forms a reliable basis for challenging control tasks and the compact size of the shunts means they take up no additional space in the module, ensuring the module is identical to the standard version of the 17mm SEMiX 3 press-fit modules. The rated current is unaffected, i.e. none of the costly chip area is lost. There are also fewer interfaces thanks to the press-fit connection, resulting in better FIT (failure in time) rates in the final converter system. Likewise, separate pin connectors and their corresponding wires, as well as an addition sensor power supply are no longer required.

Figure 5: SEMIX Press-fit module with integrated shunts replaces external sensor solutions

The use of integrated current sensors in power modules also brings about challenges: the voltage signal lies on DC link potential and has to be isolated and digitalised before it can be processed by the application controller. The module design has to work without restrictions in current symmetry and within the required temperature range. In addition to electrical specifications for shunts, including those for operation in threshold regions, e.g. losses under short circuit conditions, another aspect that has to be taken into account is the inductance of the shunt interconnection, bearing in mind that the shunts are integrated in the module. The voltage drop across this inductance during switching has to be as low as possible to prevent interference signals. Knowing these challenges, the new SEMIX pressfit with integrated shunts was successfully designed. The next challenge is to get the shunt signal without interference and in the right dynamic range and accuracy to the controller.

The isolation of the shunt signal can be optical, capacitive or inductive, although most sensor ICs that exist today use optical or capacitive coupling and the transmission can be realised using various protocols. One possibility is digitalise and transmit via a serial protocol like an UART that is later offered as differential interface to keep the noise robustness. Another possibility is to use delta sigma modulation to the controller requiring the addition of a clock signal. Knowing what system is more suitable depends on the given requirements for response, electric insulation capability, the interface definition for the controller solution and of course, costs.

Digital sensor signals lead the way

The UART based possibilities include the D/A conversion of the voltage signal on the secondary side and isolated transmission as a serial signal to the control unit. The dynamic response and the insulating properties have to be adapted to the given requirements. The main advantage of this solution is that it offers real galvanic isolation via transformers. For customers, this means separate isolation is not needed, especially in the >300A range. Another merit of this method is its high level of accuracy. In addition to the specified 0.5% error deviation of the shunts the accuracy is also subject to other A/D conversion and amplification stage tolerances. The performance characteristics with 6 Mbit/s that the controller can process directly, are sufficient to ensure efficient control. Plus, new controller families can process the serial protocol directly and a clock signal is not required.

Best performance with SEMIKRON evaluation Kit

Besides solutions with reinforced galvanic isolation in the higher voltage range, IC integrated couplers are also becoming increasingly important for shunt signal evaluation. The most common method used in the market is shunt signal conversion, using a sigma delta modulator with an isolation barrier in the IC itself.

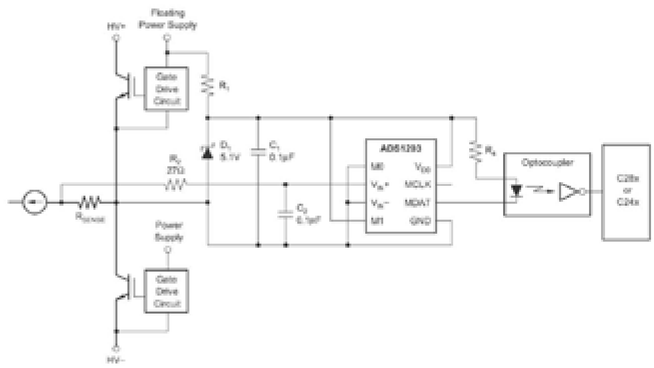

Figure 6a: Sigma delta conversion IC ADS1203 with optical insulation

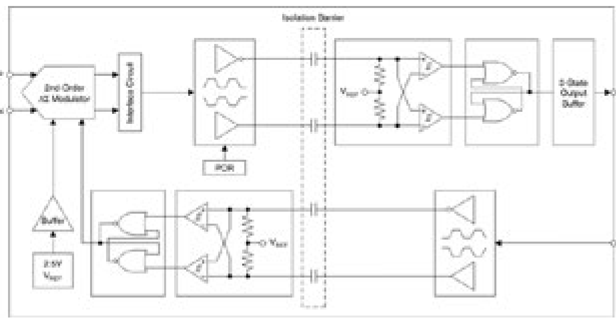

Figure 6b: Sigma delta conversion IC ADS1203 with capacitive insulation

In this process, it is only the difference that is integrated and transmitted with a 1bit signal over a single line. With oversampling of that signal the result can be optimized between accuracy and dynamics, depending on the application. If these solutions are used on the same circuit board as the main controller, there are no specific interference protection requirements. Using the same circuit board, the bit current can be fed directly to the controller which is delivering also the clock signal. If there is an interface between the controller board and the driver board, however, the low signal will mean that a signal transmission that is immune to interference has to be selected. Here, SEMIKRON works with a differential RS485 interface which allows the option of using wire based controller connections so that system designs can be realised without from factor restrictions.

SEMIKRON offers a complete 3-phase application KIT based on the new SKYPER 12 and SEMIX press-fit shunt with fully integrated current sensing.

Figure 7: SEMIKRON Evaluation Kit without external current sensors

The new driver core SKYPER 12 is a galvanically isolated driver for SEMIX 3 press-fit modules featuring integrated shunt resistors. With an adjustable filter time, fast error management and an MTBF rate of 8 million hours, this driver delivers a reliable 2 watts and 20A peak output in a driver that's smaller than the size of a matchbox. Thanks to the isolated voltage supply, the delta sigma IC draws its power on the secondary side of the SKYPER, meaning external isolation is not needed. SEMIX press-fit modules feature parallel shunts that are fed to the adapter board directly using press-fit pins, and thanks to the IC based sigma delta modulator, include galvanic isolation. The bit current is converted to an interference-free differential signal with a 20 MHz clock signal. This allows for direct digital signal filtering and resolution. The SEMIX modules are suitable for up to 600A and 1700V despite the integrated shunts. Thanks to the integrated NTC sensors and optional DC link measurement via auxiliary contacts, all the isolated signal conditioners can be integrated onto one PCB.

With this evaluation Kit of SKYPER 12 and SEMIX press-fit shunt, customers no longer need additional space for separate current sensors, a separate power supply, wiring or circuit board assemblies. One board now incorporates all of the isolated sensor signals. Depending on the alternatives, in the converter stack this can bring about savings of up to six percent. The use of integrated shunts in standard package 17mm modules therefore meet the all-important requirement to realise simple cost down projects in new converter solutions. Additionally, the direct connection covers the performance requirements of bandwidths of over 50 kHz and 1% accuracy. With the evaluation kit, the system can also be adjusted to meet the requirements of the given application in absolute minimal time. Plus, thanks to the press-fit architecture, the entire electronics are mounted in one single step. The converter has a single interface and does not require separate signal conditioning boards, making it an optimum low-cost current sensing solution for use in future developments.

Johannes Krapp studied industrial engineering at the University of Applied Sciences Würzburg-Schweinfurt. As senior product manager he is responsible for driver electronics and stack assemblies at SEMIKRON.
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Smart Transformer Condition Monitoring with Smart Meter and Rogowski Coils

Accurate and easy-to-install smart current sensors empower the internet of energy (smart cities).

By Patrick Schuler, LEM

Smart Grid for the City

The intelligent electricity network (smart grid) is the backbone of every smart city, since it:

- Informs "prosumers" (proactive consumers or producers of energy) about their energy usage and enables them to make decisions about how, when to use, store or even resell electricity, as with solar panels on roof tops. This promotes the participation of residential, commercial and industrial buildings in energy conservation, efficiency and demand response programs.
- Provides reliable integration of distributed renewable energies, energy storage and electric vehicle charging stations. This means smarter protection equipment and smarter substations to enable faster management of fault detection, isolation and restoration.
- Improves the grid with smarter components (sensors, intelligent electronic devices, smart meters and so on) allowing control, automation, remote monitoring and real-time data sharing. By working together, these components provide the control center with information on current and future performance of the grid and a detailed status of critical components such as a transformer.

Smart Transformer = Smart Meter + Rogowski Coil

A leading metering provider has introduced the use of flexible LEM Rogowski coil sensors (ART) with a smart meter connected to the low-voltage (LV) side of a distribution transformer in an MV/LV substation. The software in the smart meter calculates the thermal and electrical models of the transformer based on the LV measurements information, providing its oil temperature and ageing rate as well as MV current values and energy flows. It is an innovative, more economical way to manage the distribution grid without having additional sensors on the MV side. The smart meter's overall accuracy with the LEM ART is better than 1%, superior to conventional Class 0,5 meters associated with Class 0,5 current transformers (CTs).

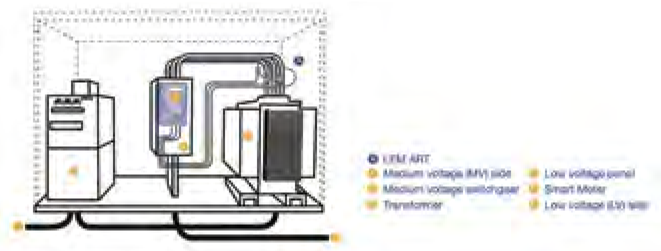


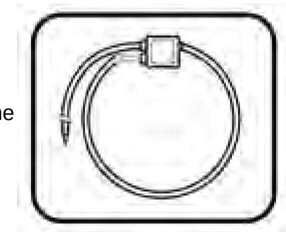
Figure 1: MV/LV Substation

Within the MV/LV substation, the incoming power flow from the MV side (1) is managed by the MV switchgear (2) before being converted by the transformer (3) into LV (6). The smart meter (5) installed in the LV panel (4) measures the transformer's (3) health with three independent current sensors – LEM ART (A). The ART allows safe commissioning of the smart meter on an existing live transformer.

Benefits for distribution system operators include:

- Real-time thermal behavior, ageing rate, active and reactive losses of each distribution transformer.
- LV load curves of consumers, producers and transformers allowing detection of non-technical losses.
- Aggregation of active energy distributed by each MV-LV transformer allowing detection of non-technical issues on the MV side of the grid.

LEM Rogowski Coil



LEM has developed the ART current Rogowski sensor with the capability to measure up to 10,000A and beyond. The ART is a raw coil achieving IEC 61869 Class 1 accuracy without the need for additional components such as resistors or potentiometers, which have a risk of drift over time. In addition, the ART labelled "Perfect Loop" has a unique patented coil clasp curing the inaccuracy caused by the sensitivity to the position of the conductor inside the loop. Finally, the ART provides the same ease of installation as split-core current transformers and the same Class 1 accuracy. The ART also has the best performance among other Rogowski coil players.

Features		LEM ART	Other Rogowski Coil
Precision	Class	Class 1 without Calibration	Class 1 with Calibration
	Positioning Error	Below 0.65%	Below 1%
	T° Coefficient Mutual	30 PPM/K°	50 PPM/K°
	Orthogonality Error	Low	High (above 1%)
	Operation temperature	-40°C to +80°C, IP 67	-30 °C to +60 °C
Coil	Coil clasp position error	None (LEM Patent)	Yes (1-2% Error)
	Coil diameter	6.1mm thin and Flexible	12mm Thick & Less Flexible
	Electrostatic shield	Yes (Standard)	Yes (Optional)
Case	Security seal lock	Yes (2 mm hole)	No
	Closing Connection	Twist and Click	Screw or Click
	Output cable length	Customized 1.5m, 3m, 4.5m	3m

Figure 2: LEM ART features and performances versus competition

What is a Rogowski coil?

A Rogowski Coil is used to make an open-ended and flexible sensor that easily wraps around the conductor to be measured. It consists of a helical coil of wire with the lead from one end returning through the centre of the coil to the other end, so that both terminals are at the same end of the coil. The coil length is selected according to the relevant primary cable diameter to provide optimal transfer characteristics.

This technology provides a very precise detection of the rate of change (derivative) of the primary current that induces a proportionate voltage at the terminals of the coil. This is then a current measuring technology only for AC currents. An electronic integrator circuit is usually added to convert that voltage signal into an output signal that is proportional to the primary current. In other words, the Rogowski Coil enables the manufacturing of very accurate and linear current sensors, at the price of additional electronics and calibration.

A Rogowski coil has a lower inductance than current transformers, and consequently a better frequency response because it uses a non-magnetic core material. It is also highly linear, even with high primary currents, because it has no iron core that may saturate. This kind of sensor is thus particularly well adapted to power measurement systems that can be subjected to high or fast-changing currents. For measuring high currents, it has the additional advantages of small size and easy installation, while traditional current transformers are big and heavy.

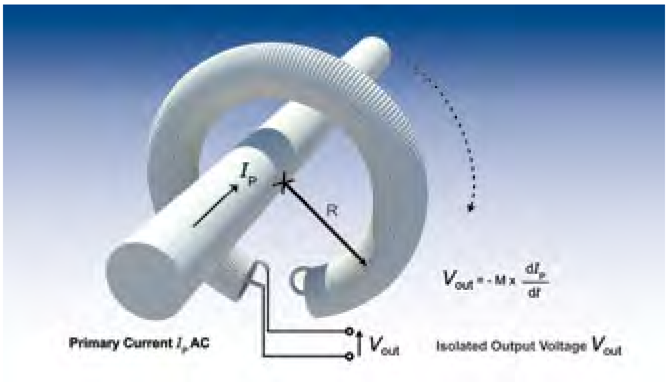


Figure 3: Rogowski Coil principle

$V_{OUT} = - M{*}dI_P/dt$.

M is the mutual inductance between the primary conductor and the coil, which to some extent represents the coupling between the primary and secondary circuits.

The performance of such current sensors highly depends on the manufacturing quality of the Rogowski coil, since equally spaced windings are required to provide high immunity to electromagnetic interference; the density of the turns must be uniform otherwise the coefficient M could change versus the position of the primary into the aperture.

Another critical characteristic is the closing point that induces a discontinuity in the coil, creating some sensitivity to external conductors as well as to the position of the measured conductor within the loop. The locking or clamping system should ensure a very precise and reproducible position of the coil extremities, as well as a high symmetry while having one of the extremities connected to the output cable. Some new technologies have recently appeared in this area, with special mechanical and electrical characteristics that allows much better accuracy and immunity to the primary cable positioning. While the error due to primary cable position was typically not better than +/-3% in the 50/60Hz frequency domain, it has been reduced to less than +/-1% on some of the latest Rogowski coil sensors.

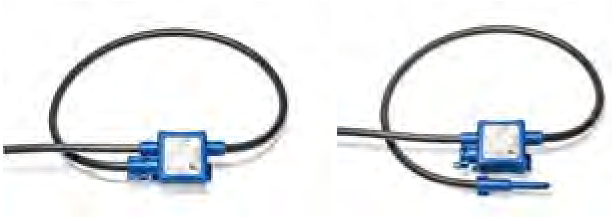


Figure 4: ART Rogowski Coil current sensor from LEM

How LEM managed the challenge

Two main technics are on the market to make Rogowski coils accurate:

- The first is to buy standard wound wire on the market and to make the loop connected to a resistor, which will be used for the accuracy calibration.
- The second is a so-called “pure Rogowski coil” consisting in winding very accurately a regular copper wire all along its length to ensure the final accuracy of the sensor.

While the first is really easy to produce at a low cost, this is nevertheless highly sensitive to external environments, less accurate, and less reliable as it brings in more components.

At the opposite end, the Pure Rogowski coil requires much more investment and knowledge on the manufacturing process.

The really thin LEM ART Rogowski coil is part of this second method and has a gain of 22.5 mV/kA; it includes an electrostatic shield to protect against external fields (LEM patent), optimising performance for small current measurements.

The locking system has also been a key point in achieving the class 1 accuracy. And here again LEM had to find an efficient design to make the closure the most efficient possible.

To mask the imperfections on the closing mechanism as well as the connections of the sensor’s secondary wires, LEM engineers created a sleeve acting as a magnetic short-circuit (or more precisely a reluctance short-circuit), virtually bringing together the two sections of the coil located on each side.

Figure 5: LEM patented Rogowski coil clasp

The sleeve is formed of a piece of ferrite as represented in Figure 5. This approach was a complete success (LEM patent) – the error associated with the coil clasp has become almost negligible (Figure 6).

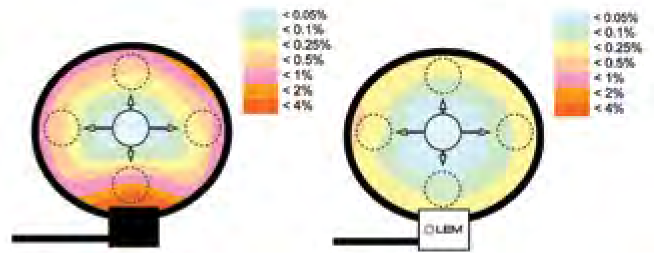


Figure 6: Rogowski coil accuracy comparison between a regular Rogowski coil and one using the LEM patented Rogowski coil clasp with primary conductor located at various positions inside the loop

The accuracy is not only a question of position of the primary conductor in the loop but also of orthogonality, how the primary conductor is crossing the loop, how is it located versus the Rogowski loop axis at 90°, or 45° or 0° or 180° (Figure 7).

Here again, the ART loop is insensitive to this phenomenon and this has no impact on its accuracy thanks to the LEM know-how and patent.

Figure 7: Orthogonality effect. Primary conductor position versus the axis of the Rogowski loop.

Finally, in addition to these high performances, the product had to be easy to use, to install and adapted to any conditions of use.

The ART series provides the same ease of installation as existing split-core transformers, but with the benefits of being thinner (6.1mm diameter) and more flexible.

Whatever the chosen dimension – 35 to 300mm diameter for the coil aperture – the ART can be mounted very quickly by simply clipping it on to the cable to be measured thanks to an innovative, robust and fast twist-and-click closure method. Contact with the cable is not necessary, and the ART ensures a high level of safety as well as providing a high rated insulation voltage (1000V Cat III PD2 - reinforced) and can be used in applications requiring a protection degree up to IP67.

Its fixing on the primary cable can be ensured using a cable tie through its expected slot.

The ART also allows disconnection of the coil to be detected through the use of a security seal passed through a specially designed slot, making it really useful when used with a meter (Figure 8).

Figure 8: ART mechanical features: Twist-and-click closure, security seal, and slot to attach the loop to the primary cable.

Intelligent electricity network (smart grid) applications such as power generators, home energy management (HEM), battery monitoring systems (BMS), medium voltage/low voltage substations, sub-metering, electrical vehicle stations, and solar power plants integrate more and more current sensors to ensure reliable integration of distributed renewable energy, energy storage, production and consumption. This leads to the implementation of more current sensors to allow control rooms to automate, monitor remotely and share real-time data of equipment.

With the aim to bring more harmonization in the smart grid landscape, the International Electrotechnical Commission (IEC) builds foundations in every field to provide a strong, resistant and secured electrical grid. Robust and accurate sensors in this network are major challenges to respond to this demanding environment.

IEC 61869 is the new performance standard for sensors, replacing the old IEC 60044 standard for current transformers. ART Rogowski coils sensors are designed and tested against a strict characterisation test plan established by LEM experts to comply with and contribute to this evolution. Due to its strong knowledge in accurate measurement, LEM guarantees the measurement repeatability of all of its transducers and accuracy of Class 1.0 according to IEC 61869-2 for ART models for use in future smart cities and their applications.

ART series current sensors are CE marked, UL 2808 recognised and conform to IEC 61869, as well as being covered by LEM's five-year warranty.

About the author

Patrick Schuler, LEM
Patrick Schuler has been working in the internet, telecommunications, smart grid, power electronics and power utility sector for more than 15 years. Since joining LEM in September 2014, Patrick has been responsible for defining the global smart grid offering and managing smart grid business development. As a smart grid expert, Patrick is a member of the IEC's world smart city community in Geneva and was the former smart grid chairman at the China European Chamber of Commerce in Beijing.

About LEM

LEM is the market leader in providing innovative and high quality solutions for measuring electrical parameters for a broad range of applications in drives and welding, renewable energies and power supplies, traction, high precision, conventional and green cars businesses. LEM City answers the demand for an accurate, reliable and easy-to-install energy sensor for future Smart Cities.

LEM City- at the heart of our planet's energy measurements.

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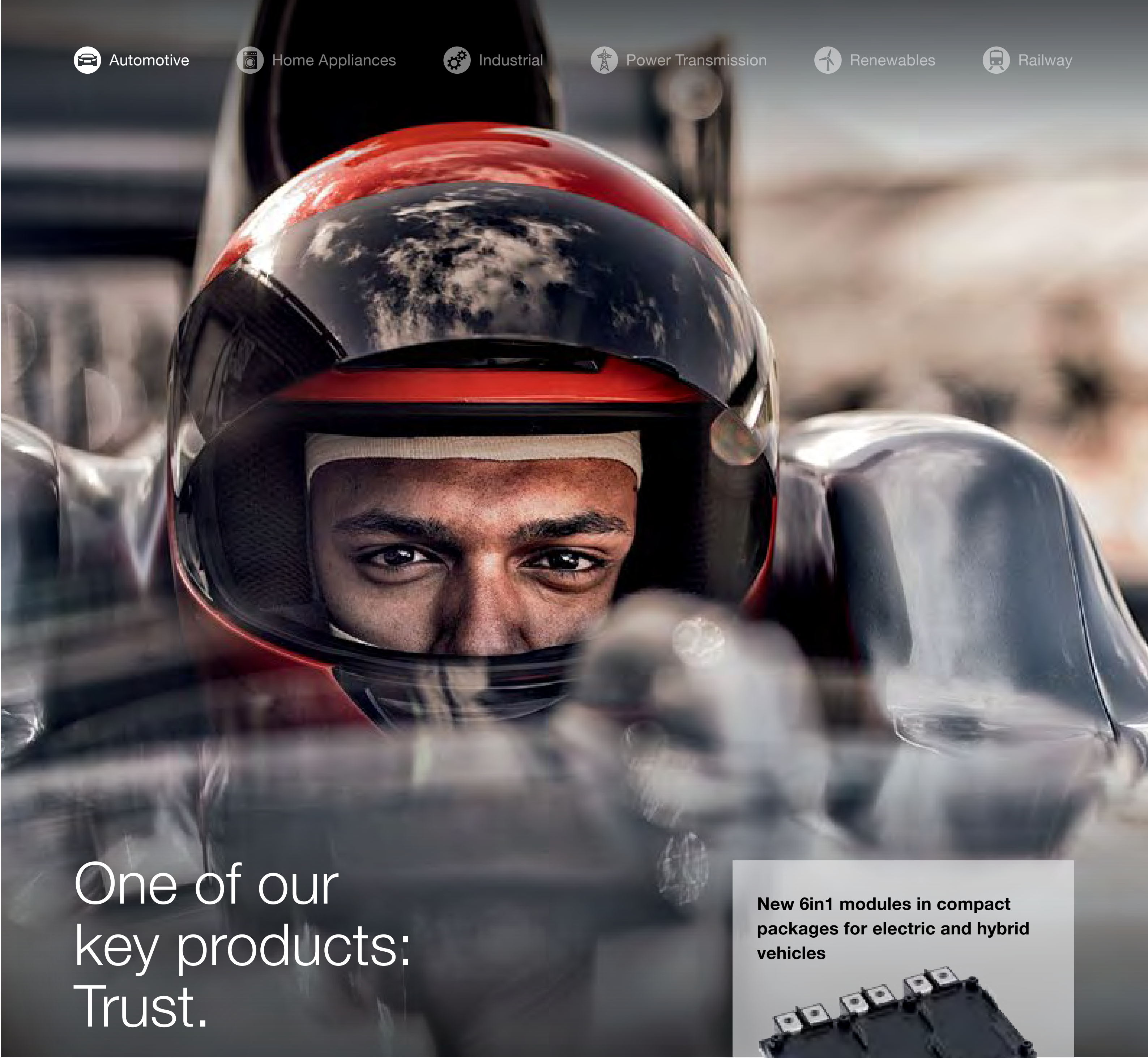

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Overcoming Creepage Concerns for Miniaturization in High-Voltage Automotive Drives

The inverters and charging systems in hybrid or fully electric vehicles provide a topical example of a high-voltage application that faces extreme space constraints. Where multilayer ceramic capacitors (MLCCs) are used as filters across high-voltage lines, pressure to miniaturize can direct designers to select devices in the smallest available case sizes, such as 0603. An 0603 chip-size device saves 75% of the board space occupied by a 1206-size MLCC, for example. However, these smaller case sizes challenge device manufacturers to maximize capacitance within the reduced package volume, and to ensure reliability.

By Reggie Phillips, High Voltage Product Manager, KEMET Corporation

As far as reliability is concerned, the shorter distance between the device terminals brings a greater risk that creepage – the natural tendency of an electric field to spread out over a dielectric surface – may allow arcing between the terminals (figure 1) when the full working voltage is applied across the device. This can result in failure of the capacitor and may cause thermal damage to other components nearby. Factors such as high atmospheric humidity or contamination on the component surface further increase the likelihood of arcing.

Figure 1: Surface arcing between MLCC terminations

Analysis of Arcing Phenomenon

When a high-voltage DC bias is applied to a high voltage MLCC, a potential difference is established between the opposing terminations and the opposing electrode structure. Simultaneously, an electric field concentration is localized in the termination area and respective first counter electrode within the MLCC, as illustrated in figure 2. This difference in potential begins to build along the surface of the chip, ionizing the air above it once the electrical breakdown of air is reached.

Once the inception voltage of the ionized air is reached, a conductive path is created allowing the energy in the concentrated electric field of the termination area to discharge. This discharge of energy travels through the air, along the surface of the capacitor and onto an area of lower potential, rather than through the capacitor. During discharge, there is a visible and audible electric arc across the surface of the chip.

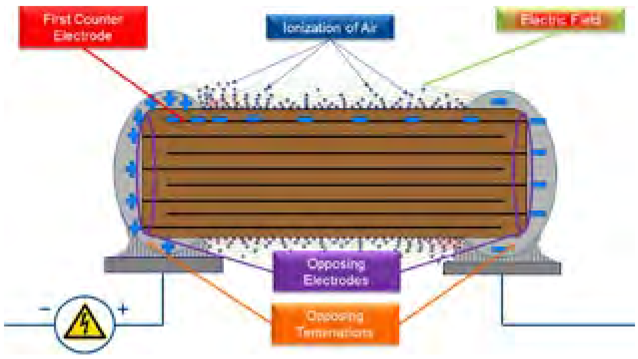

Figure 2: Electrical conditions around the capacitor surface that can allow arcing to occur

This type of arcing can occur at applied voltages of about 300V or more. For some high-voltage capacitors, this may be lower than the rated voltage of the device.

If the arcing occurs between a termination surface and through the dielectric material of the ceramic body to the first internal counter electrode, this usually causes dielectric breakdown of the capacitor resulting in a short-circuit condition that leads to catastrophic failure.

Prevention of Arcing

Capacitor vendors have tried a number of approaches to prevent arcing. One of these is to apply a polymer or glass coating along the surface of the chip to fill any voids and provide a smooth surface that has naturally lower susceptibility to creepage.

Filling these voids with insulating material also helps exclude contaminates and improves the dielectric stability across the surface of the chip. Improving this stability reduces the ionisation of the air and increases the inception voltage along the surface, thereby reducing the potential for arcing and improving the voltage performance of the capacitor.

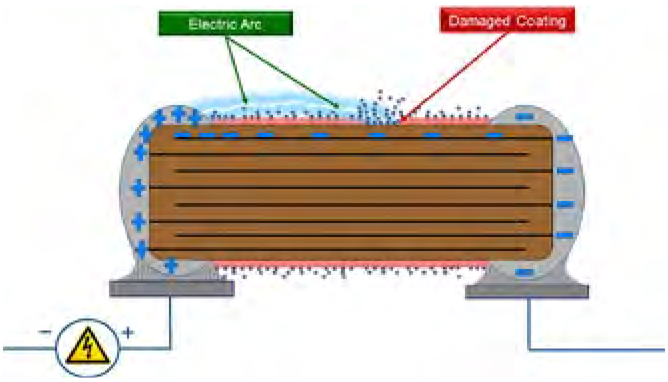

Figure 3: Imperfections in the coating can leave the device vulnerable to arcing

Designers have used surface coatings on PCBs in high-voltage applications for decades. This technology has been proven to increase performance, but its primary disadvantage is the cost of applying the coating. Many designers choose to avoid such cost unless it is deemed absolutely necessary to meet specific electrical safety standards.

Another hazard is that surface coatings can be damaged during handling and assembly processes. A breach in the coating effectively reduces the creepage distance capability along the surface, leaving the capacitor susceptible to contamination and arc-over concerns (figure 3). In addition, when choosing a device that has a pre-applied coating, it is important to ensure that the coating material is compatible with all applicable assembly materials, processes and conditions. Incompatibility could result in damage or premature failure of the surface coating.
There are also concerns with air gaps under mounted components, and voids in and under the epoxy coating. These gaps and voids allow for the same arcing potential as an uncoated device.

Serial Electrode
An alternative technique, illustrated in figure 4, is "series electrode" construction. The first part of the diagram illustrates how five individual 1000V 1000pF capacitors can be connected in series to form an array that effectively raises the breakdown capability to 5000V, even though the total electric field experienced is the same as that for a single capacitor. One disadvantage, however, is that the total capacitance is reduced to 200pF. The second part of the diagram shows the entire block of capacitors placed into a single monolithic structure with the same characteristics as the five serial devices with floating electrodes connected with.

KEMET has implemented floating-electrode, or serial-capacitor technology in a number of device families covering low-to-mid capacitance values. These devices feature a cascading internal electrode design that effectively forms multiple capacitors in series within the device.

ArcShield

An additional internal shield electrode, as shown in figure 5, opposes the effects that can cause surface arcing, without the known disadvantages of a coating or serial-electrode construction. The shield electrodes form a barrier to the terminal-to-terminal arcing seen in standard designs. In a standard design the electric field at the surface is very close to the terminal, which reduces the energy barrier for arcing to occur across the surface. The ArcShield design has a larger energy barrier because of the presence of the shield electrode of similar polarity to the termination.

When a high-voltage bias is applied to an ArcShield MLCC, a potential difference is established between the opposing terminations and the opposing electrode structure, but the electric field concentration is localised in the shield electrodes rather than the termination surface and respective first counter electrode. This minimizes the difference in potential along the surface of the chip and drastically improves the creepage distance capability even in smaller case size devices and when there is high porosity in the dielectric surface.

Review of shield effects

A standard overlap X7R MLCC is vulnerable to three basic high-voltage failure mechanisms. These are arcing between a terminal and the nearest electrode of opposite polarity, arcing between terminals, and internal breakdown.

KEMET ArcShield MLCCs address these failure mechanisms by introducing a shield electrode prevents arcing between terminals and any nearby opposing electrode. The devices also incorporate thicker active areas that effectively increase the breakdown voltage.

Surface arcing can occur at voltages as low as 300V, especially with small case sizes. Applying ArcShield technology to smaller case sizes such as 1206 (figure 6) and 0805 or 0603 (table 1) results in high voltage breakdown and reliable life test performance.

The results show the capacitors can withstand exposure to voltages much higher than typical hybrid/EV inverter or battery-charging voltages, indicating that X7R high-voltage MLCCs in case sizes as small as 0603 can be used safely. More information about capacitors with ArcShield™ can be found at

www.kemet.com/arcshield

Figure 4: Top: Five individual capacitors in series. Bottom: Monolithic series-electrode construction raises the breakdown voltage but reduces capacitance.

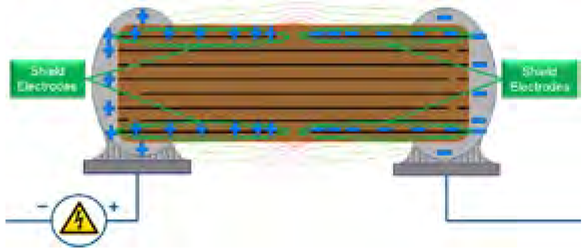

Figure 5: The shield electrode reduces field strength in the region of the capacitor surface and first counter electrode

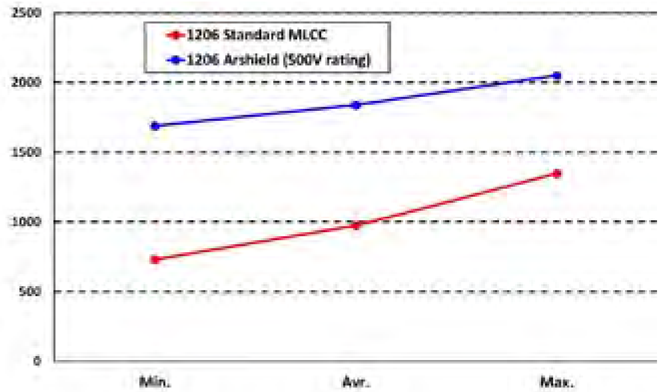

Figure 6: Voltage breakdown in air (50pcs), comparing standard 1206 MLCC to ArcShield

KEMET Part Number	Voltage Rating	Mean Capacitance (pF)	Mean DF (%)	IR (GΩ) 25°C	Mean Voltage Breakdown	Life Test @ 1.2Vr 125°C 1000hrs
C0603V392KCRAC	500	4,100	1.24	77	2100	0/300
C0603V392KCRAC	500	4,200	1.23	80	2000	0/77
C0603V152KBRAC	630	1,400	1.08	394	2900	0/77
C0603V152KBRAC	630	1,500	1.08	469	2600	0/77
C0603V102MDRAC	1000	900	1.01	805	3100	0/77
C0603V102KDRAC	1000	1,000	1.04	815	3100	0/77
C0805V223MCRAC	500	20,300	1.09	23.3	2600	0/77
C0805V223MCRAC	500	20,000	1.09	20.7	2300	0/77
C0805V123MBRAC	630	11,200	1.16	48.8	2800	0/77
C0805V123MBRAC	630	11,200	1.13	53.8	2700	0/77

Table 1: Performance data for smaller case size ArcShield MLCC

Capacitors for Power Electronics

IGBT Snubbers
RF Mica Capacitors
DC Link Capacitors
-High Current, High Voltage Film
-High Capacitance Aluminum Electrolytic
AC Output Harmonic Filter Capacitors

CDE CORNELL DUBILIER
ENERGIZING IDEAS

www.cde.com

High Current Power MOSFET with Current Mirror and Temperature Sense Diodes

Using current mirror for current sensing in high current MOSFET applications significantly reduces power loss in current sensing circuit and lowers design cost by replacing expensive high power current sensors with inexpensive standard resistors. Two temperature-sensing diodes monolithically integrated in the MOSFET's die monitor the junction temperature of the MOSFET, rather than that of the package or heat sink temperature. This significantly increases the precision of temperature measurement and reduces the protection gap for operating ambient temperature with minimal risk of damaging the device.

By Anatoliy Tsyrganovich, Leonid Neyman, and Abdus Sattar, IXYS Corporation

IXYS MMIXT132N50P3 contains the current mirror to monitor the drain current in a major device and two diodes with common cathode utilizing the same die as the major device for temperature monitoring. The MMIXT132N50P3 symbol is shown in Figure 1 [1].

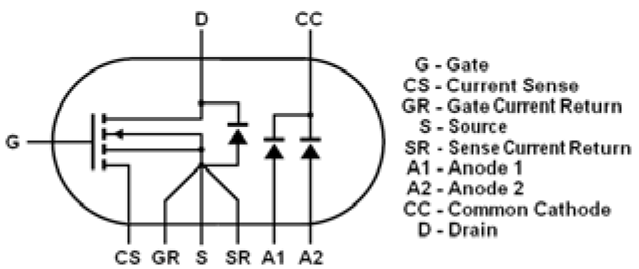

Figure 1: MMIX1T132N50P3 Device Symbol

The current mirror is created as a part of the major MOSFET structure with common drain (D) and gate (G) terminals and separated source terminals (S and CS). To minimize errors related to the voltage drop on bounding wires from the source current of the major device, two separate terminals, one for a current mirror current return (SR) and the other for gate charge/discharge current (GR), are provided in the device. Temperature sensing diodes have separate terminals for anodes (A1, A2) and common cathode terminal (CC).

Current Mirror Description

The schematic diagram for the MMIXT132N50P3 current mirror is shown in Figure 2.

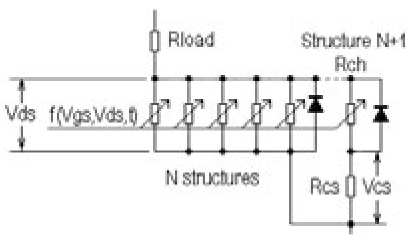

Figure 2: Current Mirror Schematic Diagram

As shown in Figure 2, MMIXT132N50P3 contains an N+1 identical structure with which N structures create the major MOSFET and the (N+1)th structure creates the current mirror. For this particular design, N = 200, and if no current sense resistor in the current mirror's source is used (R_{CS} = 0), the current mirror's current is exactly 1/200 of the major device source current. There is no dependency on the MOSFET's drain/source voltage VDS, and, as a result it is temperature-independent, providing measurements with maximum precision. However, if some sensor with finite resistance is used to convert current into voltage, the result of the measurement becomes V_{DS}-dependent because of the resistive divider created by the MOSFET's channel resistance R_{CH} and current sense resistor R_{CS}. This is especially important at low I_{DS} when drain/source voltage is low as well.

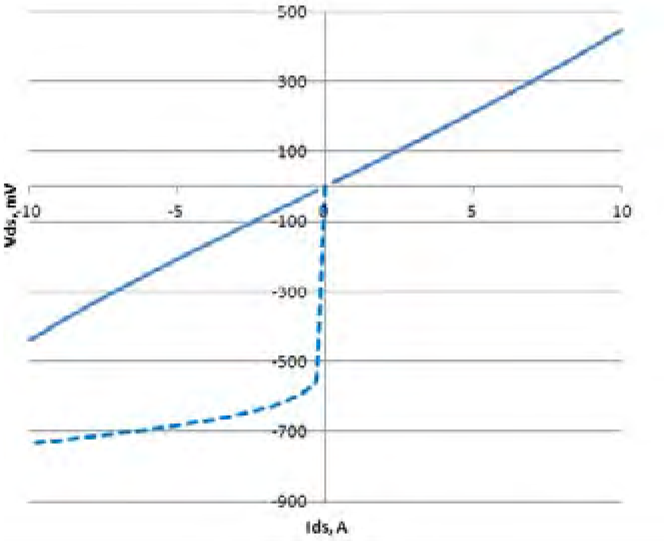

Figure 3: V_{DS} vs. I_{DS}
Legend: Solid line - MOSFET is in ON state and channel is connected in parallel to the body diode Dashed line – MOSFET is in off state and body diode is conducting only

Figure 3 shows the MMIXT132N50P3 drain/source voltage drop (V_{DS}) as a function of the drain/source current (I_{DS}) at currents below 10 A, with currents flowing in both directions when drain is positive with respect to source (normal operations) and drain is negative with respect to source (inverse connection) with the MOSFET in ON and OFF states. If the MOSFET is in ON state, V_{DS} is described as $V_{DS} = R_{DS(on)} * I_{DS}$ irrespective of I_{DS} polarity. If MOSFET is in OFF state and the body diode only sources current, V_{DS} is determined by the voltage drop across the body diode. Figure 4 shows a voltage drop across the current sense resistor (V_{CS}) and Figure 5 represents the current through the current sense resistor at the same conditions as in Figure 3.

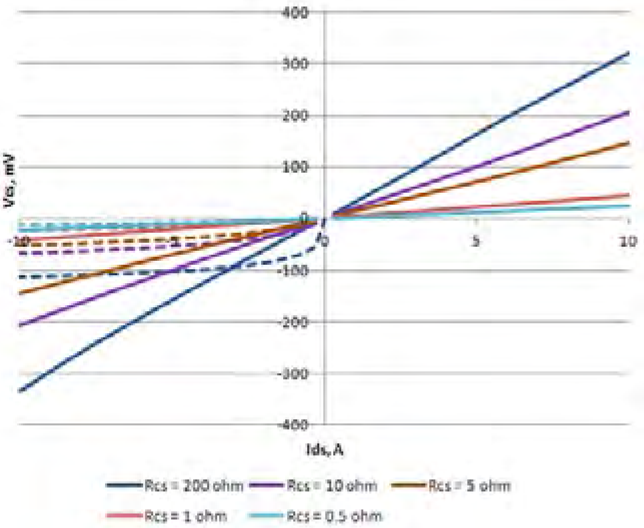

Figure 4: VCS vs. IDS

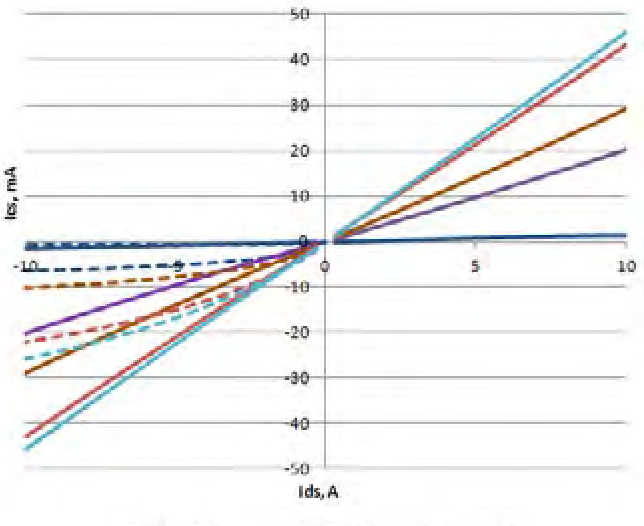

Figure 5: ICS vs. IDS

Figures 4 and 5 clearly demonstrate that increasing current sense resistance R_{CS} increases V_{CS} but decreases I_{CS}. With R_{CS} = 0.5 ohm, I_{CS} is close to the expected current mirror current, but V_{CS} is low. For example, at I_{DS} = 10 A, expected I_{CS} = 10/200 = 0.05 A, while actual I_{CS} = 46 mA, while with R_{CS} = 200 ohm, V_{CS} is close to V_{DS} (320 mV vs. 440 mV), but I_{DS} is only 1.57 mA, i.e. only 3.1% of the expected current. Figure 6 shows that it is a linear function between the current mirror's "head room", i.e. difference in voltage between V_{DS} and a voltage drop across the current sense resistor (V_{CS}) and maximum I_{DS} current that can be provided by the current mirror.

If full V_{DS} voltage is applied to the current mirror, its current has maximum value, which is equal to I_{DS}/200. Decreasing this voltage to 54% of the V_{DS} due to high R_{CS} decreases I_{CS} to 40% of its expected value.

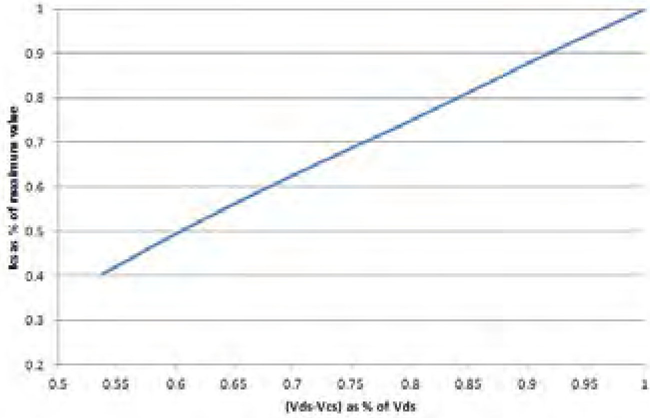

Figure 6: Utilizing Current Mirror's Current ICS vs. Current Mirror's Head Room (V_{DS} – VCS) at I_{DS} = +10 A

Therefore, a compromise between precision of measurement and signal level is required. High precision of the current measurement requires low value current sense resistors and signal amplifying, while low precision measurement may utilize high value current sense resistors at the expense of temperature dependency.

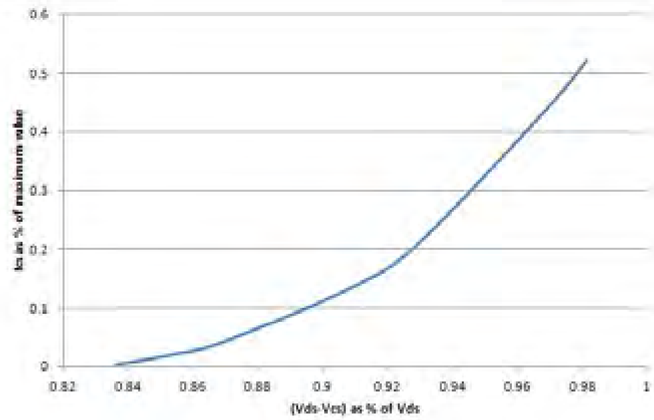

Figure 7: Utilizing Current Mirror's Current I_{CS} vs. Current Mirror's Head Room (V_{DS} – V_{CS}) at I_{DS} = -10 A

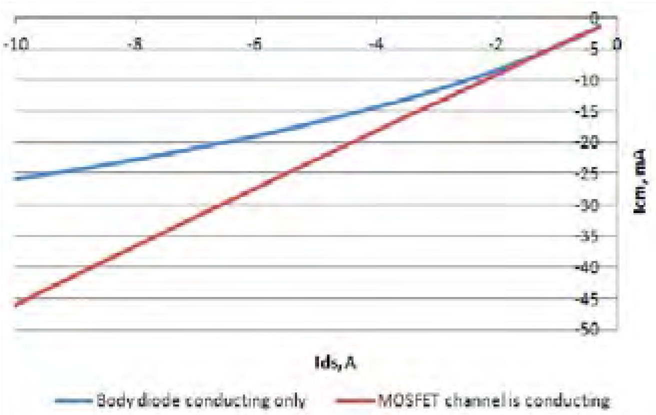

Figure 8: I_{CM} vs. Negative I_{DS} with MOSFET in ON and OFF States

Current Mirror Behavior with Body Diode Active

Figure 3 shows that when the MOSFET is in ON state and negative voltage is applied to the drain with respect to source, the channel intercepts the entire current as long as the voltage drop across the channel is less than the body diode forward voltage and current is not flowing through the diode. In this case, the current mirror's behavior is the same as with positive current (see Figures 4 and 5).

However, if the MOSFET is in OFF state and negative voltage is applied to the drain with respect to source, the current mirror's behavior varies significantly from the expected behavior.

At first, the proportion between currents through the current mirror's body diode and major body diode is not equal to 1/200 as expected; instead, it is ~0.52/200, i.e. two times less. This can be due to the current mirror's body diode utilizing significantly less silicon volume than that of the major body diode, resulting in higher resistance.

Further, as shown in Figure 7, ICM dependency from the current mirror's head room is not linear any longer, and without regard to relatively high head room voltage, current falls dramatically. Therefore, in this case, the current mirror's output primarily copies V_{DS}, determined by a major body diode's voltage drop. Even the highest head room voltage on the current mirror does not guarantee linearity between IDS and ICS currents, as shown in Figure 8.

Because of such behavior, the current mirror is not recommended for precise current measurements at negative IDS currents, if the body diode is conducting. However, the signal from the current mirror can be used to trigger the gate driver to activate the MOSFET and connect the channel in parallel to the body diode. It significantly decreases the voltage drop on the MOSFET and improves efficiency at currents creating lower voltage drop on the channel than the body diode conducting voltage.

Current Mirror Behavior at High Negative Currents
Figure 9 shows the MMIXT132N50P3 drain/source voltage drop (VDS) as a function of the drain/source current (IDS) at currents up to -40 A, with currents flowing when drain is negative with respect to source (inverse connection) with the MOSFET in ON and OFF states.

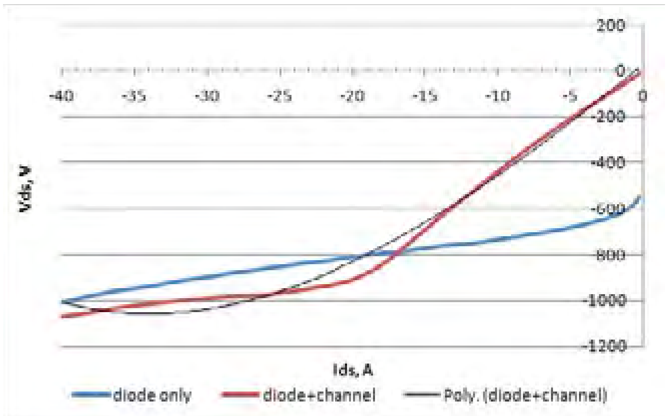

Figure 9: VDS vs. IDS at high negative currents
Legend: Red line - MOSFET is in ON state and channel is connected in parallel to the body diode
Blue line – MOSFET is in off state and body diode is conducting only

If the MOSFET is in ON state, $R_{DS(on)}$ becomes function of I_{DS} at high negative currents. When absolute value of the drain/source voltage drop $|V_{DS}|$ raises above 0.6 V, body diode starts conducting, which results in increased $R_{DS(on)}$ value. As a result, interception of two curves appears earlier than we may expect based on steady $R_{DS(on)}$ value at low currents, i.e. at -17 A instead of -20 A. Moreover, after interception point, two structures (body diode and conducting channel) working in parallel results in higher V_{DS} voltage drop than if body diode is conducting only. At this region, body diode and MOSFET's channel cannot be interpreted as two independent structures like diode and resistor connected in parallel. It means that to get higher efficiency, MOSFET should be turned off after absolute value of the negative current goes above interception point.

Also, current mirror behavior in this region becomes very complex. Figure 10 shows the current mirror's current ICM as function of the drain/source current I_{DS} with R_{CS} = 0.5 Ω, and figure 11 shows utilization of the current mirror's current normalized to expected value of 1/200 of I_{DS}.

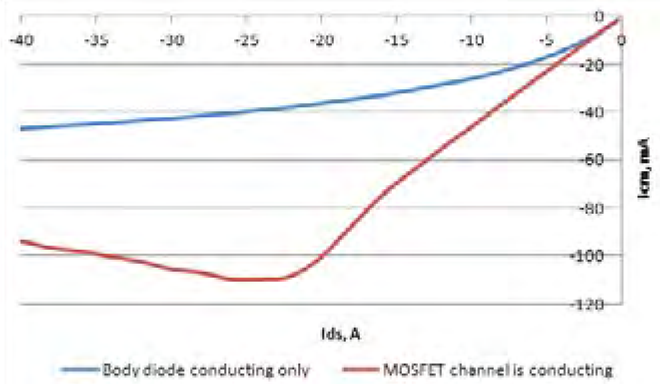

Figure 10: ICM vs. Negative IDS with MOSFET in ON and OFF States

I_{CM} current lost linearity immediately after interception point at I_{DS} = -17 A. Utilization of the ICM raises up to 1 immediately after that point and falls fast after that to the level determined mostly by a body diode. Using current mirror's current at $|I_{DS}|$ > 17 A for regulation or current monitoring purposes becomes problematic due negative current mirror's resistance, which may results in oscillations.

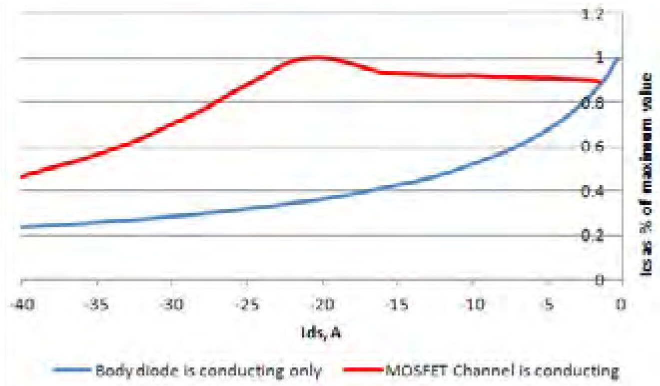

Figure 11: Utilizing Current Mirror's Current ICS vs. Negative IDS

Current Mirror Application Schematic
Figure 12 depicts a typical application circuit for positive current measurement. It contains operational amplifier U1 with gain = 10 that allows converting of a 40 A drain/source current into a 2 V ADC input signal.

It is recommended that the A to D conversion be started with a ~600 ns delay time after the Q1 gate is activated to avoid errors related to gate charge current flowing through current sense resistor R1. Additionally, close attention should be paid to the PCB layout to avoid high source current flowing through signal ground traces. Signal and power ground traces should be kept connected at one point only at the source current output.

Figure 13 represents an application with a circuit that monitors cycle-by-cycle overcurrent conditions and turns the MOSFET off immediately upon occurrence of such conditions. It includes comparator U1 with a 64 mV threshold and 36 mV hysteresis, which has logic high output if voltage drop at current sense resistor does not exceed 100 mV. This circuit also includes trigger U3, gate driver U5, input buffer with Schmitt trigger U9, blanking time generator U6, U7, U8, and auxiliary logic U2, U4.

The device starts with a signal applied to the IN input, which sets the gate driver's U5 output high turning MOSFET Q1 on. Both channels of the driver U5 are used in parallel to increase the driver's current capability. Schmitt trigger U9 is used to improve input signal noise immunity.

If the drain/source current exceeds the comparator's threshold, which corresponds to I_{ds} = 14.8 A, the comparator trips into logic low state that resets trigger U3 and aborts the input pulse which kept the MOSFET's Q1 gate high. When current falls below the comparator's threshold and the comparator's output becomes logic high again, trigger U3 output remains low until the next pulse is applied to the IN terminal.
Logic elements U6, U7, and U8 with the R8C3 network create a blanking time generator that keeps the comparator's output logic high for ~600 ns to finalize the transition process related to gate charge.

The drain/source current value at which current is interrupted can be adjusted by the current sense resistor value or comparator's threshold value, or both.

Figure 14 represents an application with a circuit that monitors negative current flowing through the MOSFET's body diode. It turns the MOSFET ON if the current exceeds the preset threshold, and switches it OFF, when it falls below this value. It includes comparator U1 with a 47 mV threshold and 34 mV hysteresis, which has logic low output if the absolute value of the voltage drop at current sense resistor does not exceed ~80 mV. This circuit also includes trigger U5, gate driver U10, input buffer with Schmitt trigger U11, blanking time generator U7, U8, U9, and auxiliary logic U2, U3, U4, and U6.

If a signal is applied to the IN terminal, the device operates as a standard gate driver regardless of the direction of the drain/source current setting gate driver's U10 output high and MOSFET Q1 ON state. Both channels of U10 are used in parallel to increase the

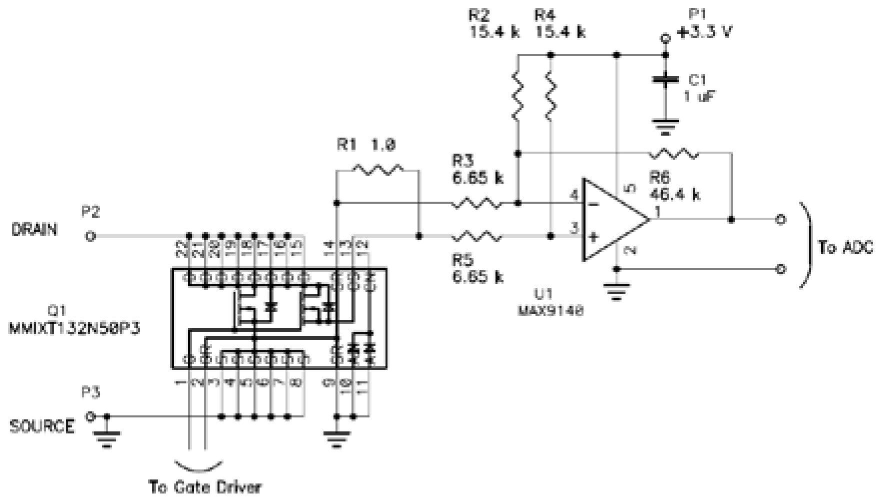

Figure 12: Positive Current Mirror Current Measurement Circuit

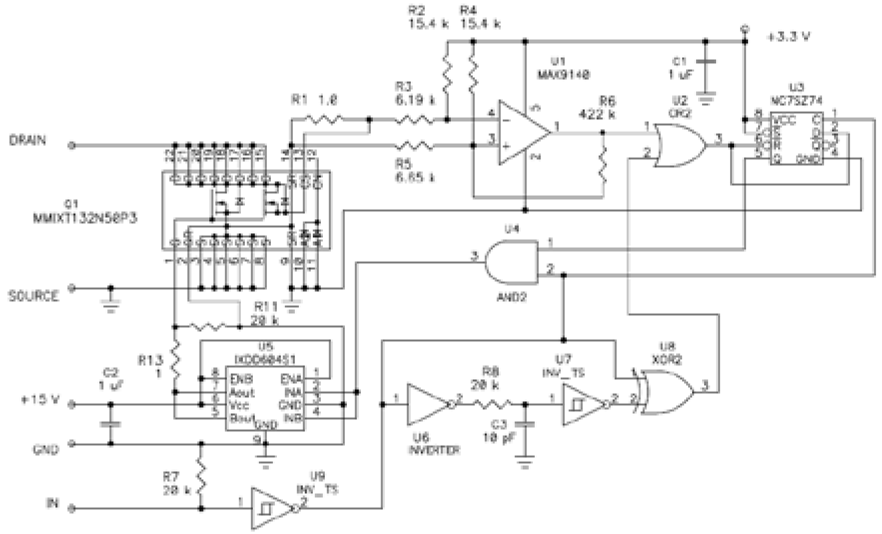

Figure 13: Positive Current Cycle-by-Cycle Overcurrent Monitoring System

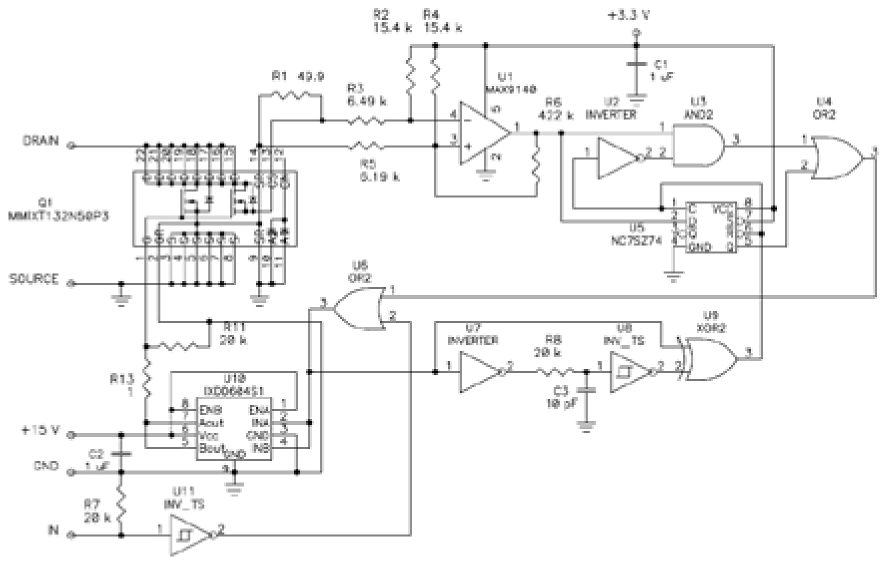

Figure 14: Negative Current (Body Diode Current) Monitoring System

driver's current capability. Schmitt trigger U11 is used to improve input signal noise immunity.

However, if no external signal is applied to the IN terminal and the MOSFET's body diode current exceeds the comparator's U1 threshold, its output goes logic high, activates the gate driver, and turns the MOSFET to ON state, connecting the MOSFET's channel in parallel to the body diode and reducing the drain/source voltage drop to increase efficiency.

currents. One possible solution is to separate current sense resistors with low forward voltage diode, as shown in Figure 15.

Current sense resistors R1 and R4 are separated by diode D1. For a negative current, only resistor R4 is used and its value determines the sensitivity to negative current. For a positive current, both resistors are connected in parallel with diode D1 in series with resistor R1. This creates some nonlinearity at low positive currents; however, it does not affect the area where positive current should

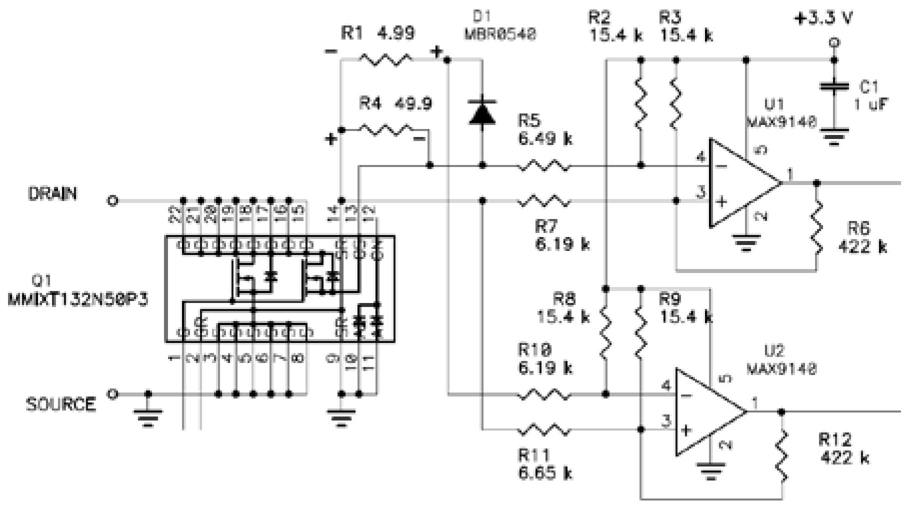

Figure 15: Separating Current Sense Resistors with Diode

When negative current falls below the comparator's U1 threshold, its output goes logic low, which turns gate driver U10 and the MOSFET OFF. After that, low negative current flows only through the body diode again. This allows for automatic turn on/off of the MOSFET in case it operates as a diode in motor drive circuits or buck converters without engaging special controllers to synchronize the input signal of the gate driver with actual diode current.

The comparator's threshold in this schematic corresponds to Ids ~ –0.8 A to turn the MOSFET on and ~ –0.4 A to turn the MOSFET off. The threshold can be adjusted to another current value by changing current sense resistor R1 or the comparator's initial setting.

Logic elements U7, U8, and U9 with the R8C3 network create a blanking time generator that keeps the comparator's output logic level unchanged for ~600 ns to finalize the transition process related to gate charge/discharge.

Using both positive and negative current comparators in the same design requires different current sense resistors to provide desired thresholds for positive and negative

be limited. Figure 16 represents a voltage drop at current sense resistor R1 vs. drain/source current with R4 = 49.9 ohm and R1 = 10 ohm and R1 = 4.99 ohm.

Temperature Measurement Diodes

Use diodes as temperature sensors based on the relatively high temperature coefficient of about 0.2 mV/°C, which is fairly linear.

The current flowing through the diode when it is forward biased is equal to [2]

$$I = I_s(e^{\frac{V}{\eta V_T}} - 1)'$$

where I_S is the reverse saturation current, V is the diode's forward voltage drop, η is ideality factor (a constant which has a value ranging from 1 to 2), V_T = kT/q is the thermal voltage of the diode, T is the absolute junction temperature in Kelvin, $q = 1.602 \cdot 10^{-19}$ C is the electron charge, and $k = 1.38 \cdot 10^{-23}$ J/K is the Boltzmann's constant:

If a known current is flowing through the diode, its temperature can be determined as a function of the forward voltage drop as follows assuming that $e^{\frac{V}{\eta V_T}}$:

$$T = V\frac{q}{k\eta}/\ln(\frac{I}{I_S})$$

This equation contains the reverse saturation current IS and ideality factor η, which are part-dependent and should be determined before measurement.

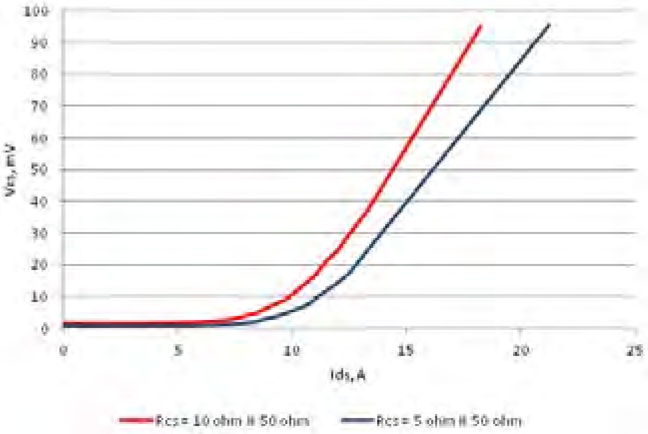

Figure 16: Voltage Drop at Current Sense Resistor vs. Drain/Source Current with Diode Separating Current Sense Resistors

If two known currents I1 and I2 are passed through the diode, or two identical diodes are used simultaneously, its temperature can be determined as

$$T = (V_2 - V_1)\frac{q}{k\eta} / \ln\left(\frac{I_2}{I_1}\right) ,$$

with I_S excluded from the equation.
If I_2/I_1 = 10, this equation simplifies to

$$T = (V_2 - V_1)\frac{q}{2.3k\eta}. .$$

The MMIXT132N50P3 contains two identical diodes that can be used for temperature measurement, either in a single-ended or differential scheme. The recommended forward currents are 1 mA for a single-ended scheme and 1 mA and 100 µA for a differential scheme with short pulses every 1–3 seconds. Higher, steady currents are not recommended to avoid self-heating of the diodes, which may create incorrect results.

Application Schematic for Temperature Measurement

Figure 17 shows a typical schematic diagram which is recommended for temperature measurement using two MMIXT132N50P3 integrated diodes. It contains two current sources generating stable currents. The first current source (U1:A, U2:1) generates 1 mA current, while the second current source (U1:B, U2:2) generates 100 µA current. Variable resistor R5 provides the ability to adjust current from the first current source to obtain an exact 1:10 proportion. Voltage drop across diodes is measured by ADC converters and used to calculate the die temperature of the MMIXT-132N50P3. IXYS recommends the use of the microcontroller unit's port as a 3.3 V voltage source to activate the circuit during temperature measurement only. Doing so helps prevent self-heating of the diodes, which can be a source of errors in temperature measurement.

References

1. MMIXT132N50P3 Data Sheet; IXYS Corporation. 2016
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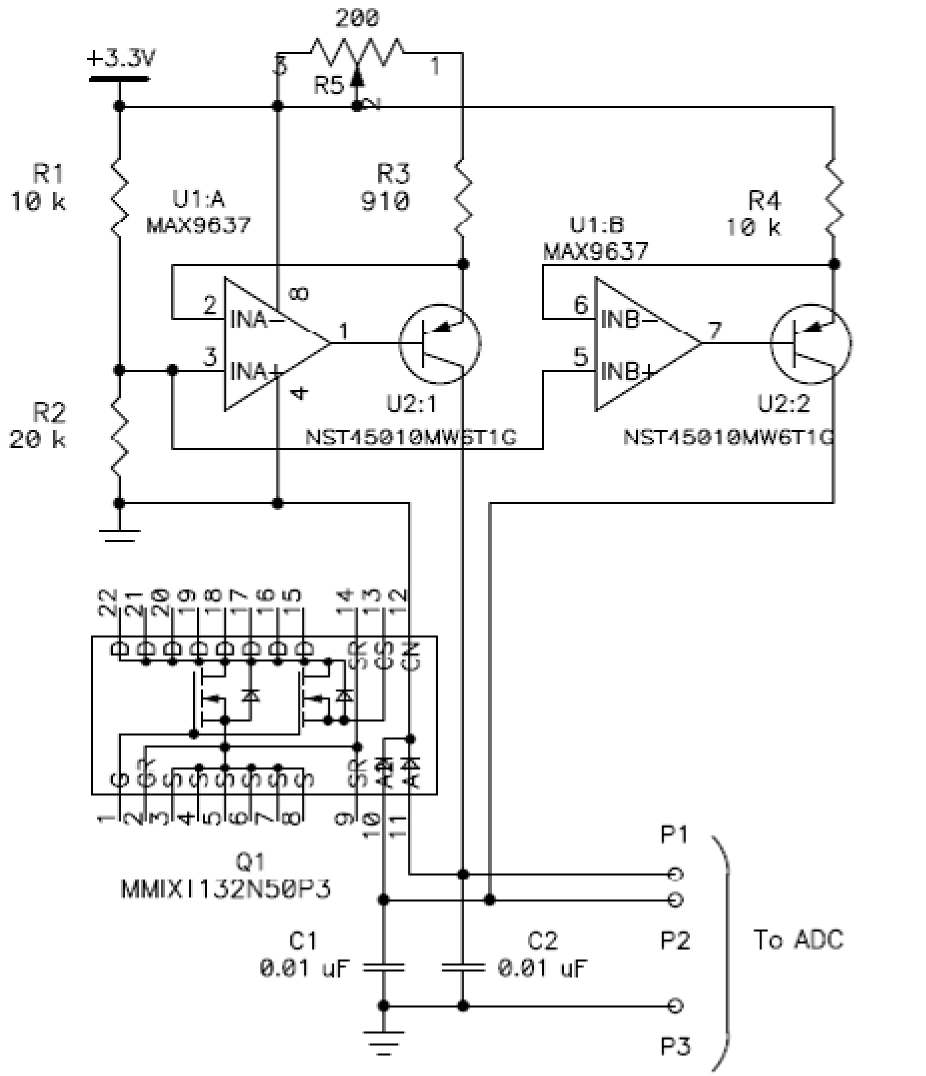

Figure 17: Typical Application Schematic for Temperature Measurement with Two Diodes

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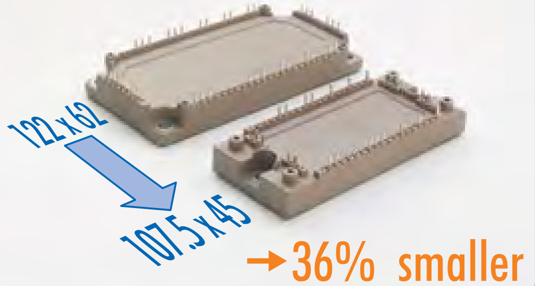
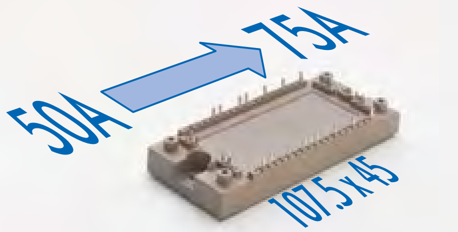
Fuji Electric's X-Series - 7G IGBT

with improved package technologies

- Improved heat transfer properties
- Enhanced power cycling capability
- Increased output power/$T_{j(op)}$ = 175°C
- Expanded current rating/downsizing





Type	Package & Configuration	V_{CE}	I_C
IPM	26.0x43.0mm (Pre-Driver)	600 V	15-35A
PIM	33.8x62.8mm, Solder Pins & PressFit	650 V	10-30A
PIM	33.8x62.8mm, Solder Pins & PressFit	1200 V	10-25A
PIM	56.7x62.8mm, Solder Pins & PressFit	650 V	50A
PIM	56.7x62.8mm, Solder Pins & PressFit	1200 V	15-35A
PIM	45x107.5mm, Solder Pins	650 V	50-100A
PIM	45x107.5mm, Solder Pins	1200 V	35-75A
PIM	62x122mm, Solder Pins	650 V	75-150A
PIM	62x122mm, Solder Pins	1200 V	75-150A
6-Pack	62x122mm, Solder Pins & PressFit	1200 V	100-200A
2-Pack	34x94mm	650 V	150-200A
2-Pack	34x94mm	1200 V	100-200A
2-Pack	34x94mm	1700 V	75-150A

Type	Package & Configuration	V_{CE}	I_C
2-Pack	45x92mm	650 V	300-400A
2-Pack	45x92mm	1200 V	200-300A
2-Pack	62x108mm	650 V	400-600A
2-Pack	62x108mm	1200 V	300-600A
2-Pack	62x108mm	1700 V	150-400A
2-Pack	80x110mm	650 V	600A
2-Pack	80x110mm	1200 V	450-600A
2-Pack	80x110mm	1700 V	300-600A
2-Pack	62x150mm, Solder pins / PressFit	1200 V	225-800A
2-Pack	62x150mm, Solder pins / PressFit	1700 V	225-600A
2-Pack	89x172mm	1200 V	900-1200A
2-Pack	89x172mm	1700 V	650-1200A
2-Pack	89x250mm	1200 V	1400-1800A
2-Pack	89x250mm	1700 V	1000-1800A

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Avoidance of Reverse Recovery Ringing in Wide Band Gap Devices

Can changing your package really be that simple?

HITACHI highlights the necessity of High Power Density Dual nHPD^2 packaging Attaining the highest levels of Silicon chip efficiency whilst paving the way to avoid reverse recovery oscillations commonly observed in WBG semiconductor modules.

By Neil Markham, Hitachi Europe Ltd.

2.46 million Google results, a US Presidential backing and the European Union's carbon emissions darling of the future. Savior of World? Who knows for sure, but Wide Band Gap (WBG) semiconductors continuously grab column inches in the specialist publications, the wider press and the conference circuit. Investment is booming despite wider macro economy woes. A significant reduction in global energy consumption will occur, by WBG adoption in consumer switched-mode products for example, but the industrial Power Electronics sector has a demanding job ahead with one hand tied behind its back due to ringing behaviour in conventional packages.

The intrinsic behavior of the Wide Band Gap semiconductor with a unipolar structure offers significant energy efficiency improvements due to negligible recovery current. So what is the catch, the chip level reports look fine? The challenge is realizing laboratory level chip performance as a working solution at industrial power levels. This will typically require a power module which offers convenient mounting and isolation complimentary to various cooling solutions. Switching 1200A @1500V, for example, across a wide temperature range, whilst maintaining compliance with the Electromagnetic Compatibility (EMC) Directive 2014/30/EU, is one part of a multi-faceted challenge. Factor in WBG characteristics and managing high power within Directives becomes a significant challenge.

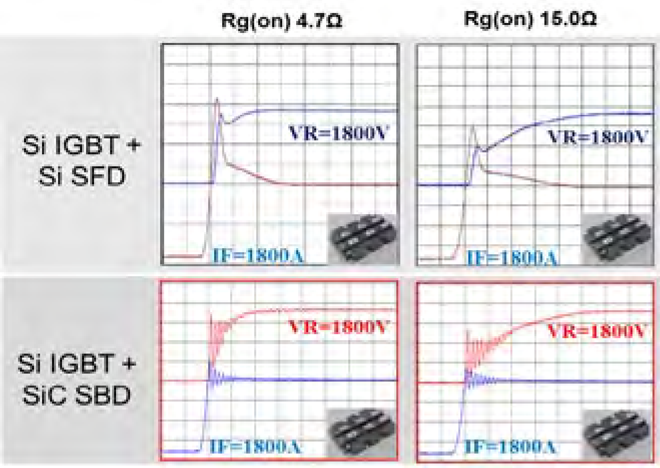

Figure 1: Recovery waveforms of conventional 1800A/3300V IGBT module with and without SiC SBD. Test conditions: 1800A, 1800V, 25°C, Lσ 90nH, Rg_on 4.79Ω

Suppressing recovery ringing

In Figure 1, the recovery waveforms of two conventional modules are presented. The right-hand side module adopts a Silicon Carbide (SiC) Schottky Barrier Diode (SBD) to form a "Hybrid SiC" module with Si IGBT. "Conventional module" refers to classic 190mm x 140mm packages, also known as IHM or HVIHM. Problematic oscillation is evident in the SiC hybrid device.

Whilst it is possible to mitigate oscillation without a significant impact to the losses using active gate control architecture, to monitor the diode current direction and to react in real-time to dynamically adjust the turn_on time, this can be a complex and expensive design process especially without costly investment. Controlling the oscillation by simple gate resistor tuning will significantly drive up losses and eradicate the WBG efficiency benefits. Other options also exist, but considering price-performance merits at a system level, it is worthwhile managing the system loop inductance as a viable alternative. With this in mind, the nHPD2 high power dual module was developed.

LCR modelling

Special focus is given to IGBT turn-on and diode recovery where the ringing highlighted in Figure 1 was evident.

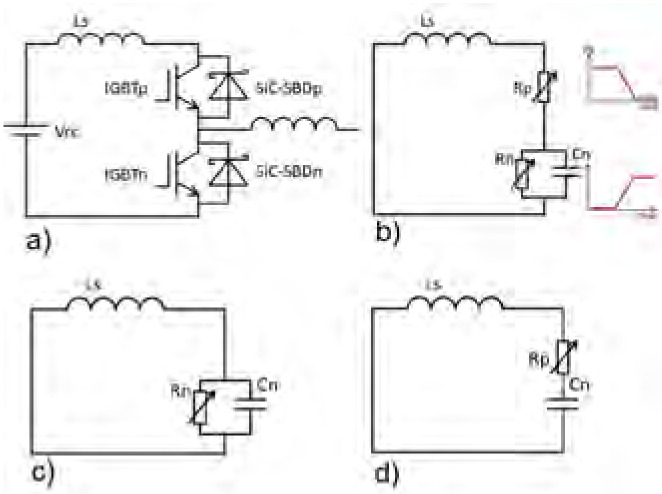

Figure 2: Equivalent circuit diagrams

By considering the nHPD2 phase leg as a combination of LCR models similar to Figure 2., which differ according to the switching state and diode type (i.e. Si or SiC), a differential equation may be established:

$$L\sigma \cdot \frac{diL\sigma}{dt} + Rp \cdot iL\sigma + \frac{1}{Cn}\int iCn \cdot dt = 0 \quad (1)$$

$$iL\sigma = iCn + iRn \quad (2)$$

Assuming a silicon IGBT, the turn_on is significantly faster than the diode recovery period thus can be ignored and Figure 2c) applied.

$$Rn \leq 2 \cdot \sqrt{\frac{Ls}{Cn}} \quad (3)$$

To be free from oscillation, the result of equation (3) must be zero. For the SiC SBD, acts much faster than and thus Figure 2d) can be considered.

$$L\sigma \cdot \frac{diL\sigma}{dt} + Rp \cdot iL\sigma + \frac{1}{Cn}\int iCn \cdot dt = 0 \quad (4)$$

It is now possible to simply identify the importance of the three key elements: ; ; . Having identified that increasing will elimate the beneficial WBG zero recovery characteristic, the IGBT's is known to have a substantially higher capacitance than the diode due its thinner charge carrier zone, then we can consider the beneficial influence of the system inductance and attribute a realistic package inductance to suppress the oscillation seen in Figure 1. Since is a combination of the module package, DC link capacitor and busbar, 25% of the total allowable stray inductance was defined as the target value for module package.

Defining the allowable package inductance
Testing Hitachi's first generation* 3.3kV SiC MOS chip (rated 25A) and 3.3kV SBD (25A) in combination with different Rg_on and stray inductance values (package), a trade-off map was plotted to determine suitable WBG performance points. Refer to Figure 3.

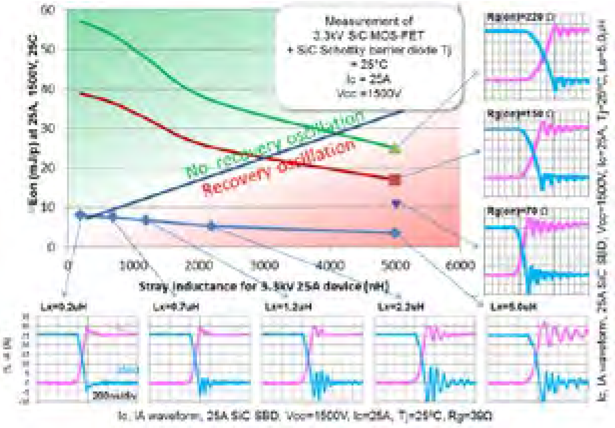

Figure 3: Equivalent circuit Stray inductance versus Rg(on) turn_on waveforms

Using the plotted data it was determined necessary to set the 3.3kV LV nHPD2 package inductance to 10nH, allowing for a 3.3kV system level of 40nH.

Optimizing package structure
A typical 3.3kV 1500A 190mm x 140mm IHM package the module stray inductance is about 6-7nH. With market acceptance for the next generation module footprint set at 100mm x 140mm, the 10nH target value does not disadvantage system output power requirements enjoyed today allowing package introduction using silicon technology whilst offering platform to mount SiC without the ill-effects of electromagnetic interference.

By way of electromagnetic simulation, the internal and external package design is investigated to acquire an optimum P-N terminal gap clearance. Whilst a wider gap offers simpler bus-bar connectivity, it adversely affects performance.

According to existing IEC convention, strict rules apply to creepage and clearance. With consideration of functional isolation and a 4kV Voltage impulse (3.3kV IGBT), the minimum functional terminal-terminal distance shall be 7.5mm. A higher gap will linearly increase the module inductance and negate the WBG performance benefits. A higher gap will also increase design pressure on capacitor and bus-bar manufacturers to meet the system level goal, identified earlier as 40nH total stray inductance.

Validation
Using experimental tests, two type names were assessed using the same Hitachi advanced Trench gate HiGT structures, both adopting SiC SBD. Switching curves are compared in Figure 4. under three switching states.

Figure 4 confirms the genuine merit of the low inductance package solution for high power WBG applications. Turn_on and reverse recovery ringing is suppressed whilst enjoying WBG technology, as highlighted by the MBM450FS33F-C example. (Additional loss benefits exist but are not explored in this article. See published papers: PCIM2014 KAWASE APEC2016 SAITO).

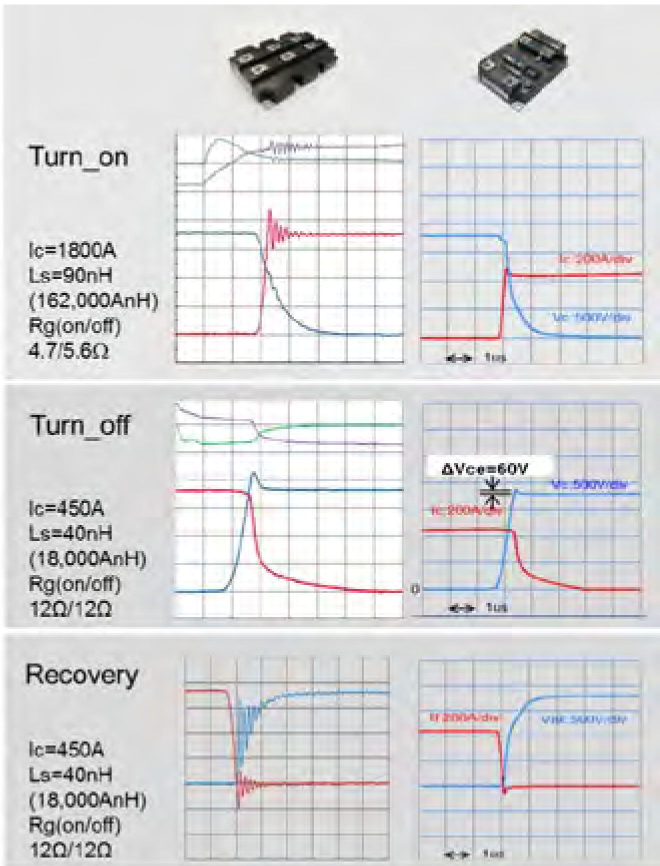

Figure 4: Validation of oscillation suppression using low inductance package (nHPDD2)

Conclusion
By adopting nHPD2 packaging technology Hitachi has demonstrated its pioneering spirit to realize the wider market need for operational high power WBG devices. Benefiting from a 9nH module inductance (using the 3.3kV example), nHPD2 is able to realize potential reductions in turn_on losses up to 50% and almost 100% of the reverse recovery losses. For cost sensitive applications requiring a silicon only solution, nHPD2 still delivers performance and lifetime advantages compared to conventional packages, in addition to several secondary cost benefits of adopting a modular design approach using a single standardized footprint. Referring to the opening title "Can changing your package really be that simple?". Yes. The caveat? The best solution is a system solution. With the combined efforts of capacitor and bus-bar manufacturers, the system engineers and the semiconductor industry, each striving to reach key stray inductance targets, yes it really can be that simple.

Figure 5: LV nHPD2 (available) & HV (under development)

http://www.hitachi.eu/pdd/products/

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Low Loss Thyristors for High Power Applications

In many cases thyristors are still the first choice for high power applications like industrial drives and high voltage direct current transmission (HVDC). Industrial drives for pumps and compressors, with power levels up to 80 MW and beyond, are needed in different markets i.e. Oil and Gas. Due to the demanding requirements of these drives, a wide operation temperature of up to 125 °C maximum junction temperature (T_{vj}) is essential for thyristors. Additionally, they have to fulfill the need for long term stability and high surge current capability for designing highly efficient, high power drives able to perform for more than several decades.

By Jens Przybilla, Uwe Kellner-Werdehausen, Dr. Sebastian P. Sommer, Infineon Technologies Bipolar GmbH & Co. KG

Due to the long period of operation the losses of thyristors used in industrial applications are an important factor for the design of such drives. Additionally, the long term stability and the surge current capability are also crucial issues that have to be taken into account. Today the blocking voltage of thyristors in such applications is usually 7 kV to 8 kV, this helps in reducing the number of serial devices for medium voltage (MV) drives.

To serve these needs of industrial applications Infineon Technologies Bipolar introduced a new 8.5 kV thyristor with low losses at on-state and switching with high blocking capability at T_{vj}=125 °C. This performance was realized by the optimization of the silicon design, as well as the use of well-established processes like Low Temperature Sintering (LTS) and an electroactive amorphous carbon passivation (a-C:H). Also, the definition of maximum blocking voltage has been tailored to application demand. The low loss thyristor features a silicon diameter of 150 mm (6-inch) with outstanding parameters in a package with 135 mm pole piece diameter (see Figure 1). This new thyristor offers the same advantages as the existing 9.5 kV 6-inch thyristors already developed for HVDC [1, 2]. The large diameter enables the adaption to smaller dimensions like 100 mm (4”) and 125 mm (5”) in a short period of time.

Figure 1: New 8.5 kV 6-inch electrically triggered thyristor with 135 mm pole piece

New thyristor concept with LTS

The LTS technology is based on the concept of diffusion welding and forms a solid metallurgical transition (see LTS-layer in Fig. 2a) between Silicon and Molybdenum carrier over the entire area. In contrast to the dry interface between Silicon and Molybdenum of Free Floating assembly (FF) shown in Fig. 2b, the thermal resistance of LTS designs is significantly lower. In addition, there is no direct thermal coupling between the protruding junction termination area of FF-assembly with double-side negative bevel and the two Mo-contact discs. This may limit the maximum operating temperature at very high periodic blocking voltages V_{RRM} and V_{DRM}.

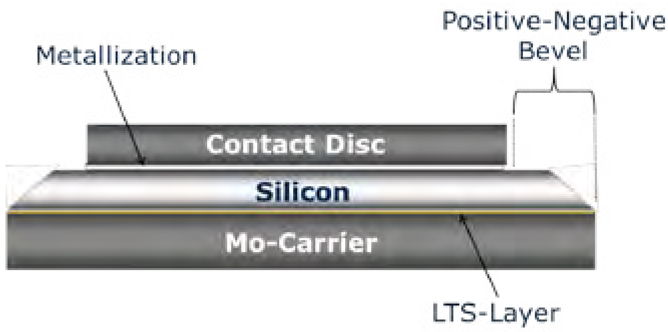

Figure 2a: Cross-section of LTS design and negative-positive bevel at junction termination

Figure 2b: Cross-section of FF design and double-side negative bevel

As a consequence, the better heat dissipation of LTS design leads to a higher maximum operating temperature of up to 125 °C. This has no negative effects on critical thyristor parameters like surge current or long term blocking voltage stability and periodic blocking voltage capability. By means of LTS the power loss during high reverse current flow, especially within junction termination, is sufficiently dissipated.

	LTS Current design	FF Competitor
Blocking capability	9.2 kV	8 kV
Surge current	65 kA@125°C	47.5 kA@115°C
Thermal resistance	5.0 K/kW	5.7 K/kW
Minimum Force	63 kN	81 kN

Table 1: Comparison of key parameters in LTS and FF design based on existing 4-inch devices [3, 4]

It has already been reported that maximum periodic blocking voltage, V_{RRM} and V_{DRM}, can be further increased by 15 -20 percent without increasing the silicon wafer thickness. Testing was conducted according to standards (IEC 60747-6) for thyristors subjected to periodic voltage stress [2]. Typical current and voltage characteristics are shown in Figure 3. The half sine with t_P=10 ms is applied with an amplitude equal to working voltage V_{RWM}. This base sine wave is superimposed by surge voltage V_{RRM} with higher amplitude during a shorter period of t_P=300 µs. In this set-up the blocking current can reach values of several amps at very high voltages V_{DRM} and V_{RRM}.

By introducing this Pulse Peak test concept two improvement options are possible:

- Silicon thickness is kept constant, i.e. the same as existing thyristors, and V_{DRM}/V_{RRM} is increased. This leads to a significant reduction of the number of series connected devices and corresponding components, but without increased on-state losses.
- Silicon thickness is reduced compared to existing thyristor, and V_{DRM}/V_{RRM} remains constant, but with significantly lower on-state voltage drop V_T of single thyristor.

For the new low loss concept described in this article the second option has been chosen reducing the silicon thickness by 6 percent in order to achieve significantly lower on-state voltage drop V_T and dynamic losses, but without negative effect on the blocking capabilities.

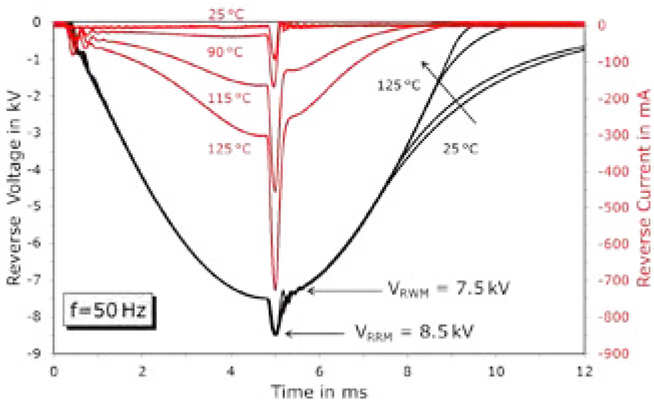

Figure 3: Periodic blocking voltage and current at different operating temperatures using half sine wave of V_{RWM}=7.5 kV superimposed by surge voltage up to V_{RRM}=8.5 kV (t_P=300 µs)

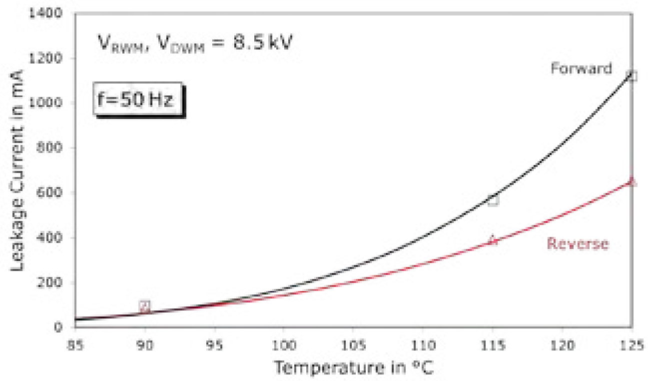

Figure 4: Leakage current vs. operating temperature from periodic blocking voltage test using half sine wave (V_{RWM}, V_{DWM}=8.5 kV, t_P=10 ms) tested on a typical device

Device Performance

Figure 3 depicts the periodic blocking test for a typical new low loss 6-inch device subjected to a periodic voltage stress at V_{RRM}=8.5 kV and f=50 Hz. The recorded blocking voltage and leakage current waveforms were tested at four temperatures, 25 °C, 90 °C, 115 °C and 125 °C, respectively. Usually, the applied working voltage V_{RWM} is between 60 and 80 percent of the peak voltage V_{RRM} as recommended by different manufacturers [2, 5]. With the new concept, the selected V_{RWM} applied is about 90 percent of the repetitive peak reverse blocking voltage V_{RRM}.

In Figure 4 the typical leakage current set against temperature behavior is shown. With this test the blocking performance of the new 8.5 kV low loss device is demonstrated for junction temperatures of up to 125 °C and frequency of 50 Hz.

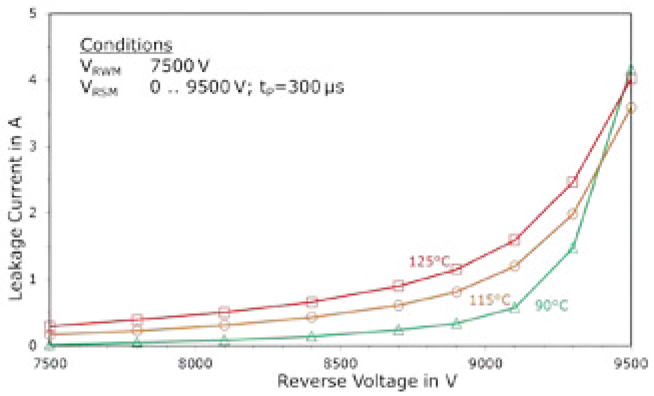

Figure 5: Leakage current vs. blocking voltage from Pulse Peak test (single pulse) at different temperatures and surge voltages (t_P=300 µs) using half sine wave of V_{RWM}=7.5 kV

In addition, the peak voltage blocking performance is demonstrated in Figure 5. The device shows a capability of up to 9.5 kV peak blocking voltage at 125 °C. This data highlights the blocking margin of the new design enabling a long term blocking stability over decades. The key technologies for this margin are the LTS joining process and the bevel passivation process using an electroactive a-C:H layer.

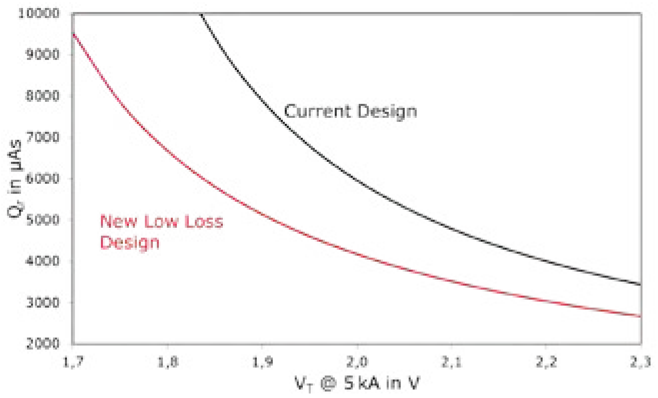

Figure 6: Qr vs. VT for existing and new low loss 8.5 kV 6-inch thyristor at operating temperature of 125 °C, derived from a few tested devices using I_T=3 kA, di/dt=-1.5 A/µs, V_R=-100 V

The new devices not only show an outstanding blocking capability, the losses of the thyristor have also been reduced significantly. In Figure 6 the reduction of losses are shown for a 150 mm silicon diameter amounting to approximately 30 percent lower switching losses. Compared to current designs, the reduced losses are caused by the recovery charge Qr, at the same on-state voltage v_T.

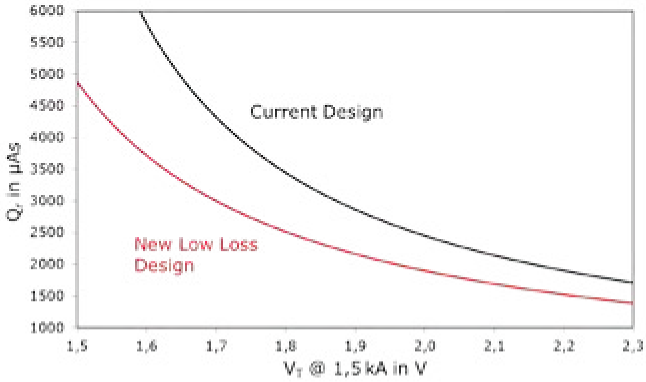

Figure 7: Calculated trade-off between reverse recovery charge Q_r and on-state voltage drop V_T of smaller 8.5 kV 6" thyristor with 100 mm pole piece using the defined conditions: I_T=1.5 kA, di/dt=-1.5 A/µs, V_R=-100 V

In Figure 7 the calculated data for the new low loss thyristor with 100 mm silicon diameter is shown. For the defined conditions I_T=1.5 kA, di/dt=-1.5 A/µs, V_R=-100 V, the blocking capability of this smaller device will be as high performing as the 150 mm silicon diameter device.

Conclusion

The article described a new 8.5 kV low loss thyristor family designed for industrial applications. With the new technology, full blocking capability at 50 Hz/60 Hz is achieved for 125 °C at 8.5 kV. Beside these key factors, outstanding surge current capability and low mechanical installation force are additional features of these devices which are important for industrial applications. This enables highly efficient and powerful applications with superior reliability for today´s and future´s demands.

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Recent Advancements in IGCT Technologies for High-Power Electronics Applications

In this article, we review the progress made recently for further developing the Integrated Gate-Commutated Thyristor (IGCT) device concept for high-power electronics applications. A wide range of newly introduced IGCT technologies is discussed and recent prototype experimental results as well as novel structures and future trends of the IGCT technology are presented.

By Umamaheswara Vemulapati, Munaf Rahimo, Tobias Wikström and Thomas Stiasny
ABB Switzerland Ltd

The IGCT has been established as the device of choice for many high power applications such as medium voltage drives, STATCOMs, and pumped hydro [1, 2]. Today, IGCTs have been optimized for current source inverter (CSI) and voltage source inverter (VSI) applications with state-of-the-art devices having voltage ratings ranging from 4.5kV up to 6.5kV and are today available as Asymmetric, Symmetric (Reverse Blocking), and Reverse Conducting devices (see Figure 1).

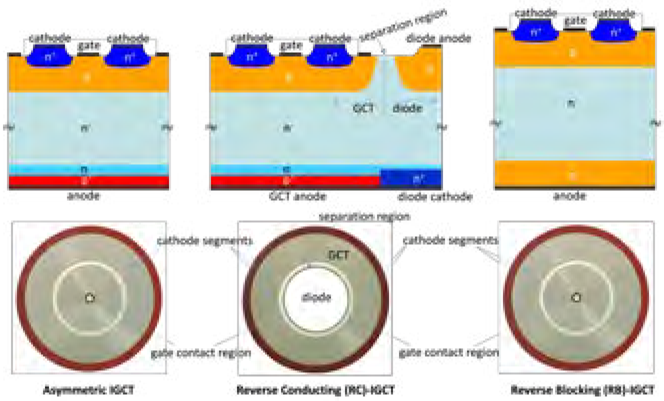

Figure 1: State-of-the-art IGCT device types and their schematic cross sections from top side to bottom side (vertical cross section).

For VSI topologies, the Asymmetric IGCT has the highest power level for a given wafer size while the Reverse Conducting IGCT (RC-IGCT) provides compactness by integrating a diode on the same GCT wafer [3, 4]. Inherent to the IGCT concept, the gate unit is critical for the device switching performance and is therefore an integral part of the device for proving a low inductive gate path. The hermetic press-pack design of the IGCT has for years proven its reliability in the field with respect to device protection and load cycling capability.

Therefore, the IGCT is the ideal device of choice for many high-power electronics applications due to its thyristor-like conduction, transistor-like turnoff and hermetic press-pack design. It can be seen from Figure 2 that the IGCT has clearly a better technology curve (turn-off losses vs. on-state voltage) compared to the IGBT, i.e. for the same losses, the on-state voltage drop is close to half in the IGCT compared to an equivalent IGBT. However, IGCTs need a clamp circuit to protect the antiparallel diode from high power failures in the circuit topology and this clamp circuit contributes to additional losses during switching.

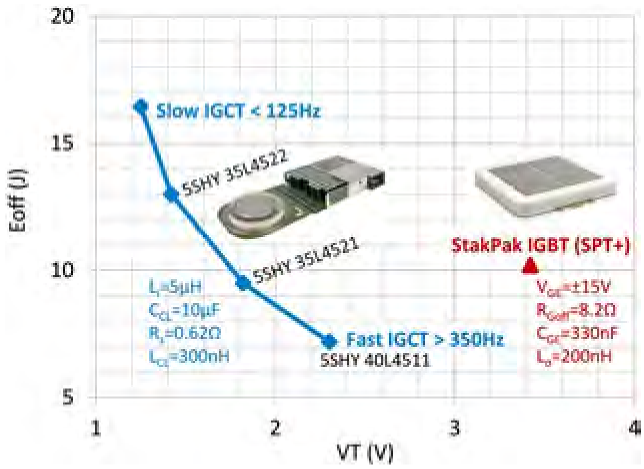

Figure 2: Technology curve comparison between 4.5kV Asymmetric IGCT and StakPak IGBT module at 2.8kV, 2kA, 125°C. The active area is nearly the same for both the devices.

IGCT performance trends

In the past 10 years, the IGCT technology has experienced major development trends to further exploit the main advantages in terms of lower conduction losses and higher power densities offered by this device design/process concept. Fig. 3 shows a basic illustration summarizing the basic IGCT performance trends for achieving higher power densities with new technology platforms. The increase in power has been divided into two categories. The first is related to an increase in power density through lower losses and/or higher operating temperatures. Furthermore, the main enabling factor for achieving these trends is linked strongly with a high current turn-off current capability for increasing the safe operation area (SOA) of the device. The second trend targets an increase in absolute power by either an increase in device size from the state-of-the-art 91mm to 150mm and/or through integration concepts which in principle provide the full targeted functionalities as per application requirement with a single wafer device instead of employing two devices (IGCT and diode).

In this article, we discuss the main features which make the IGCT an attractive option for high power applications with respect to the technology developments outlined above. Each of the technology platforms will be presented with regard to the device design and targeted performance while providing the results from fabricated prototypes.

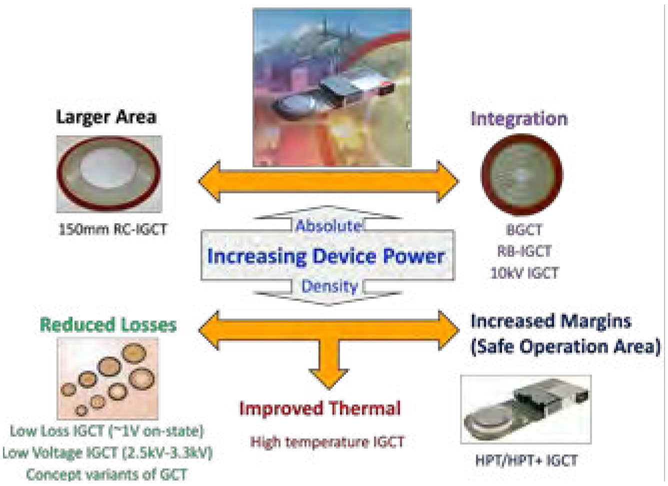

Figure 3: IGCT development trends for achieving lower losses and/or higher power handling capabilities

Current technologies

Increased margins: High Power Technology

The main limiting factor to conventional IGCTs has been related to the maximum controllable turn-off current capability and not due to losses or thermal constraints. Therefore, the introduction of the High Power Technology (HPT) platform [5] is hailed as a major step for improving the IGCT SOA performance while providing an enabling platform for future development trends as discussed below. The HPT-IGCT gives an increase in the maximum turn-off current of up to 40% at 125°C (see Fig. 4), incorporating an advanced corrugated p-base design compared to a standard uniform p-base junction that ensures controlled and uniform dynamic avalanche operation with better homogeneity over the diameter of the wafer during device turn-off.

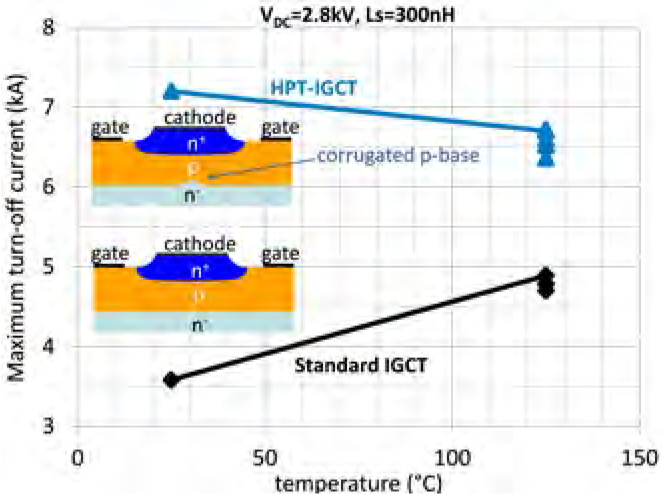

Figure 4: Experimental results of the maximum controllable turn-off current capability against standard IGCT

Integration: Reverse Blocking IGCT (6.5kV and 2.5kV)

In certain applications such as the solid-state DC breaker and CSI, a symmetrical blocking switching device is required. Although this technically could be accomplished by using an Asymmetric IGCT connected in series with a fast diode, the preferred solution is a Symmetric IGCT in a single wafer. Since the required performance and some modes of operation are different from the other IGCT, device design optimization is needed to achieve the reverse blocking performance along with low losses and robust switching performance. Both 6.5kV [6] for CSI applications and 2.5kV [7] for bi-directional DC breaker applications have been developed. The results of a 91mm, 2.5kV RB-IGCT prototype show the achievement of an on-state voltage drop as low as 0.9V at 1kA, 125°C while maintaining a very high maximum controllable turn-off current capability of 6.8kA at 1.6kV, 125°C.

Recent developments

Integration: High Voltage Ratings (10kV IGCT)

It is possible to make a 3-level inverter without series connection for line voltages of 6kV – 6.9kV if IGCTs with a voltage rating in the range of 8.5kV – 10kV were available. These high voltage devices offer several advantages such as simple mechanical design, less control complexity and high reliability compared to series connection of two 4.5kV or 5.5kV devices for line voltages of 6 – 6.9kV. Therefore, 10kV rated devices have been manufactured with the HPT platform to prove the feasibility of higher voltage ratings for IGCTs [8].

Improved thermal performance: High Temperature IGCT (HPT$^+$)

A feasible way to increase the output power of an existing converter design is to increase the temperature rating of the used power semiconductor device. To accomplish this, a number of improvements to the HPT-IGCT are being implemented such as optimized corrugated p-base design and improved metallization, with the goal of increasing the operating temperature up to 140°C. The prototype results show that the HPT$^+$-IGCT has a clearly improved technology curve compared to HPT-IGCT due to its optimized corrugated p-base design [9].

Reduced conduction losses: Towards 1 Volt on-state

In recent years, there is a clear trend towards using multilevel topologies in many power electronics applications. These converters are operating at fairly low switching frequencies but at the same time they require high current-carrying capabilities and/or high efficiency. Due to its inherent low conduction loss thyristor properties and the hard switched functionality, the IGCT is predestined for these applications. The simulation and experimental results show the feasibility of designing through "anode engineering" a wider range of high-voltage IGCTs (2.5kV up to 6.5kV) with very low on-state losses (i.e. on-state voltage values close to 1V) even at higher currents while maintaining good overall performance [10].

Larger area: 150mm

The quest for ever-growing power ratings makes the option of expanding into larger silicon diameters viable. Compared to the previous technology, the HPT has an improved scalability that enables the design of devices beyond the standard 91mm wafer size IGCT products that are available today. The first 150mm Reverse Conducting 4.5kV IGCT prototypes based on HPT$^+$ technology have recently been manufactured and a prototype with gate unit is shown in Figure 5 along with the SOA turn-off waveforms in GCT-mode [11]. With this device, it will be possible to make 3-level inverters up to about 20MW without the need for series or parallel connection of power semiconductor devices.

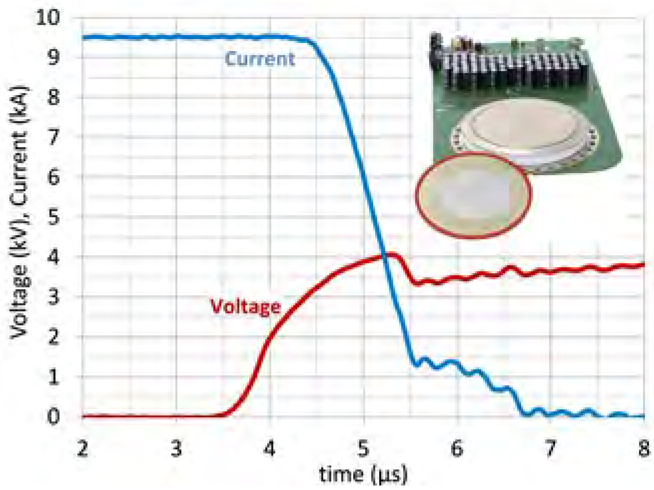

Figure 5: 150mm, 4.5kV RC-IGCT and its measured turn-off waveforms in GCT-mode up to 9.5kA at 2.8kV, 125°C

Future trends / novel concepts

Full integration: Bi-mode Gate Commutated Thyristor (BGCT)

The conventional RC-IGCT enables better component integration in terms of process and reduced part count at the system level, therefore improved reliability. However, in a the GCT and diode are integrated into a single wafer but they are fully separated from each other (see Figure 1). Consequently, in the RC-IGCT, the utilization of the silicon area is limited in the GCT region when operating in GCT mode and in the diode region when operating in the diode mode. The BGCT, on the other hand, features an interdigitated integration of diode- and GCT-areas (see Figure 6). The BGCT has the following advantages over conventional RCI-GCT:

- An improved diode as well as GCT area (leads to better technology curve)
- Better thermal distribution (leads to lower losses and enhanced reliability)
- Soft turn-off / reverse recovery behavior (results in reduced electromagnetic interference)
- Lower leakage current (enables high temperature operation >125°C)

The BGCT concept has been demonstrated first experimentally with 38mm, 4.5kV devices and the results confirm the potential advantages of the BGCT over conventional [12].

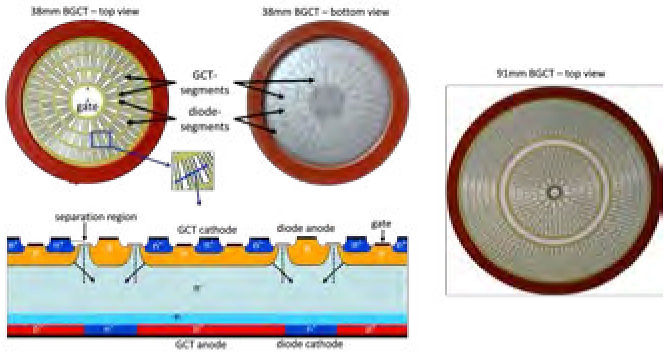

Figure 6: The fabricated 4.5kV BGCTs. Top left: 38mm BGCT prototype. Bottom left: the schematic cross section of the BGCT. Right: recently fabricated 91mm, 4.5kV BGCT prototype

Reduced turn-off losses: Concept variants of GCT (IGDT, Dual GCT)

A number of IGCT concept variations were proposed and demonstrated to reduce the switching losses of the IGCT such as the Integrated-Gate Dual Transistor (IGDT) and Dual GCT. The IGDT eliminates tail losses thereby switching losses can be reduced significantly compared to conventional IGCT [13]. One the other hand, the concept of the Dual GCT is to integrate monolithically two GCTs on a single wafer, in which one is optimized for low conduction losses and the other one for low switching losses to improve the performance of the device compared to a single IGCT [14].

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Direct Cooled Molded Power Module for Motor Integration

A cool solution to a hot issue

Smaller, more flexible – and more powerful: Technological development follows the same mantra in all areas of application from mobile phones and computers to any kind of machine operated device. The world of electric mobility, be it in the format of battery electric vehicles or hybrid cars, is no exception – for good reason.

By Ole Mühlfeld, Rüdiger Bredtmann, Klaus Olesen and Lars Paulsen, Danfoss Silicon Power

The planet is overheating and OEMs within the car industry are facing legislation to lower their CO_2 impact. Electric cars or hybrid models have been available to the market for years, but still only account for 3-4% of the entire fleet worldwide. Technologies are immature and only a small minority of end-users are prepared to pay more to reduce their footprint. To make the electric or hybrid models more attractive to consumers, car manufacturers need to lower the cost of the electrification. As price and size are often connected, this is where the smaller, more flexible and more powerful approach proves beneficial.

Mechatronic Integration is key

Today, engine compartments of hybrid-electric and battery-electric vehicles are usually designed as a solution with separate boxed traction inverters. These inverter modules are standard in many of the cars that currently dominate the market of electrified vehicles, from the Toyota Prius and the VW GTE to the Nissan Leaf. There are obvious advantages to this modular approach, as it is a simple plug-in solution, flexible in use and easy to install. But as the industry looks for improved power density and even tighter engine compartment packing, an integrated, space-saving solution is looking increasingly attractive.

At Danfoss Silicon Power, we have been working for some years on a way of merging inverter and electrical traction motor as a key enabler to improving the drives' package density to reduce production costs. Our aim is to design an electrical machine, which includes all power electronics needed for a frequency inverter. Evidently an integrated solution as suggested here requires a more robust and mechanically proof semiconductor power module, which can withstand the vibration loading and significant temperature excursions that it is subjected to when placed close to the engine itself.

Figure 1a: Direct cooled molded power module, top view

Figure 1b: Direct cooled molded power module, top view

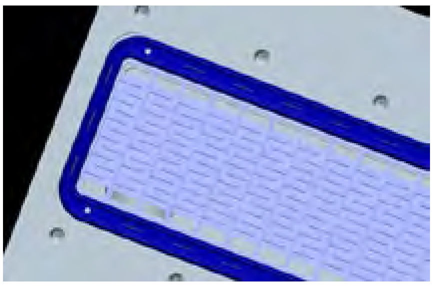

Figure 1c: ShowerPower® turbulator with o-ring sealing

Our efforts resulted in the Direct Liquid Cooled Molded Power Module for Motor Integration, which matches all requirements regarding shape, robustness and cooling. It is designed as a molded half-bridge power module, in a compact package consisting of a copper base plate in combination with a direct liquid cooling system.

Direct liquid cooling 2.0

Building power electronics into the motor space means that its cooling system is inevitably tied to that of the engine and therefore should use the same cooling system for the power semiconductor modules as that used for the motor windings. Our integrated power module therefore has to be based on liquid cooling, where the coolant comes in direct contact with the module base plate.

At Danfoss we have been working with a principle for direct cooling for more than a decade, known as ShowerPower®. For our motor integrated power module we have applied an amended version of this technology. We have named it ShowerPower® Plus, and it achieves 20 % better cooling compared to the original ShowerPower.

The thermal performance is improved by enlarging the surface area that comes into contact with the coolant. Figure 1b shows the enlarged surface structure, where the black dots are in fact pyramid shaped pin fins. This cooling system achieves a thermal resistance Rth(j.coolant) < 0,4 k/W per cm2 for commonly used flow rates of 3-6 l/min.

Stack design

For the stack we have applied Danfoss' newly developed bonding and joining technology (DBB®), which includes both sintered die attach and copper wire bonding. The firmly bonded stack tolerates demanding power cycling that is typical in automotive mission profiles and will not be subjected to harmful degradation from operating at elevated junction temperatures. The vertical stack of the power module is illustrated in the figure below.

Power and small-signal terminals on the module are created as a copper lead frame that is attached directly to the DBC substrate. The lead frame allows for a highly flexible design and a minimized inductive commutation loop, as it can be designed as a flat and wide conductor, using inductive counter coupling to reduce stray inductance. As a bonus, the lead frame eliminates the need for terminal bond wires.

Increasing breakdown voltages limit the maximum current that can be drawn from an equally sized package. A feasible approach to high-power architectures is to use more than three-phases. This allows us to distribute currents on a plurality of smaller half-bridge modules.

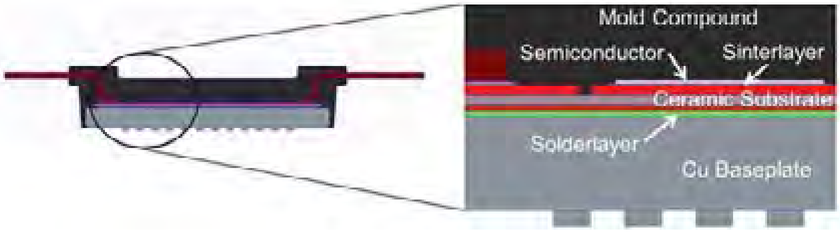

Figure 2: Thermal stack of the power module

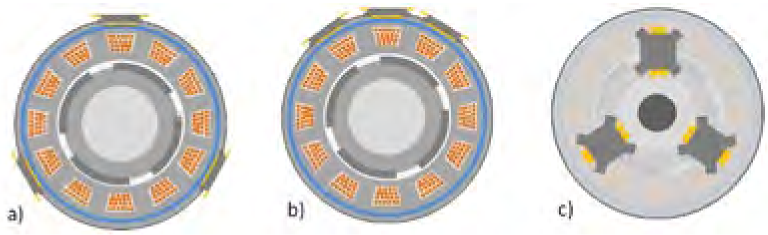

Figure 3: Conceptual drawings for motor integration in PMSM, (a: circular distributed design), (b: circular concentrated design) and (c: motor shielded mounted)

Motor integration

A motor integrated multi-chip semiconductor power module has to meet specific geometric specifications to fit into the odd-shaped assembly space in typical rotary electrical machines. This makes it impossible to use the classic full-bridge six-pack inverter module with a central DC link capacitor and gate drive board. Instead we designed a solution with a series of separate half-bridge modules that allows for easy power scaling in multi-phase motor designs. Distributed gate drive circuits complete the layout toward a multi-phase inverter, consisting of independent switching cells with identical commutation loops.

With this approach we achieved a much higher degree of design flexibility. As the power modules share the cooling channel with that of the engine, they should be mounted in close proximity to the motor windings. The figure below shows three possible positions; either distributed circularly on the outer parts of the machine (a and b) or on the bearing shield plate of the motor (c). This way we also achieve shorter cooling channels, as the heat sources are placed close to each other. In order to avoid the need for additional AC bus bar or cables, we suggest that the module terminals are connected directly to the motor phases.

Large scale benefits

At Danfoss Silicon Power we are constantly developing our technologies to match the requirements of various industries. Motor integrated power modules can make a significant difference to OEM's within the car industry in their efforts to reduce the CO^2 emissions from their fleet. The direct cooled power module can help the industry make it more attractive for consumers to move over to hybrid models, as it can be used to upgrade engines on existing conventional car models.

Integrated power modules reduce overall system costs, as considerably less copper and silicon is used – an obvious benefit for an industry, which is still struggling to make it easier for consumers to make the decision to move over to an electrified vehicle.

The market wants smaller, more flexible and more powerful - but as a rule, making components smaller also makes them hotter. The Danfoss ShowerPower® Plus technology allows a smaller module to cope with higher temperatures, to deliver more power while using less of all the materials that cost.

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Magnetic Absolute Angular Position Sensing using SpinAxis™ Technology

Angular position feedback is increasingly important in motor applications thanks to the proliferation of two important technologies – brushless DC motors and advanced control. The feedback for control is straightforward; in order to perform speed or position control, rotor position feedback is required. The same feedback sensor can also be used for commutation - from simple trapezoidal to advanced sinewave FOC.

By Ted Smith, Sr. Field Applications Engineer, Monolithic Power Systems

Recently, magnetic angle sensors have been widely adopted as a means of angular positional measurement. They are small, inexpensive, and require nothing more than a small target magnet to provide absolute angle feedback. These sensors need to accurately report the rotor angle of a spinning motor very quickly. If there is too much latency, the reported position is obsolete by the time it is communicated to the microcontroller.

The traditional approach has been to use two vertical hall cells to sense the orthogonal components of the magnetic field produced by the target magnet. The amplitude of the two components is then converted into the digital domain by a precise A/D converter. The magnetic field angle is then calculated by taking the inverse tangent of the ratio of the two values (see Figure 1).

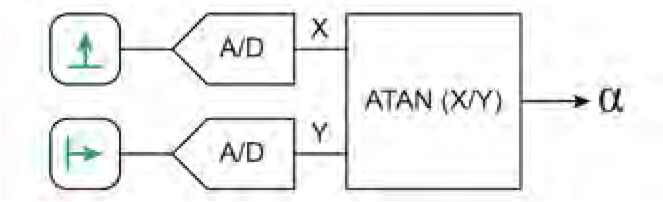

Figure 1: The magnetic field angle is calculated by taking the inverse tangent of the ratio of the two values

There are some problems with that approach. First, the A/D converters must be very precise as the arctangent function has poles, and even a small error in digitization can create a very large error in the angle calculation. This means large die footprint and increased cost. Second, the trigonometric calculations take time. The typical latency seen from these types of sensors is in the order of 100µs. This angular lag causes problems with accuracy and control. There is also the problem that if the magnetic field is too strong, one or both of the hall cells might saturate, rendering the output completely meaningless.

SpinAxis is a novel approach to angle sensing, which requires no A/D conversion or trigonometric calculation. Sampling at 500kHz, the current generation yields an accurate 12 bit angular position measurement with only 3µs latency. Consuming only 7mA at full speed, it comes in a 3x3mm QFN package providing an extremely small, low power, and cost-effective solution for angular position sensing without the associated problems of the traditional approach.

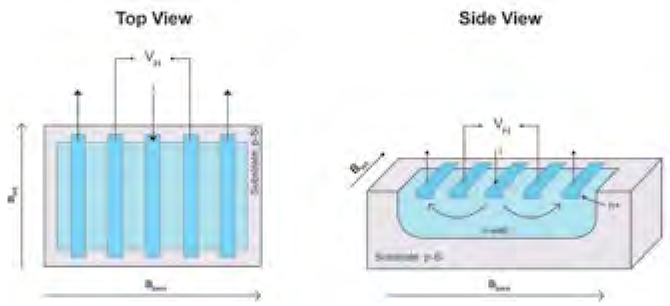

Figure 2: A current source, typically 1mA, drives into the center contact and out through the two outermost contacts

In order to understand how SpinAxis works, we must first understand the structure of a vertical hall cell. Conceptually, the device is straightforward. It consists of a deep n-well with 5 electrical contacts on the surface. A current source, typically 1mA, drives into the center contact and out through the two outermost contacts (see Figure 2). If a magnetic field imposes orthogonally onto the n-well (B_{ort}), the moving charges are deflected, creating a non-uniform current density. Therefore, a small voltage appears on the two inner contacts. This voltage is proportional to the current source, which is a known quantity, and the applied magnetic field. So, we are able to determine the amplitude of the magnetic field component orthogonal to the hall cell by the voltage across the contacts. Any parallel component of the field (B_{para} in Figure 2) will not have an effect on the output.

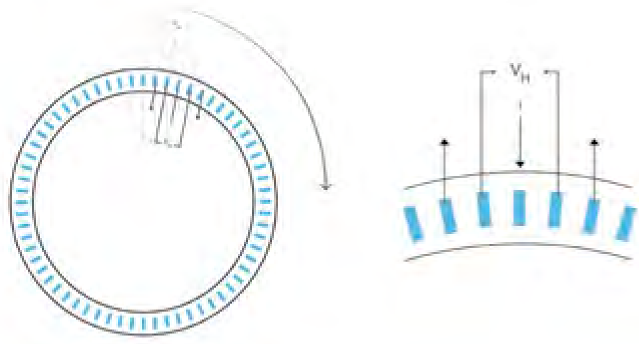

Figure 3: The novelty of SpinAxis is that we take the deep n-well and bend it into a full 360 degree ring with multiple contacts

The novelty of SpinAxis is that we take the deep n-well and bend it into a full 360 degree ring with multiple contacts (see Figure 3). We can then electrically commutate which contacts are used for current source / sink and which are used for sensing a differential voltage. We commutate in such a way as to move the utilized contacts around the circle. In this way, we can rotate a "virtual" hall cell around the ring very quickly. When the virtual hall cell is orthogonal to the magnetic field, we see a peak voltage (proportional to the strength of the field); when the virtual hall cell is aligned parallel to the field, we see no voltage. This commutation happens at 500kHz. For a static magnetic field, the output appears to be a sinewave over one full rotation of the virtual hall cell. The phase of that sinewave, which can be simply determined by timing the zero-cross, is the angle of the magnetic field.

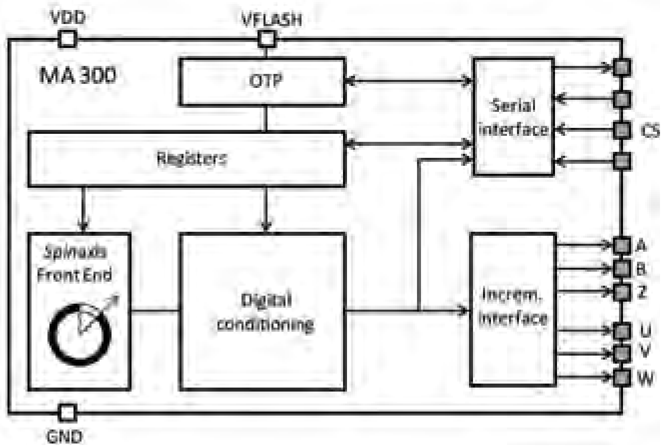

Figure 4: The MA300 device delivers multiple outputs, all conditioned off the SpinAxis frontend

There are many advantages to this approach. The main advantage is speed. There is no back-calculating the angle; it is already encoded in the timing of the sinewave. So, we can output updated angular position every 2µs with a total latency of just 3µs. Also, we don't have to worry about saturation of the hall cells. Even if they saturate in a high field, the peaks of the sinewave are clipped, but the zero cross remains the same. Die space is minimized as the SpinAxis ring is only a few micrometers diameter, and we don't require A/D converters or DSP functionality for trigonometric calculations.

The products which utilize SpinAxis are termed "MagAlpha." The MA300 device, our flagship MagAlpha product, delivers multiple outputs, all conditioned off the SpinAxis frontend (see Figure 4). The main interface to a microcontroller is the SPI bus. Every 2µs, a new 16 bit word appears encoding the absolute angle of the rotor. The ABZ output mimics what an optical quadrature encoder would output so that the MA300 can be used as a drop-in replacement of a standard optical encoder. The UVW output provides 120° offset square waves for BLDC block commutation, replacing discrete hall cells in a motor detecting rotor motion.

The MagAlpha devices are "modular" in that we can cut out parts of the backend to trade off cost for functionality. Some applications do not require UVW output; for those, we offer the MA700. Our standard products are divided into three basic families, MA1xx, MA7xx, MA3xx (see Figure 5), but each of these can be further customized to fit the needs of any specific application.

Product	Description
MA100	Angular Sensor for 3-Phase Brushless Motor Commutation with Side-Shaft Positioning Capability (SPI 8 bit + UVW)
MA120	Angular Sensor for 3-Phase Brushless Motor Commutation (no Side-Shaft)
MA300	Angular Sensor for 3-Phase Brushless Motor Commutation and Position Control with Side-Shaft Positioning Capability (SPI 11 bit + ABZ 10 bit + UVW outputs)
MA700	Angular Sensor for Position Control with Side-Shaft Positioning Capability (SPI 11 bit + ABZ 10 bit)
MA750	Contactless Turning Knob Sensor (SPI 8 bit + PWM 12 bit)

Figure 5: Our standard products are divided into three basic families

Another advantage of MagAlpha is its capability to be used in side-shaft geometry (see Figure 6). This allows for an unprecedented level of flexibility in mechanical design. If there is no motor backshaft, for instance, we can design a ring magnet to press onto the front shaft and place the MagAlpha off to the side. The front shaft can then go on to a gear train or whatever torque-carrying requirement it must bear. We can also use multipole magnets, radially magnetized, to achieve multiple electrical revolutions / mechanical revolution.

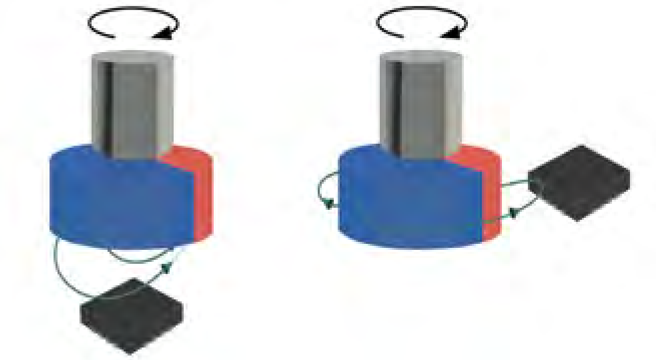

Figure 6: Advantage of MagAlpha is its capability to be used in side-shaft geometry

Spinaxis represents a true paradigm shift in magnetic sensing. It can be used as a suitable replacement for optical encoders, resolvers, and even simple potentiometers. As the heart of our line of MagAlpha angle sensors, it provides unparalleled speed, accuracy, size, and cost benefits for a wide variety of applications. Due to modular construction, solutions are available from high-end industrial applications to cost-sensitive consumer goods.

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Overcoming Challenges in Driving Silicon Carbide Power Modules

Introduction to AgileSwitch's Programmable Gate Drivers for efficient driving of Silicon Carbide (SiC) Power Modules.
Discusses methods to control turn-off ringing and voltage overshoot, with switching losses as a figure of merit.

By Nitesh Satheesh, Field Applications Engineer, AgileSwitch, LLC

Index Terms-SiC MOSFET, Two-Level Turn-Off (2LTO), Multi-Level Turn-Off (MLTO). With the cost/watt of renewable energy generation capture (e.g solar arrays, wind turbines, batteries) declining rapidly over the past few years, the focus for cost, size and weight reduction – and long term reliability - has shifted to improving the traditional weak link in the system – the inverter.

Wide Band Gap (WBG) Power Modules have been promoted as the solution to these challenges, however, until recently, the costs of SiC and Gallium Nitride (GaN) devices have been prohibitively expensive. In addition, the controls structures for controlling, protecting, monitoring and communicating with these devices have not caught up with requirements of high Switching Frequency (Fsw) and di/dt.

The cost of SiC devices have now started to work down the typical "Moore's Law" type of curve, and are truly projectable to approach those of Silicon over the next three to five years. And, now, AgileSwitch has entered this market with the objective of minimizing the impact of wild voltage spikes, while improving energy efficiency and long term reliability through advanced digital controls, programmability, and implementation of patent-pending techniques for turn-on and turn-off of the devices under various conditions.

The test waveforms shown were obtained by using the AgileSwitch EDEM3 Gate Driver with a Rohm BSM300D12P2E001 SiC Half Bridge Module (1200V/300A).

Agileswitch Experience

AgileSwitch was established in 2010 by serial entrepreneurs Rob Weber and Albert Charpentier. Both founders come from a digital electronics background and found that the time was right to introduce digital techniques to a traditionally analog power electronics world.

The AgileSwitch experience stems from its work in Insulated Gate Bipolar Transistor (IGBT) gate driving. Currently, the AgileSwitch product portfolio includes Intelligent Gate Drivers for some familiar Power Modules such as the EconoDualTM and PrimePackTM.

AgileSwitch was also the first to introduce a fully software configurable digital Intelligent Power Module (IPM) (50kW-125kW), the AgileStack – The Stack that talks back.

The Problem

Power modules based on Wide Band Gap (WBG) materials enhance efficiency, but also introduce oscillations to switching cycles due to the higher di/dt. While the transistors are robust and can handle the oscillations, the radiated and conducted noise becomes a nuisance for components or circuits downstream. This noise may lead to erroneous faults, forcing designers to significantly derate the transistors, thereby reducing usable ratings of the power module.

A certain way to achieve maximum market adoption of Silicon Carbide based power modules is by extracting maximum value from the capabilities of the modules. The robustness of the material combined with the lower switching loss should allow for designers to use Silicon Carbide Power modules closer to their maximum ratings.

AgileSwitch recognized this opportunity and has since extensively studied and implemented gate driver techniques specifically for Silicon Carbide Power Modules.

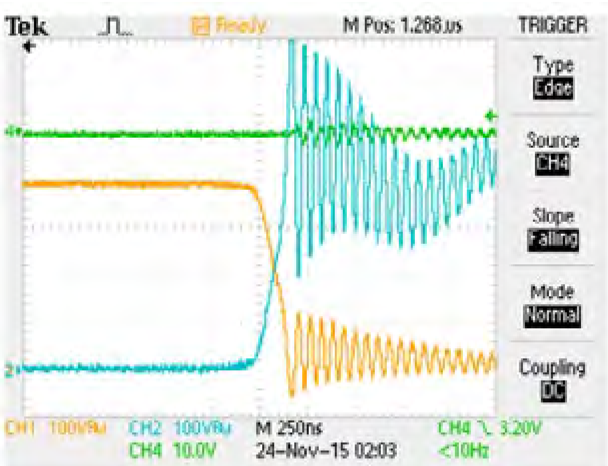


Figure 1: Base case test results – SiC MOSFET Turn-off. MOSFET Ratings: 1200V, 300A

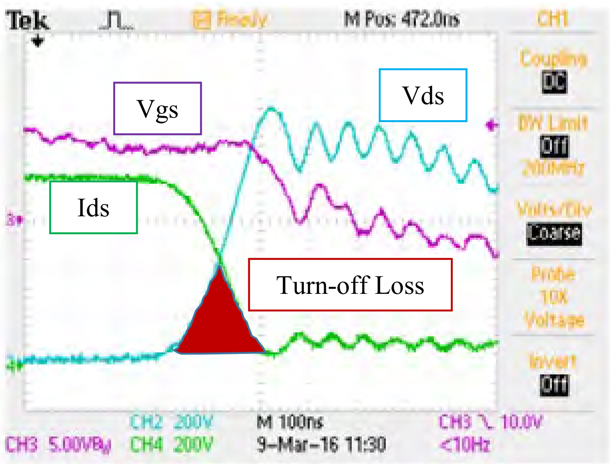
Figure 1 is a base case test result of a SiC MOSFET turn-off cycle (pulse test). The Blue Trace is the MOSFET Vds and the Yellow Trace is the Free Wheeling Diode (FWD) Vr. The ringing in Vds is caused by the stray inductance Lstray of the power module.

$$V_{overshoot} = L_{stray} \times \frac{di}{dt}$$

According to above results, switching 133A at a DC Bus of 400V results in a 300V overshoot voltage. As the di/dt increases due to an increase in switching current or switching frequency, the $V_{Overshoot}$ increases. Designers using 1200V Silicon Transistors for today's 480 VAC applications, may be forced to use less efficient/more expensive 1700V Silicon Carbide MOSFETs to accommodate the $V_{Overshoot}$.

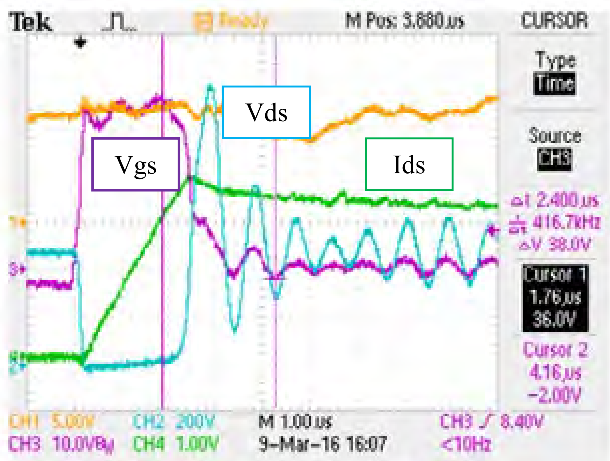
Existing Solutions

There are gate driver solutions that help mitigate some of the problems associated with using Silicon Carbide power modules. Transistors used in today's SiC Power Modules are Field Effect Transistors (FETs), ie the gate can be modeled as a Capacitor. Therefore, one acceptable solution used is to slow the switching cycle by introducing additional resistance (RG) in the gate switching path.



Rohm 800V 266A 5.6Ohm N2LTO

Figure 2: Regular Operation Vdc = 800V, Ids = 266A, RG = 5.6 Ω, $V_{Overshoot}$ = 300V



R 500V 2000A N2LTO 10Ohm DSAT

Figure 3: Fault Condition (Desat) Vdc = 500V, Ids = 2000A, RG = 10 Ω, $V_{Overshoot}$ = 700V

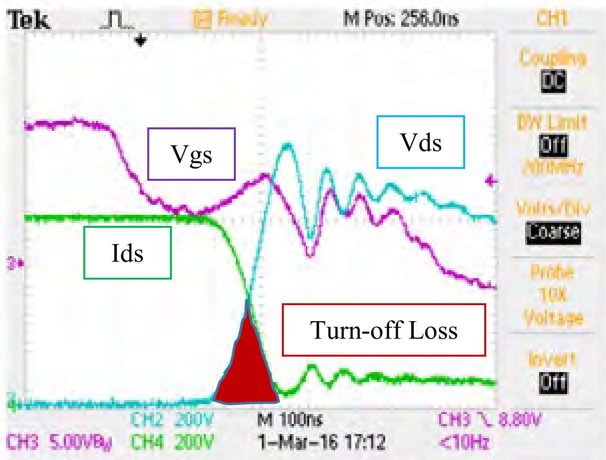
Figures 2 & 3 show a turn-off sequence during regular operation and desat condition respectively. For these tests, di/dt has been controlled by use of R_G = 5.6Ω for regular operation and R_G = 10Ω for fault condition operation.

The turn-off loss is defined as the area under the curve where Vds and Ids overlaps.

In case of a short circuit fault, where Ids reaches 2000A the Vds attains a peak of 1200V (Maximum device rating). Note that the DC Link Voltage was only 500V, in which case the overshoot voltage is 700V!

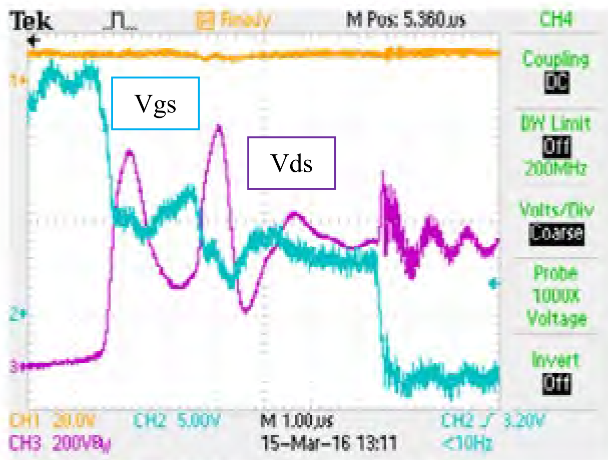
AgileSwitch gate drivers for SiC

AgileSwitch has been a strong advocate of programmable Two-Level Turn-off in driving IGBTs. The EDEM3 Gate Driver was developed to optimally drive SiC Power Modules at much higher switching frequencies, and incorporates this capability along with patent-pending Multi-Level Shut Down functions.



Rohm 800V 266A 4.5V LTO 0 Ohm

Figure 4: Regular Operation Vdc = 800V, Ids = 266A, RG = 0Ω, $V_{Overshoot}$ = 300V



RO DSAT 500V 13V,2us,9V,4us

Figure 5: Fault Condition (Desat) Vdc = 500V, Ids = 2000A, RG= 0Ω, $V_{Overshoot}$ = 500V

Figure 4 shows the turn-off event during standard operation. Please note RG = 0Ω and the Vds Peak = ~1100V, ie. Overshoot voltage = 300V. Two-Level turn-off was implemented, with the intermediate step being 4.5V.

Figure 5 captures the turn-off event in a short circuit condition. Please note RG = 0Ω and the Vds Peak = ~1000V, ie. Overshoot voltage = 200V. Multi-Level turn-off was implemented, in this case Three-Levels with the Two intermediate steps being 13V and 9V.

The EDEM3 Gate Driver offers all of the functionality found in prior AgileSwitch intelligent gate driver products, including: Under Voltage Lockout (UVLO), Over Voltage Lockout (OVLO), Short Circuit protection, Two-Level Turn-Off, Temperature and DC Link Voltage monitoring. The EDEM3 adds in patent pending programmable Multi-Level Turn-off technology which enables safely turning off the SiC Power Module during short circuit events, and enables controls comparable to (or better than) changing physical gate resistors. This driver also allows for monitoring up to seven distinct fault conditions.

Advantages of using AgileSwitch Technology

The use of Two-Level Turn-Off in regular operation has been shown to have an advantage in controlling overshoot voltages and improving efficiency. AgileSwitch's patent pending Multi-Level Turn-off has been clearly shown to be a safer and more efficient alternative to conventional methods.

The AgileSwitch EDEM3 Gate Driver is a Plug and Play driver that implements the technology discussed. AgileSwitch is at the forefront of driving technologies for Silicon Carbide Power Transistors and will be introducing Plug and Play drivers for other readily available power module packages.

www.AgileSwith.com

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User Configurable Gate Drives

User configurable gate drives offer the power converter stack designer faster turnaround time on testing and control over the optimization of the performance of the power stack assembly. Maintenance engineers can benefit by configuring the gate drive to be compatible with legacy systems.

By Richard Varney and Bryn Parry, Amantys Power Electronics Limited

Testing and commissioning a new converter power stack design can be a lengthy process due to the requirements to change the configuration of gate drive characteristics such as the turn on and turn off resistors (Rgon and Rgoff) and the soft turn off resistor (Rgsoft). The usual method of changing the gate resistors requires the user to disassemble the converter power stack, desolder and replace the gate resistors, reassemble and then re-run the test. For a large power converter with multiple gate drives this process could take several hours if not days.

User configurable gate drives also deliver an advantage in the retrofit market where an older piece of equipment requires a replacement IGBT that is no longer in production, or is difficult to source. This maybe because the gate drive is now obsolete or contains components that are obsolete.

The options for the maintenance team are to scrap the piece of equipment or attempt to repair the existing gate drive which can be costly and time consuming.

A user configurable gate drive offers the power converter stack designer the option to quickly optimize a gate drive in a new power converter stack design. In maintenance applications the maintenance engineer may need to replace an obsolete gate drive with a compatible design or replace both the IGBT and the gate drive to take advantage of the greater performance of new generations of power semiconductor technology.

Taking advantage of a two way communications protocol called Power Insight makes the process of optimisation or replacement easier.

User Configurable Gate Drives

The advances in microcontroller and complex programmable logic (CPLD) technology have made it possible to integrate advanced functionality into a product such as a gate drive cost effectively.

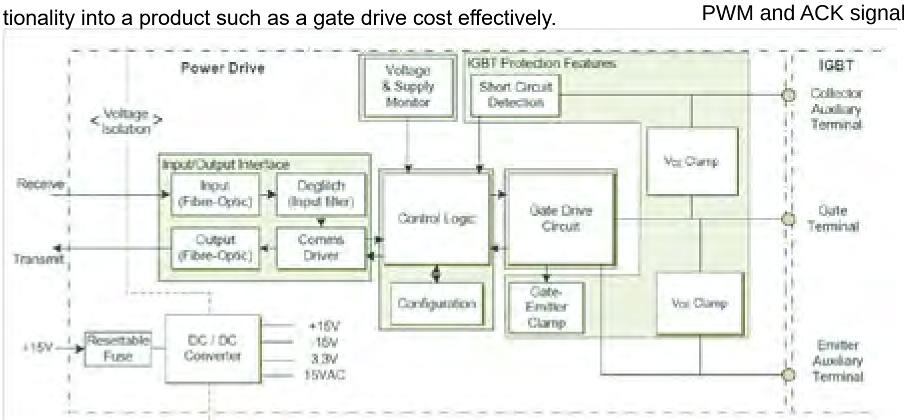


Figure 1: Gate Drive Architecture

Description	Use	Comments
Gate On Resistor	Adjust timing, dv/dt and di/dt during turn on	Existing 1200/1700V 15 values.
Gate Off Resistor	Adjust timing, dv/dt and di/dt during turn on	As above
Gate Soft Turn Off Resistor	Select speed of turn off after short circuit fault	Typically 10Ω+, but select from list of turn-off resistors
Feedback protocol	Choose standard signalling (compatible with other third party drives) or a custom feedback protocol	Used in retro-fit applications
Fault Lock-out time	After a fault condition the gate drive prevents turn-on for this time	Typically 100ms – 3s (Used on high voltage drives)
Desat Detection Time High	Time at which the high level (or single) desaturation comparator is enabled	Typically 7-9us (Used on high voltage drives)
Desat Detection Time Low	Time at which the low level desaturation comparator is enabled	Typically 10-20us (Used on high voltage drives)
Fault Lock-out time	After a fault condition the gate drive prevents turn-on for this time	Typically 100ms – 3s
Level Mode	2 level mode means the gate drive will turn-off after a fault. 3 level mode means the gate drive will signal a fault, but not turn off	Used to control the behaviour of inner and outer IGBTs in 3 level converters.

Figure 2: Configuration Table

One such application of this technology is to create a two way communications protocol that runs over the same fibre as the traditional PWM and ACK signals. The two way communications protocol can be used to configure the gate drive in situ over the fibre optic link.

The architecture of gate drive is shown in Figure 1.

The communications drive interfaces directly to the control logic which stores the configuration in memory on board the gate drive. The operation of the gate drive is determined by the parameters stored in the configuration memory. The user configurable parameters are shown in Figure 2.

The most important configurable parameters are the gate resistors Rgon and Rgoff. The gate drive has four gate resistor values that are arranged in parallel to form the effective gate resistance. Each of the four gate resistors are controlled by a MOSFET drive stage that is controlled from the CPLD on board the gate drive. The configuration thus allows for fifteen choices of Rgon and fifteen choices of Rgoff.

The soft turn off resistor Rgoffsoft is again controlled by the selection of gate drive resistor from the CPLD on the gate drive.

A further advantage of the configurable gate resistors is that the same gate drive can be used to target IGBTs from different vendors. The user can optimize the configuration for each IGBT then program the required configuration on the production line. This gives the supply chain managers in the OEM the option of sourcing multiple IGBTs for the same design giving options on cost, and supply chain security.

In situations where the maintenance engineer needs to find a compatible drive for one that is obsolete it is sometimes required to reconfigure the protocol between the gate drive and the central controller. In the configurable gate drive this is straightforward as the protocol is controlled by the CPLD which can be programmed to be compatible with a legacy protocol. Common legacy protocols can be included as standard which allow the user to switch between the standard and alternative protocols.

Some applications require that the fault lock out time, i.e. the time during which the gate drive will not respond after a fault, is as short as possible to allow the central controller to continue controlling the power converter stack. Making this a configurable parameter allows the converter designer to choose the appropriate value to protect the converter.

Gate drives used in two level or three level inverter designs require a different response to a fault in the converter. The gate drive needs to know where it is in a power converter phase leg and respond accordingly. This behaviour can also be configured in the gate drive over the fibre optic link.

Configuration Made Easy

Whilst user configuration of the gate drive is beneficial to the converter power stack designer it needs to be easy to use in order to get the full benefits. To achieve this, an interface box called the Power Insight Adapter and a software tool called the Power Insight Configurator have been developed by Amantys to make the process as easy as possible.

Figure 3: Power Insight Adapter

The Power Insight Adapter

The Power Insight Adapter (Figure [3]) enables a Windows PC to communicate with the gate drives using a USB or local area network (LAN) connection. . The Power Insight Adapter can be used in two different ways: i) direct mode, where the PC is used to control the test pulses to the gate drives directly or, ii) gateway mode where the Power Insight Adapter will pass through PWM and ACK pulses from an existing central controller and gate drive but still allow communication using Power Insight with a PC.

Power Insight Configurator

The Power Insight Configurator is a Windows application that will discover and communicate with Power Insight enabled gate drives attached to the Power Insight Adapter. Each gate drive that the Power Insight Configurator finds is displayed as a button with the name of the gate drive, serial number and IP address.

The Configuration Pane

Clicking the gate drive button will open the Configuration Pane for the associated gate drive. An example of the Configuration Pane is shown in Figure 4.

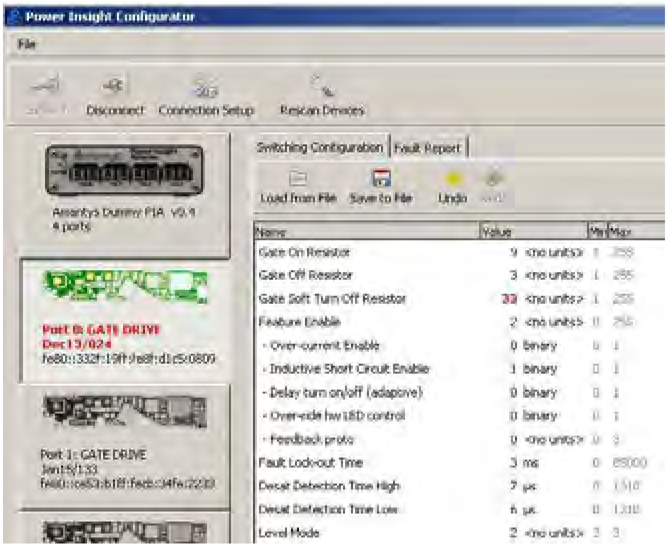


Figure 4: Configuration Panel

The Configuration pane will show all of the parameters that can be configured on the gate drive.

The user can select a parameter and enter a new value which will be displayed in red until it has applied the new configuration to the gate drive. Programming a new configuration into the target gate drive takes a few seconds.

The user also has the option to programme the same configuration into all of the attached gate drives or revert to the original configuration and start again.

Configurations can be stored to a file and retrieved at a later date by using the “Save to File” and “Load from File” buttons. The user can develop the optimum configuration for the target converter power stack and send the configuration file to Amantys for programming into a production batch of gate drives.

Conclusion

User configurable gate drives along with the appropriate support infrastructure make it easy for the converter power stack designer or the maintenance engineer to optimize the performance of the converter power stack or retrofit an existing power converter with a compatible gate drive and the latest generation of power semiconductors.

www.amantys.com

To Protect and to Serve

This article is about a novel Silicon Carbide based hybrid surge suppressor module for safeguarding AC and DC power circuitry.

By Dr. Dominique Tournier (CTO) and Dr. Pierre Brosselard (CEO), CALY Technologies and
Phil Burnside, Business Development Manager of Raytheon UK's Semiconductors Business Unit

Transient and surge suppressors are commonly used to protect systems from lightning strikes, ESDs and short-circuit scenarios. They fall roughly into two categories, the first of which is a 'fuse and crowbar circuit'; examples of which are shown in Figure 1. Such circuits are used to prevent an input over-voltage (surge) condition from damaging downstream circuitry. They all operate by creating a very low resistance path - using a thyristor, TRIAC, trisil or thyratron - to effectively create a temporary short-circuit. Current is then limited on the source side by a circuit breaker tripping or a fuse blowing. Or, to put it another way, circuit breakers and fuses rely on overcurrent to protect against overvoltage. Both leave downstream circuitry without power once tripped/blown.

The second type of transient/surge suppressor is a clamping device. Whilst not short-circuiting, it does decrease its resistance to limit the voltage (to a rated clamping voltage). Common devices used are the Zener diode and the Metal Oxide Varistor (MOV), which have both strengths and weaknesses. For instance, in the ideal world, the clamped voltage would be constant, irrespective of current. In reality, MOVs and Zener diodes are not linear devices and above a certain current the voltage will start to rise. Of the two device types, an MOV is able to sustain a high voltage and dissipate a large amount of energy, but above a certain current the voltage across its terminals will once again increase. Conversely, a Zener diode can maintain a relatively constant voltage, but is unable to dissipate a lot of energy while triggered (typically just a few mJ).

Clearly, in order to efficiently protect downstream circuitry from the effects of a lightning strike or ESD, voltage clamping alone will not suffice. An optimal Surge Protection Device (SPD) must: clamp the over-voltage at the load; limit the over-current; dissipate the power surge energy and remain functional after the surge has passed. It must also have a fast response time, as a limiting factor with traditional Silicon-based suppressors is that they take about 10µs to short-circuit.

Best of Both

CALY Technologies, a spin-off from the Ampere-Lab at INSA de Lyon, is currently developing a hybrid Surge Current and Voltage Limiting Device (SCVLD), which will ultimately take the form of a three-pin module. It comprises an MOV, a Zener diode and a SiC-based Current Limiting Diode (CLD). The architecture (see figure 2) is such that, with suitably-sized components, it is possible to get the clamping benefits of both the MOV and the Zener while avoiding their shortcomings; i.e. not being able to limit voltage over certain currents and not being able to dissipate high energies, respectively.

When subjected to an ESD with a pulse shape of 8/20 or 4/440, the SPD has four distinct phases of operation:

- Phase 1 [0 < t < 0:8µs]: The induced overcurrent is limited to the saturation current of the SiC-based CLD;
- Phase 2 [0:8µs < t < 2 µs]: The increased (but saturated) current produces a voltage across (and is clamped by) the Zener diode (avalanche voltage Vz), which clamps in less than 10ns;
- Phase 3 [2µs < t < 2.5 µs]: With the current limited to the value of the CLD saturation current and voltage across the load limited to Vz, the voltage across the MOV will increase to its clamping voltage.
- Phase 4 [t > 2.5 µs]: Once triggered, the voltage clamping devices are dissipating the remaining energy of the surge, until the voltages fall below their triggering values (V_{CLAMP} and V_Z). At the same time, the voltage drop across the CLD remains high, as long as the current is at saturation.

The principle of operation depends on the MOV clamping voltage being higher than the Zener avalanche voltage (Vz). Also, the CLD must be able to sustain short circuit operation and have a very fast response time. In this respect, Silicon Carbide's low electron mobility comes in to play; 1,000cm^2/V.s compared to Silicon's 1,500cm^2/V.s (and GaN's 1,250cm^2/V.s, by the way). The CLD must be able to dissipate the bulk of the surge energy, which it does by producing heat. Here, Silicon Carbide's high Thermal Conductivity is essential; 4.9W/cm.K, compared to Silicon's 1.5W/cm.K (and GaN's 1.3W/cm.K). In addition, when two CLDs are placed in series, back to back, the circuit is able to protect AC as well as DC power lines.

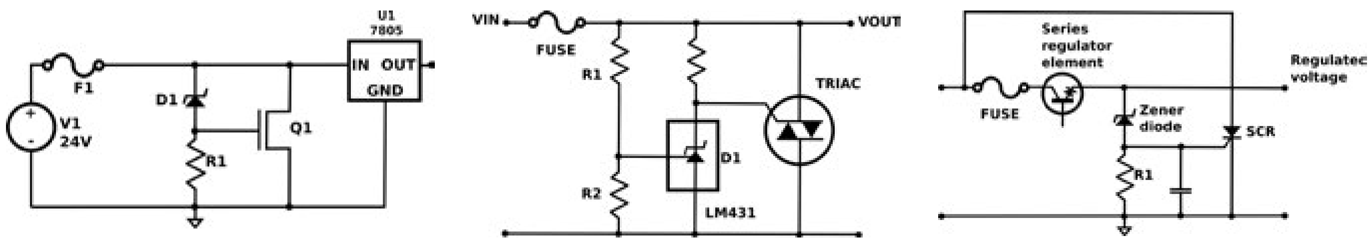


Figure 1: A variety of fuse and crowbar surge protection circuits. The shorting components are (left to right) a MOSFET, a TRIAC and Thyristor (SCR). In all cases the shorting elements producing an over-current which blows the fuse.

Spice models of all three devices were explored in order to set optimum clamping voltages for the MOV and the Zener as well as ISAT for the CLD, and in late 2015 a prototype circuit was produced and tested at Mersen's facilities in Terrassa, Spain. It was designed to protect a 540V load (typical of an aircraft's or a solar plant's DC bus, for example) and subjected to a series of surges. For comparison, the load was also subjected to the same surges with just an MOV for protection and without any protection at all (see Table 1).

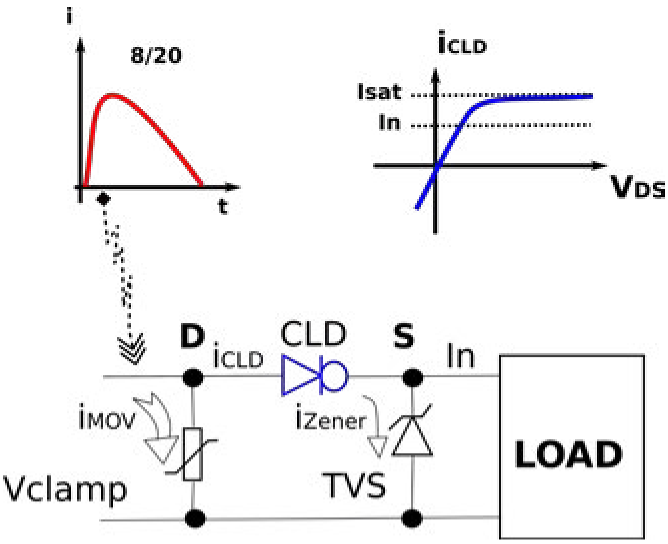


Figure 2: The architecture of the hybrid SPD, in which the SiC-based CLD makes it possible to get the best clamping benefits of the MOV and the Zener (TVS)

Surge current : 1.8kA	Energy recorded	Over-current recorded	Over-voltage recorded
Load unprotected	691 J	1.8 kA	3.6 kV
Load MOV protected	1.18 J	44 A	900 V
Load SCVLD protected	439 mJ	20 A	550 V

Table 1: The SCVLD provided considerably more protection than the MOV alone.

The results were extremely encouraging, with the circuit providing more than a 2.7 times the protection of the MOV (alone) when the surge current was 1.8kA – see Figure 3. Moreover, voltage and current were clamped within a nanosecond, in comparison to more than 25ns for MOVs.

In the Making

Presently, the hybrid surge protection technology is only available as a DIN mounted unit, and the circuit within is built from discrete components. However, CALY Technologies is working closely with Raytheon UK's Semiconductors Business Unit in Glenrothes with a view to commercialising the technology as a three-pin and much smaller module.

Raytheon has more than 13 years of SiC device fabrication experience, including involvement on a project to develop current limiting technology for protecting aircraft electronics and wiring from the secondary effects of a lightning strike. However, while this experience is important, it is only part of the reason for the collaboration on the hybrid surge protector. Raytheon is Europe's only independent production–qualified foundry, offering a SiC fabrication service that is flexible enough to support short process loops (e.g. development work) as well as turn-key volume work.

The company can also manage the entire supply chain, from SiC substrate sourcing through to wafer sawing and packaging. In this respect, and of most appeal to CALY Technologies, Raytheon UK represents the fastest and lowest risk route to market for its innovative SPD design.

Acknowledgement

CALY Technologies would like to thank Mersen for granting access to the Cirprotec lightning test facilities in Terrassa, Spain.

Figure 4: Presently available only as a DIN module CALY Technologies' hybrid SPD could soon be available as a much smaller form factor 3-pin module and the company is working closely with Raytheon UK's Semiconductors Business Unit in Glenrothes regarding the fabrication of the SPD's SiC-based Current Limiting Diode.

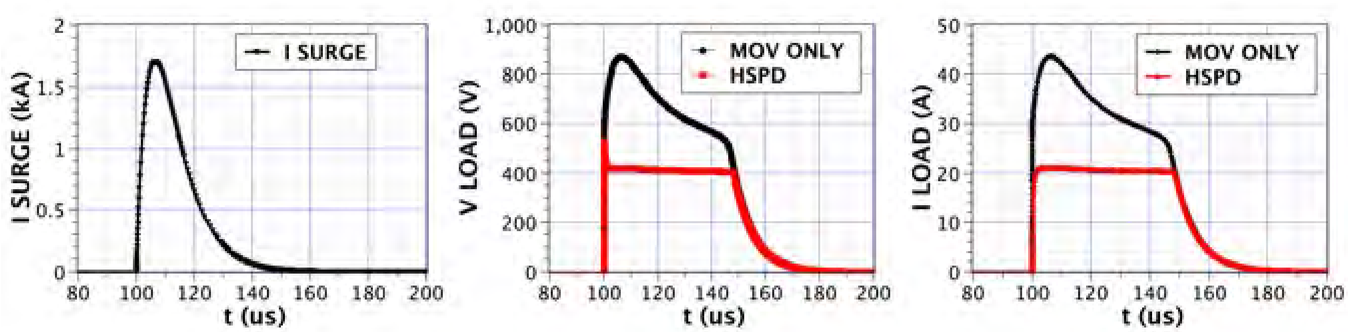


Figure 3: An experimental comparison of an MOV (only) and the HSPD protecting against a 1.8kA surge. In all cases the shorting elements produce an over-current which blows the fuse.

www.caly-technologies.com

www.raytheon.co.uk

High Voltage Ceramic Capacitors for Power Electronics

This article presents the characteristics and performances of a new range of high voltage ceramic capacitors manufactured using a new ceramic material. This dielectric allows to get under working voltage the same capacitance values than using an X7R material with the advantage of a very low dissipation factor typical for NPO/COG materials (less than $5 \cdot 10^{-4}$). What makes these capacitors to be ideally suited for power applications where heat dissipation may be detrimental for performances and reliability.

By Dr. Henri Laville and Maud Fabre, Exxelia Technologies
** 93, rue Oberkampf * 75540 Paris Cedex 11 * France*

Miniaturization is a driving need for future power electronics. This evolution, which is true whatever the application is, implies some modifications linked to a greater difficulty to dissipate the heat generated by the components and the temperature increase of the electrical circuit. Two options can be considered to enable multilayer ceramic capacitors to withstand these new constraints:

- To design capacitors able to work at higher temperature with the same reliability, what means a complete change of the design and/or materials of these components.
- To design alternative components with reduced losses in order to minimize heating. As losses are mainly due to the ceramic dissipation factor, such a choice implies a complete change of the ceramic dielectric.
- This second possibility lead up Exxelia Technologies to develop a completely new High Voltage ceramic capacitors range based on a new dielectric material we called "C48".

Technical Constraints

Two classes of dielectric are mainly used to manufacture ceramic capacitors.

The first class is composed of NPO ceramics. These ceramics are mainly made of titanium dioxide with a low dielectric constant ($\varepsilon_r \leq 100$). These ceramics are very stable with only minor changes under stress to (Figure 1):

- Temperature
- Voltage
- Frequency

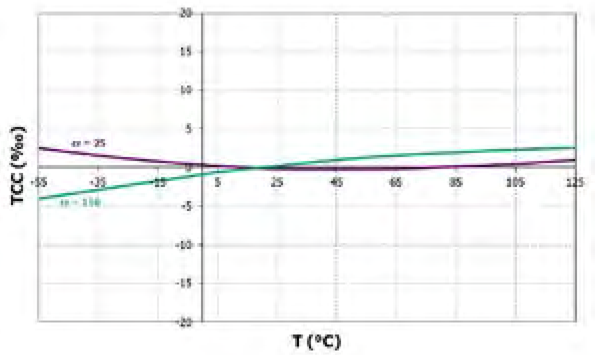


Figure 1 : Typical capacitance variation under temperature for NPO ceramics

The second class is composed of X7R ceramics. These ceramics are mainly made of barium titanate with a high dielectric constant ($1000 \leq \varepsilon_r \leq 5000$). These ceramics present some variation (Figure 2) under:

- Temperature
- Voltage
- Frequency

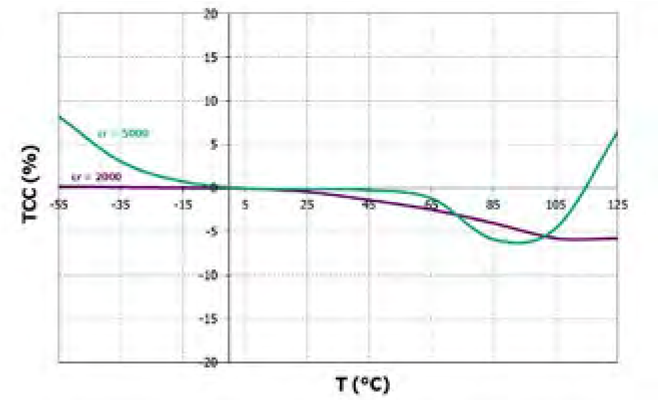


Figure 2 : Typical capacitance variation under temperature for X7R ceramics

With the aim of changing the dielectric material used to manufacture our capacitors, it was obviously necessary to use a ceramic whose performances would allow to:

- Develop ranges with the same capacitance / voltage / volume characteristics than the X7R dielectrics
- Dissipate less energy than X7R materials, what means selecting a dielectric with a dissipation factor much lower than X7R's dissipation factor – which is typically for high voltage parts much greater than $50 \cdot 10^{-4}$.

So, we had to find a material which combines most of the dielectric properties of NPO and X7R materials.

Our choice has been a dielectric with an intermediate dielectric constant value (about 500) able to be processed using a greater voltage gradient (ratio of voltage and dielectric thickness) so that its capacitance per volume could be comparable with the capacitance per volume of an X7R material.

Dielectric Performances and Comments

The main characteristics of the selected material which combines most of the advantages of NPO and X7R materials are summarized in Table 1.

High voltage ceramic with medium dielectric constant and low DF	
Dissipation factor at 1kHz, $1V_{eff}$:	$\leq 10 \cdot 10^{-4}$
Typical DF at 400Hz, $1V_{eff}$:	$\leq 5 \cdot 10^{-4}$
Insulation resistance at 20°C under $500V_{cc}$:	≥ 20 000MΩ or 500MΩ·µF
Dielectric withstanding voltage :	>1.4 U_{RC}
Rated voltage :	200V to 5kV
Temperature coefficient :	-2200 ± 500 ppm/°C

Table 1: Main characteristics of "C48" material

The dielectric constant of this ceramic, smaller than the dielectric constant of classical X7R materials, enable to manufacture about half the capacitance of X7R ranges when measured under standardized measurement conditions (Figure 3), what, at a first glance, appears, of course, to be a limitation.

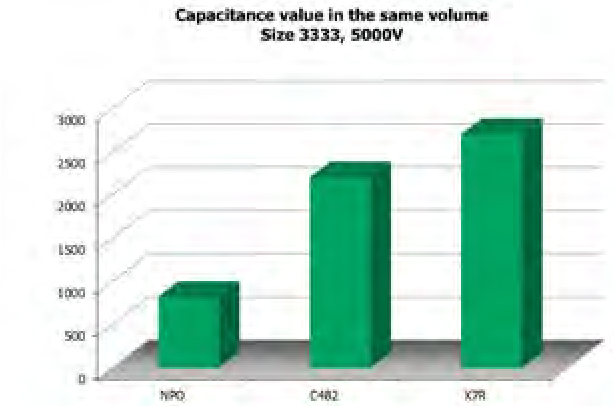


Figure 3: Comparison of capacitance ranges in the same size package for NPO, C48X and X7R

But this dielectric is very stable under voltage. The loss of capacitance versus dc voltage is only a couple of % (Figure 4) when it's about 60% or more for classical X7R (2R1) ranges.

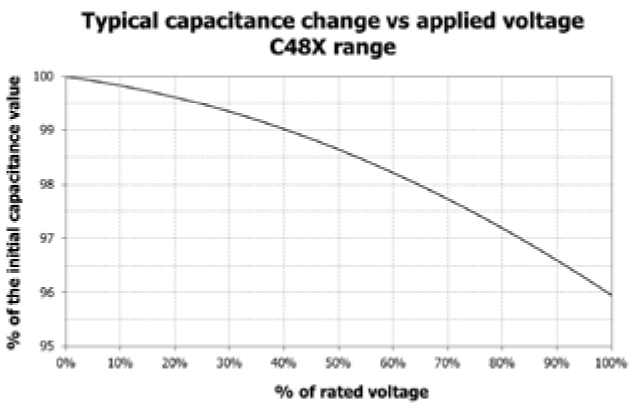


Figure 4: capacitance change of C48 versus dc voltage

So, when looking at the capacitance value left under nominal voltage (working voltage), a simple calculation demonstrates it's the same when using this ceramic and when using a X7R or 2R1 ceramic dielectric.

Furthermore the dissipation factor is very low, typically less than 0.05% what makes the heat dissipation in use not significant.

Under working conditions the capacitance values of this new range of products are equivalent to X7R values with the unrivaled advantage of no heat dissipation. Figure 5 demonstrates this performance in comparison with X7R material at 400Hz. Opposite to X7R, the C48X capacitors don't suffer a temperature increase, what makes them more reliable.

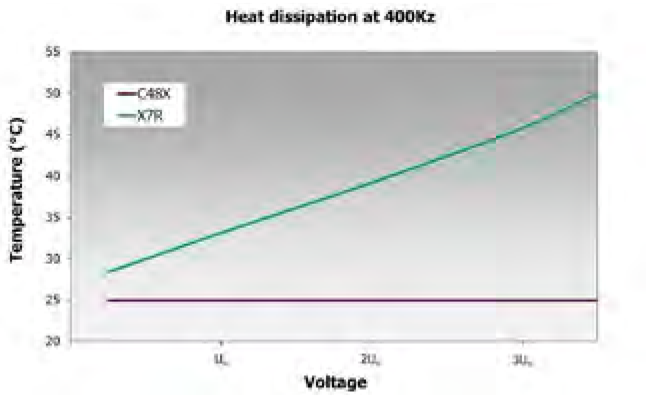


Figure 5 : Temperature increase of capacitors of the C48X range working at 400Hz in comparison with X7R material

This ceramic is clearly much better adapted to low frequencies applications (typically 50Hz and 400Hz) than the X7R materials. That's why it's by now for example widely used in plane electrical network. Moreover, it can also withstand very high dV/dt, up to 10kV/µs what makes it perfectly adapted for pulse and charge/discharge applications.

Ranges

The capacitors using this "C48" ceramic have been developed from 200V to 5kV with chip sizes ranging from 1812 to 16080, what allows a maximum chip capacitance value of 10µF 200V whereas the stacked versions are proposed with a maximum capacitance value of 47µF 200V.Taking into consideration the dissipation of this capacitor is very low, such a product appears to be perfectly suited for power applications.

Regarding the mounting of these capacitors, many configurations (Table 2) are possible to be compatible either with surface mounting or through-hole mounting. All these versions can be suitable for space use and can be designed in order to avoid any whisker growth risk (no use at all of any tin without minimum 10% lead).

For SMD mounting, the components can be mounted directly on the board or, what is recommended for the biggest sizes, using ribbons ("R" version) or DIL connections (different shapes – "P", "PL" and "L" versions) which will absorb most of the thermo-mechanical stresses and prevent ceramic cracking.

Through-hole mounting can be processed via the help of DIL connections (version "N") or using classical cylindrical leads to be soldered by hand or with a wave. For these through-hole mounting components different coatings are available according to the level of environmental protection which is required

New Developments

The performances of this “C48” material are (except variations of capacitance with temperature) very close to NPO characteristics. So, it’s assumed that, for applications where the temperature stability is not the key parameter, the capacitance of NPO capacitors can be multiplied, using this ceramic, by a factor of 5. In a reverse way, for a given capacitance value, the capacitor volume could be reduced by 5, what is a very promising way for miniaturization whatever the application of NPO capacitors would be.

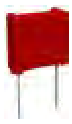
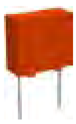
Type	Leads / Finishing	
Chip	Ag/Pd, Sn, Sn/Pb, Au	
DIL & Ribbons (chips and stacked capacitors)	DIL connections for surface mounting	
	Ribbon leads / varnished	
	DIL connections for through-hole mounting / varnished	
Radial leads	Tinned copper / varnished	
	Tinned copper / dipped	
	Tinned copper / molded	

Table 2: Summary of the different configurations proposed for the C48X range

This is of course a development way to be considered also for space applications and Exxelia Technologies is working on it. For this evaluation, the ranges proposed will be extended to lower voltages and lower sizes.

Conclusion

This new range of high voltage capacitors manufactured using a ceramic dielectric whose characteristics are intermediate between NPO and X7R (2R1) materials looks very promising for challenging power electronics applications. The common trend in power electronics with new semiconductors is demanding new components being able to handle higher power with more compact sizes for better system integration.

The material used in this C48X range is also of interest for lower voltages applications and Exxelia Technologies is working this way.

http://www.exxelia.com/all-products/capacitors/

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Energy Storage Systems

Enabling Faster Response to Changing Energy Demands with Power Modules

Tomorrow's power supply is sure to be all about smarter, more responsive grids. In fact, better energy management is already a big deal today. Conventional coal and nuclear plants' power output is difficult to adjust at short notice, so they end up dumping excess energy when demand dips.

By Stefano Gallinaro, Product Marketing Manager, Vincotech GmbH, Unterhaching

What's more, over-engineered transmission and distribution lines are larger than they need to be to handle briefly spiking demand. And without the means to store wind and solar power, energy that cannot be put to immediate use is wasted.

The antidote to the energy crisis on the far horizon is a mix of remedies that makes the most of all available technologies, specifically:

- More efficient and cleaner fossil-fuel energy sources
- Hybrid systems that draw on both renewable and fossil fuels
- Legacy infrastructure that evolves and gives way to streamlined transmission and distribution systems
- Better time-of-use management and technologies to keep the scales of energy supply and demand balanced.

But the success of all these advances hinges on one key factor, energy storage. Battery powered devices' ability to store excess energy for use when it is needed will have to be scaled up to the magnitude of power plants and huge grids. These energy storage systems (ESS) can cut back the amount of energy wasted today, ramp up to peak power in no time at all, and relegate oversized transmission lines to the dustbin of history.

ESS will also close the gap between renewable energy production and deployment. The irony of wind and solar sources' remarkable upswing is that the more renewable energy is generated, the more often it is being curtailed, mainly because of transmission congestion. Storing that excess energy relieves congestion, reduces power curtailment, and ensures all this greener energy is put to good use. As an added bonus, ESS can also be set up at many points along the grid, close to the power plant as well as near the companies and small communities that use the energy. Storage capability can thus be rolled out rapidly and incrementally, which slashes costs and speeds up ROI. Both are powerful incentives to go all out in deploying energy storage systems, and once that rollout picks up momentum a smart, distributed grid will be within easy reach.

Energy storage solutions come in many guises ranging from small batteries to big pumped water systems. This article narrows the focus down to electrical energy storage, and more specifically, to power electronic subsystems, which for present purposes, shall simply be called systems. Mechanical, hydraulic and chemical storage systems' different power ranges and technologies put them out of the scope of this paper. And although application level controlling units, metering and cloud integration units are clearly important, they too are beyond the scope of this article.

Breaking energy storage systems down by power level

Energy storage systems come in three main categories—utility/grid, industrial and residential—as determined by the level of power they are called upon to handle. Batteries are becoming the first choice for storing energy, and the future belongs to lithium-ion technology. Anything from kilowatt-hour residential systems to multi-megawatt-hour for utility/grid systems is possible.

Utility/grid (>MWh)

Energy storage systems can be a good fit for renewable power plants, on-grid and off. For example, a sizable solar/wind farm with integrated energy storage can reap the benefits of energy arbitrage, locational capacity and infrastructure upgrade deferral. These terms may sound exotic, but the concepts are straightforward:

- Energy arbitrage involves storing excess electricity that is produced cheaply at night for later use, when demand peaks during the day. Revving up plants to run at peak capacity is dirty, inefficient business, so arbitrage cuts both costs and emissions.
- Locational capacity, in a nutshell, means leveraging long-term storage capability to source power locally, at on-site load centers where it is needed most. This keeps the frequency of supplied energy constant and power generation cleaner, more cost-effective and easier to deploy.
- Infrastructure upgrade deferral is a fancy way of saying that energy storage serves to trim peak loads and alleviate congestion, sparing utilities and consumers the financial burden of expensive upgrades to transmission and distribution networks.

Energy storage requires power electronics systems that include high-power AC/DC and DC/DC converters. In the main, the power module topologies consist of three-level inverters, high-current half-bridge-based inverters, and high-power battery chargers. The given battery configurations determine what types of boost and inverter topologies are needed.

Industrial/commercial and midsized communities (10kWh-1MWh):

Commercial and high-tech industrial facilities run complex machinery that demand high-quality power. ESS are best at delivering power reliably and at a stable frequency, even at peak loads. They can furnish plenty of back-up power to ride out temporary outages. And they provide a central accumulation point so that renewable energy generation can be reconciled with high-quality power generation. Even a self-sufficient micro-grid that can power a facility for weeks on end is a viable option. The most cost-effective solution for both on- and off-grid systems will be sized according to how much energy is stored during times of low demand and displaced during peak hours of the day.

Energy storage in this power range requires power electronics systems that include medium-to-high-power AC/DC and DC/DC converters. In the main, the power module topologies consist of single- and multi-phase PFC, high-current half-bridge-based inverters, and high-power chargers.

Residential (1-10kWh):
Residential ESS are real energy-savers that can serve to connect mainly photovoltaic systems to the power grid. Storing solar energy at home can slash the consumer's electricity bill, so residential ESS are certainly gaining traction. They are also a reliable source of emergency power during outages.

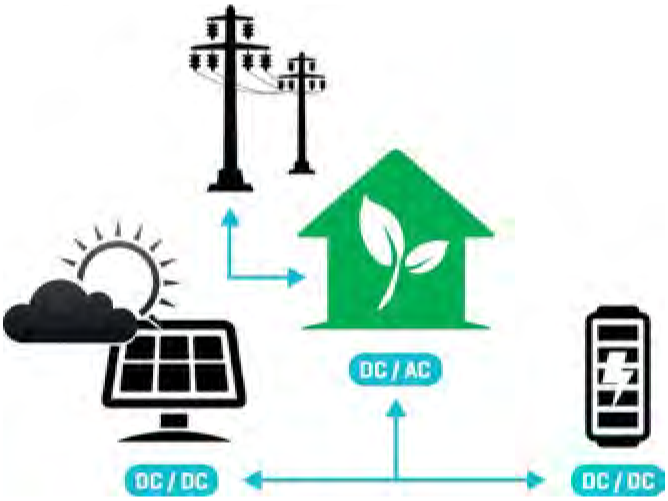

Figure 1: Block diagram of residential ESS

Residential storage requires these power electronics systems:
- Compact medium power DC/DC and DC/AC solar converters (such as three-phase boosters and three-level, three-phase inverters)
- Low-power, single-phase solar inverters (single-phase H-bridge)
- Bidirectional DC/DC and AC/DC battery chargers to charge the battery from the PV system and grid, and to feed energy back to the house and grid (half-bridges and H-bridges as the basic building blocks, plus boosters for battery management)
- Compact, highly efficient bidirectional DC/AC converters to connect the home energy storage system to the grid

Although various designs for converters with different purpose-built topologies are in the works, they all aim to achieve the same objectives: utmost efficiency, reliability, cost and robustness.

There are applications where these three categories intersect, and this common ground is readily covered using the same building blocks and a modular approach to design. Tremendous benefits may be achieved by multiplying and scaling up these basic building blocks. This modular approach can even be revisited within the design of each block, and the best-in-class solution is undoubtedly an electronic design centered on power modules. A reusable core expedites all other processes and ups the overall system's efficiency and reliability.

Vincotech's modus operandi follows much the same pattern. The company develops standard products and rapidly customizes solutions to cover all ESS categories' topologies, power ratings, housing technologies and performance requirements.

Market potential

Demand for energy storage solutions is strong and picking up steam around the world. The market for PV inverters may be up and down, but many players are rushing to integrate energy storage systems with their PV systems. The biggest markets for ESS are North America, China, Japan and Europe, and projected annual sales of storage technologies is growing fast from €6 billion in 2015 to €26 billion in 2030.

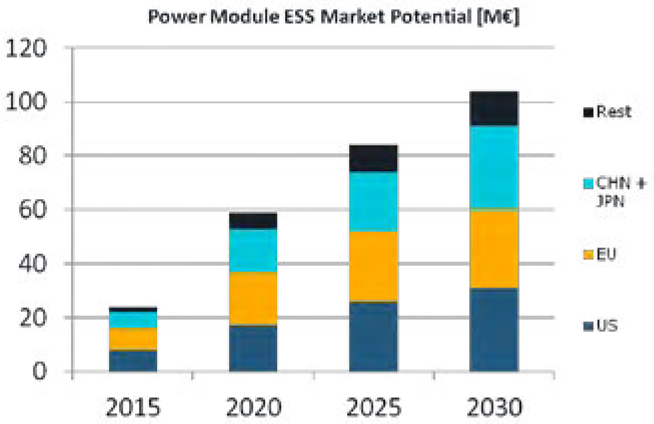

Figure 2: Power module ESS market potential

Taking the percentage of business accounted for by power module components as the baseline, Vincotech's total addressable market will grow from €24 million in 2015 to €100 in 2030.

Power modules for ESS

All standard and customer-specific topologies can be integrated into any Vincotech housing, whereby low-power solutions generally come in small, compact *flow* 0 and *flow* 1 housings, while high-power systems ship in *flow*SCREW housings engineered to achieve high power density.

Figure 3: A flowSCREW 4w housing

Standard topologies such as half-bridges and H-bridges are used in SMPS and charger applications. They constitute the basic building blocks of a classic inverter. Typical applications require 1200 V modules with > 100 A current rating. Off-the-shelf *flow*PHASE and *flow*PACK modules are rated for these application requirements, and more are in the pipeline.

Four-quadrant, three-level inverters featuring NPC and MNPC topologies (*flow*NPC, *flow*MNPC) are state of the art in terms of both integration and performance. A range of 650 V, 1200 V and 2400 V modules with various current ratings is available now.

Power Factor Correction power modules (*flow*PFC) may be integrated into multistage converters and used with battery management modules, even bidirectionally when the storage system—typically the battery—is feeding the grid.

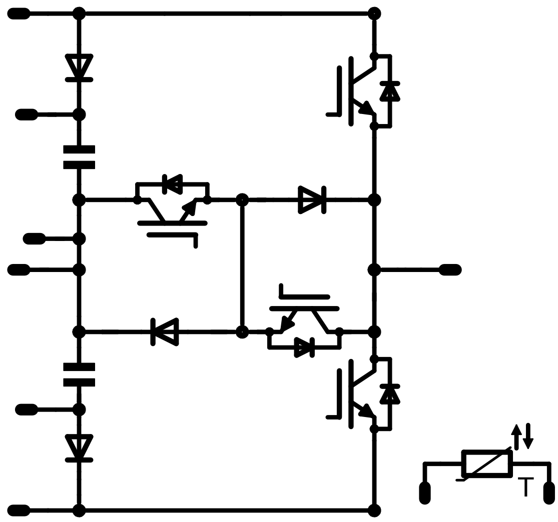

Figure 4: flowMNPC topology

Booster modules (*flow*BOOST) used in battery management applications factor high conversion efficiency, fast switching and a compact, modular design into the performance equation.

The new *flow*RPI 1 family is the solution of choice for designing compact, fast and efficient energy storage systems for less than 10 kW. Engineered for welding, charger and SMPS applications, the new *flow*RPI 1 family combines a rectifier with highly efficient, low-voltage drop diodes, a two-leg PFC featuring ultrafast 650V IGBTs and diodes, integrated filtering capacitors and diodes for current sensing via an external transformer, as well as an inverter with H-bridge open emitter topology and optional capacitors. All this comes in a single module that enables engineers to save design-in time and cost. A special version comes with a PFC featuring IGBTs with higher current ratings for a wider input voltage range. It is rated for applications with Vin = 110 – 220 VAC. These painstakingly selected components provide the best solution for high-frequency switching paired with utmost efficiency.

The new *flow*RPI 1 family's enhanced layout is more EMC-friendly. With the latest IGBT chip technologies on board, the module delivers ultra-fast switching speeds at ultra-low conduction and switching losses. Given the option of three power stages in a single module, engineers will find it very easy to design highly compact PCBs. Vari-

Figure 5: flow 1 housing used in flowRPI 1 modules

ous power ratings are available in the same *flow* 1 housing with the same pin-out, so applications may be scaled up with the PCB design remaining intact. This latest generation module covers application power ranges from 1.5 kW up to 7 kW in various steps.

The upside of using power modules

The market is growing fast and players are agile, so new developments have to be ramped up swiftly to deliver state-of-the-art technology under great time-to-market pressure.

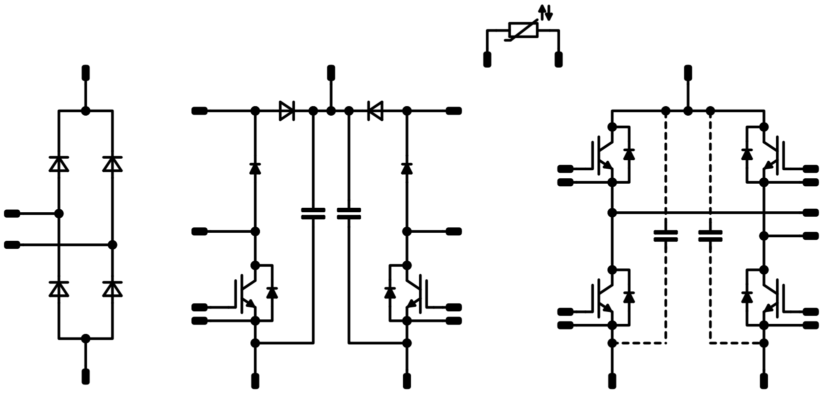

Figure 6: flowRPI 1 schematic

Power modules outclass discrete components when it comes to reliability and service life. On top of that, they streamline and accelerate the design effort, driving time to market and development costs, and power integration, performance and reliability up.

Customers can design very compact applications centered on the power block and enjoy the fringe benefits of high efficiency, reduced EMI and best-in-class switching performance. An application built on a power module is easier to upgrade and may be scaled up to achieve higher power levels. ESS demand precisely the properties that power modules have and discrete components lack—modularity and flexibility.

Vincotech provides the full range of topologies, power ratings and housings. Our customers can opt for standard products or custom fast-tracked solutions tailored to their specifications. Either way, outstanding quality and performance are always assured.

www.vincotech.com

Using DC-DC Converters in Parallel

Using power supplies in parallel is an attractive and viable technique to realise benefits in inventory and stocking, product commonality, additional output current and N+1 redundancy. However, it must be done with an understanding of the possible paralleling topologies, as well as how the closed-loop supply regulation will be maintained across the multiple supplies.

By Arthur Russell, Principal Applications Engineer, Vicor Corporation

The most obvious and simplest way to put supplies in parallel is to simply tie their outputs together. In general, this won't work, as each supply has its own output voltage regulation, and so would be not only trying to maintain this regulation with changes in load, but also attempting to regulate against the closed loops of the other supplies.

This also applies to supplies which include their own traditional internal error amplifier and reference, where parametric differences from supply to supply will always cause one supply to carry all the load current, while all the remaining supplies will carry no load, with resultant overstressing and potential collapse of the entire supply rail.

One way in which this direct-connect topology can work well is if one supply is set to constant-voltage (CV) mode and the others are set to constant-current (CC) mode, but at slightly higher output voltage – bearing in mind that not all supplies allow a choice of output mode. The supplies which are set to the higher output voltage will provide constant-current output, and each of their output voltages will drop until it equals the output of the CV supply. The load must draw enough current to ensure that the supplies which are in CC mode must stay in that mode.

The direct-connect approach is viable if the supply is specifically designed to support that topology, or if there is a single control-loop error amplifier which feeds the error signal back to all of the other supplies, so that they share the load. However, the latter method also requires a "share bus" for the control signals from the master to the slaves.

Another approach adds small ballast resistors in series with each supply's output to equalise the distribution of the load current among the supplies in the array (Figure 1). The ballast resistors create some loss of load regulation and also dissipate heat, which degrades system efficiency.

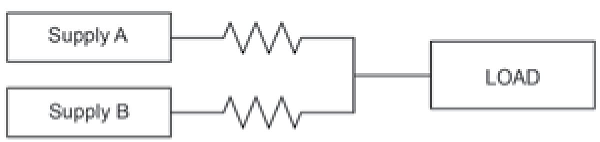

Figure 1: One sharing approach is to use relatively low-value ballast resistors on each supply's output, but this has issues due to resistor-related dissipation and overall efficiency

Diode OR-ing

A seemingly "simple" solution to this direct-connect dilemma is to use a diode between each supply and the common tie point of all the supplies: a technique commonly referred to as "diode OR-ing" (Figure 2). OR-ing diodes are very effective at preventing a supply from sinking current away from the shared output, but are generally insufficient to address sharing errors among supplies with independent error amplifiers.

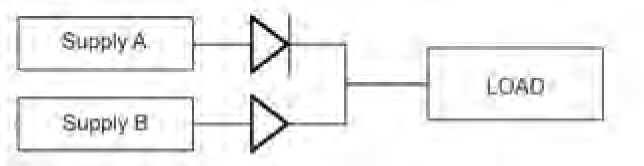

Figure 2: In principle, multiple DC-supply outputs can be combined by using diodes to isolate one supply from the other, but this configuration has many performance issues related to balance and current sharing

Diode OR-ing is generally required for supplies acting independently whose outputs can both sink and source current (two-quadrant operation). The effect of directly paralleling such supplies without OR-ing diodes is far worse than it is for single-quadrant supplies, and is likely to lead to immediate overload of one or more of the supplies.

In addition, if the diodes have a negative temperature coefficient for their conduction threshold, they will actually promote current "hogging" in the array. One way to minimise the problem is to use a method of rectification with a positive temperature coefficient.

Under some circumstances – for example, if one of the supplies suffers a shorted output FET or capacitor, OR-ing can still offer reliability improvements because the OR-ing diodes will quickly decouple the short from the output bus, improving reliability and system robustness.

Control strategy

Supplies generally must be designed specifically for parallel operation in order to operate reliably and predictably in an array. For a parallel array of supplies to deliver increased levels of usable current to a load, some type of control-loop strategy that factors in array use is needed. A popular control strategy is to group the supplies together with a common control-signal input controlled by a single error amplifier whose single feedback signal is then distributed to all the supplies in the system.

This strategy offers excellent output-voltage regulation and reduced sharing errors, but the use of a single error amplifier and a single wired control bus represents a single point of failure, which may present a problem for some types of high-reliability systems. In addition, parametric errors on modulator gain can be difficult to control.

For a single control-loop approach, sharing errors are minimised if the supplies feature tight tolerance on their control-node inputs. If the sharing errors are large, then either the power rating of the array must be reduced to avoid overloading of any single supply in the array due to sharing imbalances, or specific countermeasures need to be used.

Techniques for sharing errors which result from part-to-part variations of the control node include a production-based adjustment to calibrate out errors, or adding a current-control loop local to each supply inside the array. Sensing current for these local loops typically involves adding a shunt resistor to the supply.

A further problem for isolated power supplies that have their control nodes referred to the primary side of the DC-DC convertor results from transmitting the output of the error amplifier across the primary-to-secondary isolation boundary. Isolation techniques often add cost, take valuable board real-estate, and can have adverse effects on reliability.

An alternative control-loop strategy which permits separate supplies to be arranged in a parallel array uses a load line to emulate the path resistance of the ballast resistor method. By implementing what is called the “droop share” method of load sharing, each supply has a separate reference and integrating error amplifier, but the reference is deliberately and linearly reduced by a nominal amount as the load current of the supply increases.

Paralleling supplies may have negative consequences on transient response and load regulation, particularly for droop-share arrays. However, an external control loop can be used around the droop-share array to effectively cancel out the negative-regulation term. The resulting static-regulation error is identical to that in the traditional error-amplifier case, since the external loop is itself an error integrator.

Power-supply design

Power-supply vendors can take steps to ease the paralleling challenge. For example, Vicor’s DCM DC-DC converters in “Converter housed in Package” (ChiP) packaging feature a built-in negative-slope load line; thus, as the load increases, the DCM’s internal regulator reduces the output voltage slightly. This effectively acts like the small ballast resistor approach but without any actual resistors (Figure 3) and with a few additional key differences: notably a lack of wasted heat in physical resistors and enhanced dynamic response due to the lack of high-frequency parasitic effects. As a result, any instantaneous change in voltage across the resistor results in an immediate corresponding change in current.

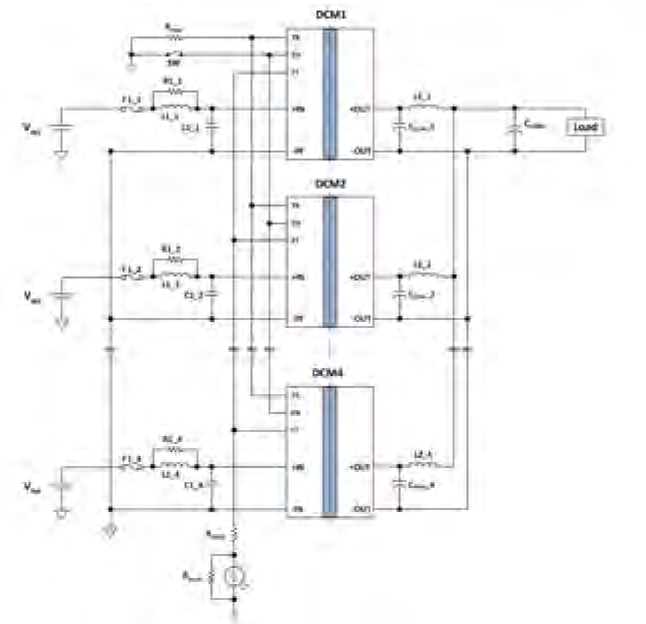

Figure 3: Vicor’s DCM devices in ChiP packaging are designed to be paralleled by simply connecting their outputs together; no diodes, ballast resistors, or other load-balancing components are needed

In the DCM converters, the load line is implemented through a discrete time modulation of the digital/analogue converter that creates the reference for the error amplifier. As a result, the resistor that the DCM load line emulates is one that acts as if it has a significant capacitor in parallel with it.

This load-line output characteristic permits multiple DCM outputs to be placed directly in parallel, with each having its own error-amplifier control-loop still active. The distribution of the load current over the DCMs in the array is ideally equal, so that parallel DCMs thus behave like a single DCM but with a higher output current (Fig.4). If one supply is loaded more than the others, its temperature will rise relative to the others, which in turn will cause its output voltage to decrease. Since the output voltages of the other parallel DCMs match that of the loaded DCM, their outputs follow their load lines, increasing their share of the load current and bringing the circuit back to equilibrium.

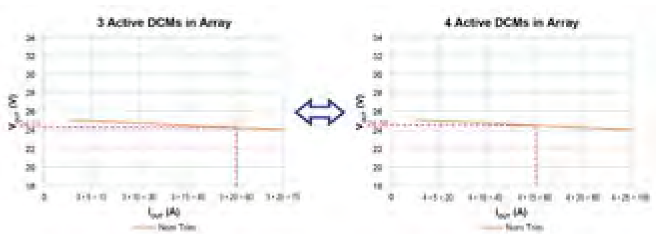

Figure 4: With Vicor DCM converters, units connected in parallel perform as a single converter; also, as the load-line shows, if the array is sized as N+1 redundant relative to the maximum load, the array continues to function despite the failure of any single converter

Similar considerations apply to power-supply ICs that are intended for much smaller loads. For example, the LT3083, a 3 A low-dropout (LDO) linear regulator from Linear Technology Corporation, supports parallel operation using a 10 milliohm ballast resistor between each supply and the common output rail.

http://www.vicorpower.com/

Reference Design for Inverters

First integrated solution for e-mobility and industry

Infineon Technologies has joined forces with TDK to develop an integrated solution for inverters to be used in e-mobility powertrains and industrial applications. The design enables developers to test and implement drive concepts quickly and easily.

By Wolfgang Rambow, Senior Director, Sales Reference Designs TDK and Michael Mankel, Senior Stuff Application Engineer, Electric Drive Train, Infineon AG

Reference design HybridPACK

Asynchronous motors are used in the majority of electrical drives for industrial applications, while automotive drives employ synchronous motors with permanent magnets. For both automotive and industrial applications, the manufacturers limit these motors to a maximum permissible voltage rise (dv/dt) at the inverter terminals of about 5 kV/µs (according to IEC 60034-18-41). The reason for this limit is the dielectric strength of the windings. When these motors are driven by an inverter high earth leakage currents occur that are caused by parasitic capacitance in the windings in combination with the dv/dt of the inverter. These currents can lead to sparking in the bearings, cause surface erosion and therefore severely limit the service life of the bearings.

In order to achieve high energy efficiency, the power semiconductors of the inverters are operated at switching frequencies in the range between 4 kHz and 15 kHz. Due to the necessary slew rate and switching frequencies, this results in harmonics with a high amplitude in the frequency range around 1 MHz. In automotive applications, in particular, the power drive causes significant interference in the MW band (526.5 kHz to 1606.5 kHz), making MW reception nearly impossible in a car, for example.

New development delivers significant improvements

To be able to create an inverter that is gentle on the motor and that is electromagnetically compatible, Infineon and TDK have redeveloped the key components and matched them perfectly with each other, thus improving on the existing HybridPACK™1. Apart from using the latest IGBT3 chip generation with a dielectric strength of 705 V, it now features six DC terminals on the HybridPACK module instead of the previous two (Figure 1). In combination with the modified EPCOS DC link capacitor, this enabled the ESL in the DC link to be almost halved from typically 30 nH to about 15 nH. The overvoltage generated when switching off the IGBT at the rated current (400 A) is correspondingly reduced by a significant amount: from 500 V to 420 V (Figure 2).

Together with the busbar to the DC link capacitor, the four additional DC terminals enhance the current capability of the HybridPACK module. In this way the new HybridPACK1-DC6 module is designed for more efficient future IGBT technologies with higher current capabilities. The power capability of existing applications based on the current HybridPACK1 with two DC terminals can be expanded easily with the HybridPACK1-DC6 because the new module has nearly the same dimensions as its predecessor. This provides good scalability for various xEV applications.

HybridPACK1 with its two DC terminals features a very compact design thanks to its integrated busbar. This feature was retained in the new HybridPACK1-DC6 for compatibility reasons. The external

Figure 1: HybridPACK1-DC6 IGBT module.

The new HybridPACK1-DC6 is designed for 705 V and 400 A. Thanks to the six terminals of the DC busbar this design has very low inductance.

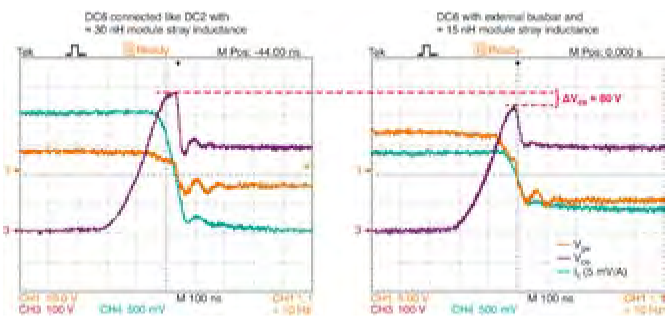

Figure 2: Significant reduction of the overvoltage. Thanks to the lower voltage spikes when switching, the IGBT module and the motor are protected.

busbar to the EPCOS DC link capacitor allows the DC supply current to be better distributed, thus achieving a better utilization of the module. Figure 2 (right) shows the current flow through the internal busbar at a rated current of 400 A. It represents a symmetrical distribution of the current between the busbar of the EPCOS DC link capacitor and that of the module.

EPCOS DC-link capacitors prevent noise in the DC link

A further new development is the EPCOS B25655P4477J DC link capacitor. Its terminals are designed to fit precisely with the DC terminals of the IGBT module. This is a further development of the existing EPCOS capacitors that were designed for the HybridPACK and EASY series from Infineon. The capacitor has a capacitance of 470 µF and is available with rated voltages of 450 V DC or 500 V DC. It features dimensions of just 154 mm x 72 mm x 50 mm. The basis of this space-saving design is power capacitor chip (PCC) technology, which employs a stacked film to achieve a volume fill factor of nearly 1 for the capacitor housing. There is also a flat winding version with 380 µF (B25655P4387J), which is the most economical type. Both types are each available with or without direct connection to an EMC filter.

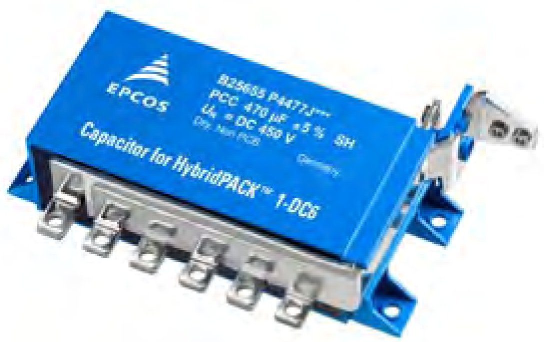

Figure 3: Space-saving EPCOS DC link capacitor. Thanks to PCC technology a volume fill factor of nearly 1 is achieved.

High EMC performance despite unshielded cable

TDK has also developed a series of twin-conductor high-voltage DC filters specially tailored to the demands of electric drives for vehicles. They thus ensure the fulfillment of all EMC requirements according to UN ECE Regulation No. 10 – Rev. 5. The P100316* series of EPCOS high-voltage DC filters (Figure 4) are designed for a maximum voltage of 600 V DC and thus correspond to the typical voltages that are supplied by high-voltage batteries. The current capabilities of the filters are around 150 A DC or 350 A DC, which means that even drive systems with outputs of up to around 100 kW can be filtered. The DC resistance is only 0.05 mΩ for all types, which means that there are no significant losses, even in the case of high currents.

Figure 4: EPCOS high-voltage DC filters for automotive inverters. The connections of Version P001 are formed in such a way that they can be connected directly to the EPCOS DC-link capacitor. Apart from the space-saving design, they also offer electrical advantages such as low inductance and contact resistances.

The efficiency of the filters is so great that there is no longer any need for the usual shielded cables between battery and inverter (Figure 5). This not only has advantages in terms of cost and weight, but also ensures greater long-term stability as the expensive and fault-prone shielding connection can be dispensed with.

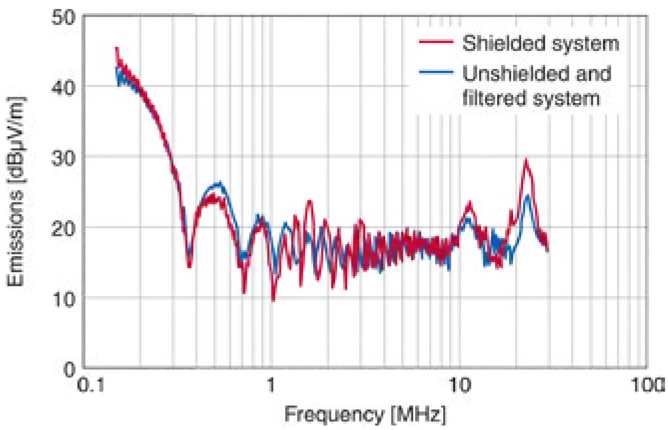

Figure 5a: Emissions when using the EPCOS HV DC EMC filter

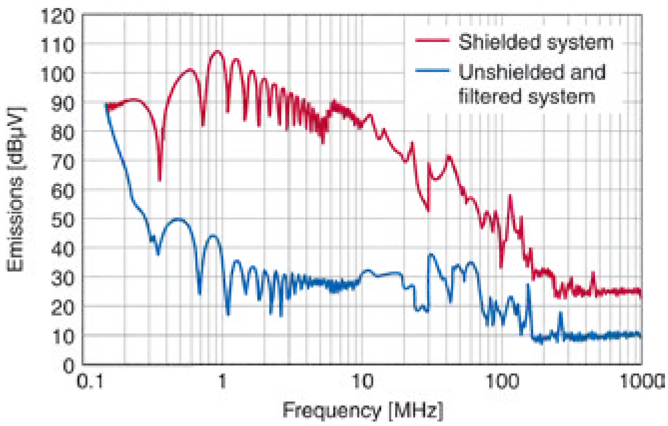

Figure 5b: By using the new EMC filter between battery and inverter, it is possible to dramatically reduce the conducted interference – despite using an unshielded cable.

Despite using an unshielded DC cable, use of the EPCOS HV DC EMC filter reduces the conducted interference in particular by up to 70 dB, which is equivalent to a factor of 3000. This is not the only advantage: The new filters also enable a considerable reduction in the number of conventional EMC measures necessary for the individual system components.

Apart from outstanding electrical values, the filters are also impressive for their low weight and compact dimensions – technical parameters that are essential for to their use in vehicles. Depending on the type, these dimensions typically range between 186 mm x 65 mm x 65 mm and 121 mm x 52 mm x 52 mm. Apart from the versions with a general common-mode rejection ratio, types are also available that exhibit a particularly high filtering effect in the long-wave spectrum between 150 kHz and 300 kHz.

EPCOS ferrite cores increase the service life of motors

At the output of the inverter the steep pulse edges cause voltage spikes that can be further exaggerated by parasitic inductances of the motor cables. Under unfavorable conditions these voltage spikes can result in arcing that could destroy the motor windings. At the same time, the switching frequency of the inverter leads to a higher parasitic capacitive load between the windings of the motor and its housing (ground potential). This results in leakage currents that can flow through the motor bearing and thus cause sparking.

One remedy for this is provided by ferrite ring cores through which the motor cables are routed at the output of the inverter. Thanks to the lower dv/dt, this likewise significantly can reduce common-mode interference significantly and lower leakage currents to a non-critical level, which ensures that the limits of Classes I through III are adhered to (Figure 6). For this purpose, TDK offers a broad spectrum of ring cores from the B64290L* series in various dimensions and ferrite materials, which are optimized for certain frequency ranges and temperatures, and can therefore be tailored to any drive system. Ferrite materials such as T65, N30, N87, which are also used for EPCOS EMC chokes, are recommended for this purpose.

ID	Type / Value	Ordering code	Manufacturer
IGBT module HybridPACK1-DC6	705 V / 400 A	FS400R07A3E3	Infineon
Gate driver IC		1ED020I12FA2	Infineon
DC link capacitor	470 µF / 450 V or 380 µF / 450 V	B25655P4477J (stacked) B25655P4387J (flat winding)	EPCOS
EMC filter	600 V / 150 A	P100316-P001	EPCOS
Ferrite cores	Ring cores	B64290* series	EPCOS
Inductors	Common-mode choke 0.7 mH/4 A	B82721A2402N020	EPCOS
Gate drive transformer		B78307A2276A003	EPCOS
Capacitors	Several MLCCs		TDK

Table 1: Bill of Material for the inverter

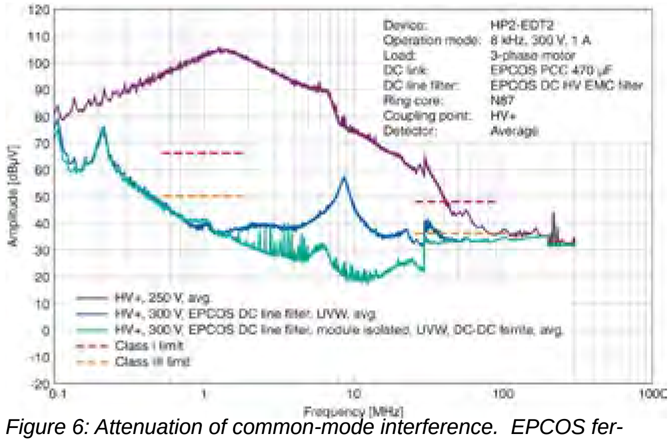

Figure 6: Attenuation of common-mode interference. EPCOS ferrite ring cores ensure that the limits of Classes I through III can be adhered to.

In addition, Infineon developed a new driver board for the HybridPACK1 DC6 module, which is based on the proven 1ED020I12FA2 series of Infineon gate driver ICs. The board ensures efficient EMC compatible operation and enables the benefits of this improved configuration to be easily implemented. The result is the first power output stage consisting of an IGBT module, DC link capacitor, EMC filter and gate driver, and in which all necessary EMC requirements are considered right from the beginning.

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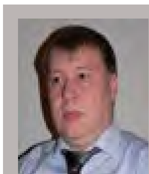

Michael Mankel,
Senior Stuff Application Engineer,
Electric Drive Train, Infineon AG

Essential Considerations Relating to Partial Discharge

Insulation voltage, test voltage, partial discharge and insulation strength – terms development engineers frequently have to deal with. But how are they related and which aspects and data are ultimately relevant to the developer?

By Werner Bresch, Tobias Gmelin and Erik Rehmann, GvA Leistungselektronik GmbH

The manufacturers' data sheets normally provide information on the so-called insulation voltage for electronic components used in power electronics systems, which must insulate different electric potentials from each other safely and reliably in addition to providing the desired function. This value is often expressed in the following format: 'Uiso = 4 kV AC' (for example), usually with a defined test time of 60 s. This parameter should help the development engineer decide whether the component is suitable for the intended application in terms of insulation strength. Nevertheless the user still needs to know how to interpret this information, or be able to at least recognise the basic correlations and know the procedure for the practical design of insulation distances and test voltages.

In the process of insulation coordination for a power electronics system, the following basic standards generally apply as a start: IEC 60664-1 ('Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests') for operating voltages ≤ 1000 Vac or 1500 Vdc and IEC 60071-1 ('Insulation coordination – Part 1: Definitions, principles and rules') for high-voltage applications. The application of these standards is then described in more detail in corresponding product standards (e.g. DIN EN 61800-5-1 for electrical power drive systems). If there is no product standard for the intended application, the relevant basic standard can be used to define the insulation requirements.

Based on these standards, the process of insulation coordination as per DIN EN 61800-5-1 would proceed as described in the following, taking the conditions defined in the standard into account:

- Divide the system in question into relevant electric circuits
- Define the safety requirements for the individual circuits based on relevant voltage classes or working voltages
- Define the impulse voltage based on the system voltage (this includes circuit and mains properties) and the relevant overvoltage category
- Dimension the clearances and creepage distances, taking the pollution degree and insulating material group into account
- Define the test voltages for:

• Impulse voltage test

- Type and sampling test
- With pulses 1.2/50 µs
- Verification that clearances have sufficient electric strength to withstand overvoltage of atmospheric origin and caused by switching processes in the equipment

• AC or DC voltage test (voltage withstand test Uiso)

- Type and routine test
- Minimum duration ≥ 1 s (typically 10–60 s)
- Verification that clearances and the solid insulation of the components used as well as of the completely set up system have sufficient electric strength to withstand overvoltage

• Partial-discharge test

- Type and sampling test
- As per IEC 60664-1
- Verification that no repetitive partial discharge events are occurring within the set voltage range in the solid insulation used in components and sub-assemblies for protective separation of electric circuits

Whereas when developing power electronics systems, the development engineers have a great amount of freedom within the limits of the specifications in the standards regarding the design of clearances and creepage distances and the insulation materials used, this freedom is lost when it comes to power electronics components such as power semiconductor modules, current and voltage sensors, IGBT drivers and auxiliary power supplies. The insulation properties of these types of components are defined by the design and the selection of insulation materials by the manufacturer. The manufacturer usually provides evidence of the insulation resistance in an AC or DC voltage test (Uiso).

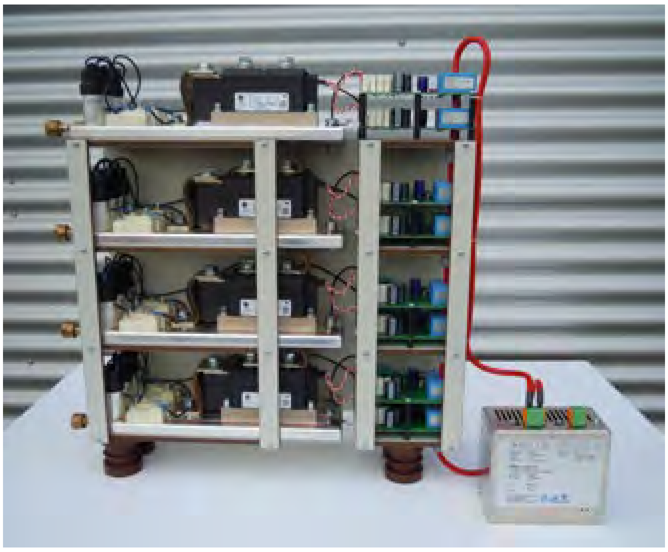

Figure 1: The auxiliary power supply units such as the 'Inductive Power Supply System (IPSS)' from GvA sensibly specify the test voltages free of partial discharge

One such AC or DC voltage test (Uiso) must be considered as an inspection to ensure the proper installation of the components, in order to verify that the required clearances inside the components were observed during manufacture. However, this test does not provide any information about the permissible voltage which can be applied to the component or system in operation! Since the insulation resistance may already experience premature damage due to partial discharge

Figure 2: In the IPSS the decoupling units on the control boards ensure the inductive transmission of the required power

when type testing using the AC or DC test voltage (Uiso) specified in the data sheet, the standard recommends conducting repeat tests only at a maximum of 80% of the specified test voltage. Essentially, the AC or DC voltage test (Uiso) only verifies that the tested component has survived the specified test time.

Therefore, the partial-discharge behaviour is more of a determining factor for the endurance strength, as partial discharge can weaken and damage a solid insulation already within short periods of time, ultimately causing a disruptive discharge. The aim of having a stable layout for an insulation system, both for components and for systems, is therefore to guarantee that all operating points are free of partial discharge. Passing the voltage withstand test (Uiso) cannot guarantee that no partial-discharge events occur during operation under worst-case conditions (maximum-duration voltage, temporary overvoltage, recurring peak voltage). Therefore, the specification of an 'insulation voltage' in the data sheet, which usually does not come with any additional commentary from the component manufacturer, is not a reliable indication, let alone verification, that the long-term electric strength is sustained for operation at this voltage under specific conditions.

For this reason, the IPSS or GPSS auxiliary power supply units developed by GvA specify the test voltage 'free of partial discharge' under the item 'Insulation voltage', too. This ultimately helps development engineers select the ideal product for their requirements and eliminates the need to address product failures for a fairly long time.

www.gva-leistungselektronik.de

Make it Easy, with GaN Power ICs

Early forms of Gallium Nitride (GaN) power devices required complex, expensive and frequency-limiting external circuits and complex packaging to protect and manipulate vulnerable gates, which severely restricted market adoption.

By Tom Ribarich, Sr. Director Systems Engineering, Navitas Semiconductor

The introduction of monolithically-integrated GaN Power ICs, with drive, logic and FET on a single die is the enabling step forward. This powerful merging of signal-to-power provides a rugged solution that is easy to use and greatly simplifies overall system design. This article highlights some of the past difficulties with early GaN, presents new GaN Power ICs, and shows high-frequency converter design examples that utilizes this new and revolutionary technology to create applications with benchmark efficiency, power density and low system cost.

AllGaN™ and GaN Power ICs

Gallium Nitride (GaN) is a wide bandgap material that allows high electric fields so high carrier density can be achieved. A two dimensional electron gas (2-DEG) with AlGaN/GaN heteroepitaxy structure gives very high mobility in the channel and drain drift region so resistance is much reduced compared to both Si and SiC. Creating lateral device structures achieves extremely low charge, for high-speed operation and also allows integration. AllGaN™ is the industry's first GaN Power IC Process Design Kit (PDK) which allows monolithic integration of 650V GaN IC circuits (drive, logic) with GaN FETs. Other functions can also be included, such as hysteretic digital input, voltage regulation and ESD protection – all in GaN (see figure 1 for construction and integration). This monolithic integration of drive and switch is impossible using vertical GaN, dMode GaN or SiC.

Figure 1: AllGaN lateral structure (Left), integration of FET, driver, logic (Right)

Easy to Drive

The earliest GaN power devices were dMode (depletion mode) which meant that they needed an additional Si FET in 'cascode' to keep them off, with subsequent negative results in packaging inductance and cost. Later, eMode (enhancement mode) GaN discrete devices had vulnerable gates and a very low threshold voltage. This made them very susceptible to noise and voltage spikes due to high-frequency and high dv/dt noise from the surrounding switched-mode converter circuit, so required complex and expensive control and gate drive circuits (see figure 2 left). Additionally, both implementations restricted the high-frequency performance of the GaN switch, to the point where there was minimal, if any, advantage over Si, so limiting market adoption.

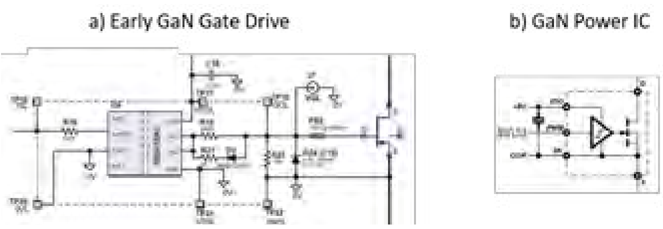

Figure 2: Early GaN gate drive (Left), GaN Power IC (Right)

Within the AllGaN solution, the GaN FET gate is driven safely, precisely and efficiently by the upstream integrated GaN driver. Simple, robust, low-current 3.3V, 5V or 15V signals, from standard, low cost, low voltage 'no driver' control ICs are fed directly into the GaN Power IC for an easy, low component count design (see figure 2 right). The waveforms exhibit a true "text book" feeling with very clean rising and falling edges, no ringing, and extremely fast turn-on and turn-off propagation delays (see figure 3). Integration eliminates gate overshoot and undershoot, while zero inductance on-chip insures no turn-off loss. This lack of ringing/overshoot makes tight control of deadtime easy in half-bridge circuits. This exceptional level of fast and quiet switching performance, together with the integrated gate drive and simple PWM input, allows for the design of a variety of different high-frequency power converters, raising practical speeds more than 10x from 65/100kHz to 1MHz+.

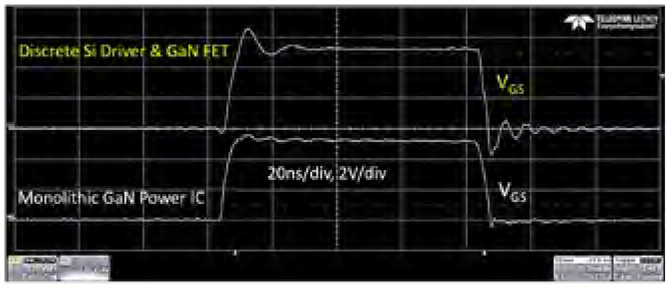

Figure 3: Comparative waveforms for (upper) Si driver, discrete GaN FET vs. (lower) integrated GaN Power IC.

Easy Electrical and Mechanical Layout

In high frequency discrete designs, more design time is required to investigate and remove or reduce parasitic inductance such as cross-coupling of devices and more PCB layers. At the same time, the gate drive solutions may need ferrite beads to protect the gate yet slow down the application. Traditional high-inductance packages like TO220 are bulky and limit system performance.

With industry-standard, low inductance, surface-mount QFN packaging, GaN Power ICs enable high performance, low cost solutions with the highest power density. Digital input means flexibility in design, with options for the GaN devices to be placed on the main board or daughtercard, close to or far from the control IC.

Easy to Meet Efficiency & Size Targets.

For a practical review of AllGaN in a real-life application, let's look at a 150W PFC boost converter running in Critical Conduction Mode (CrCM) - also known as Boundary Conduction Mode (BCM) - with a free-running frequency. Traditional circuits run at 65kHz or 100kHz due to existing silicon input/output capacitance limitations. Now, with the fast-switching and low inductance GaN Power IC, the frequency of this board was increased conservatively to a range of 200kHz to 1MHz to demonstrate the performance of the new GaN Power IC and to verify the power density benefits with increased frequency.

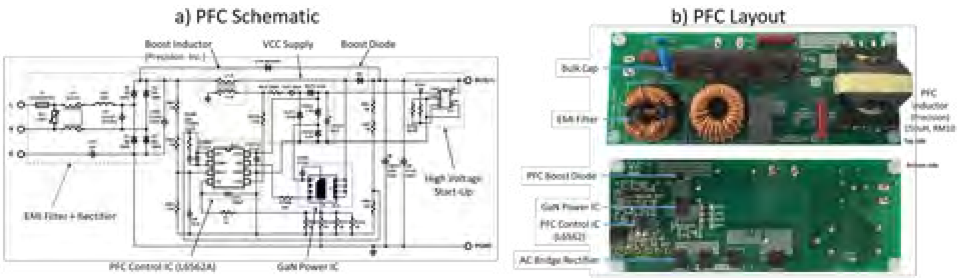

Figure 4: PFC demonstration board schematic (Left), component layout (Right)

The circuit is easy to place and route with the small 5x6mm QFN GaN Power IC located next to the critical boost switching node and the controller placed further away, next to the critical detection nodes. A simple PWM trace is then routed between the two blocks for the boost switch on/off control. All power components are surface-mounted on the bottom-side of a 2-layer, 2-oz PCB for single-pass wave soldering of the complete board. Vias are used for thermal management, no additional heatsinks are required.

The board achieves over 98% peak efficiency (with the GaN Power IC running at only 61°C) at full load and 97% average efficiency (including EMI filter and input bridge rectifier) with power factor over 99.5%. As a comparison, the same board with an 8x8mm QFN 'CP' super-junction Si FET was unable to run above ~200kHz, with temperatures over 160°C at light load.

As switching frequency increases, energy-storage elements (e.g. the boost inductor) reduce in size. Here, the boost inductor uses 3F36 core material and Litze wire (from the German Litzendraht for braided/stranded wire). A typical '100kHz' 150W inductor during low-line/full load conditions would require an inductance of about 400uH and an RM14 core size. This design, with only a moderate 4x increase in frequency, uses only 150uH and an RM10 core size – a core size reduction of 80%. Further size and cost savings may be applied to the common and differential mode EMI chokes.

While this board is designed for demonstration purposes, it still measures only 165 x 45 x 20mm – allowing the customer to optimize size and customize form-factor as needed.

A Simple Conclusion

With GaN Power ICs, high-performance, high-frequency power converter design is now easy, without the difficulties associated with complex and expensive gate drive and layout parasitics.

This simple concept, yet revolutionary achievement, has enormous potential for power supply design. For multi-stage converters, the flexibility of the design of the overall system architecture increases significantly. For example, individual GaN Power IC blocks can be placed near their respective power circuit with simple PWM signals routed easily to each block from a central controller.

This simplicity, with breakthrough performance, finally enables high voltage GaN to displace silicon.

www.navitassemi.com

SiC Cascode in 440 VAC – 800 VDC Power Factor Correction

Until recently, the selection for switching devices in 440 VAC applications has been rather limited. The choice was typically between an IGBT or a large, high gate capacitance MOSFET. This power switch selection tended to limit switching frequencies to less than 50 kHz., which then required larger, more expensive inductors to maintain good power factor.

By John Bendel, USCi

Abstract

With the introduction of wide bandgap switching devices, good efficiencies at higher switching frequencies become attainable, while producing more cost effective solutions by lowering the required inductance. This article will explore the design tradeoffs for efficiency and power factor in implementing designs at higher frequencies (>75 kHz). For simplicity, only a single phase will be analyzed.

Power Factor Correction

This article will focus on hard switched PFC's, as shown in their simplified form in Figure 1. The current through the boost inductor is PWM'd to mirror the input Voltage (Figure 2). This process makes the converter appear as a resistive load (PFC=1), and thus reducing line harmonics, which is the goal of this power stage. It is therefore important that when evaluating PFC's, one must always consider Power Factor in the context of efficiency.

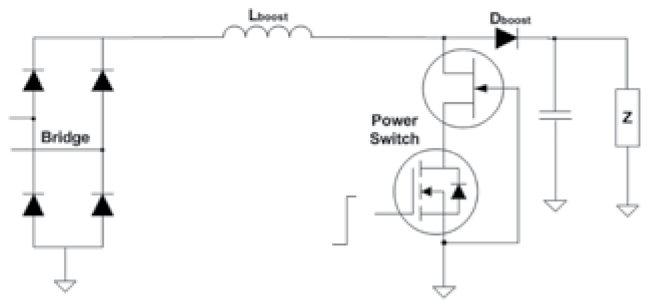

Figure 1: Basic Power Factor Correction Topology

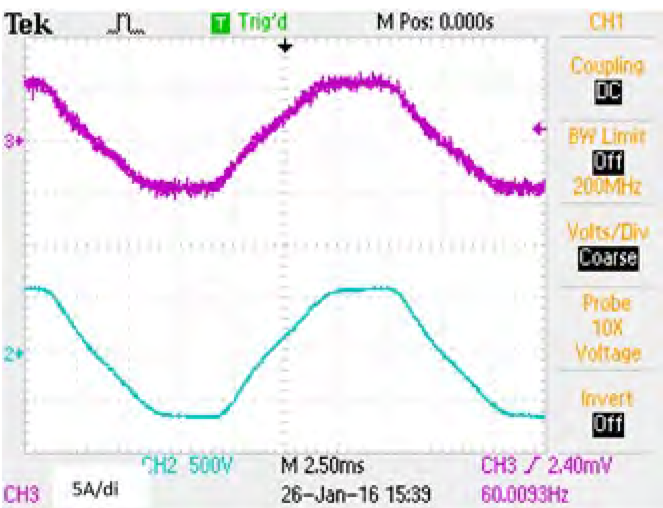

Figure 2: Vin = 440VAC, Iin = 3.8A, PF = 0.993, fs=100kHz

Efficiency and Power Factor Correction

The common elements between Power Factor, efficiency and switching frequency are the power switch/boost diode pair and the inductor. An increase in frequency lowers the required inductance, which produces a smaller, cheaper inductor. The tradeoff with this is the obvious drop in efficiency due to the increased number of cycles. The goal is to find the correct tradeoff that generates the optimum power factor and efficiency at the right cost point.

Boost Inductor

Equation 1 is the required boost inductance for continuous current mode (CCM) operation in a power factor correction converter. Figure 3 is the plot of this inductance with respect to switching frequency for a 440VAC input and an output power of 1.65kW. The inductor ripple current is set at 20% of the peak current (Note: There are many resources on the web with respect to PFC design, this paper will primarily rely on TI's UCC3818 datasheet, as it is PWM controller used in the test board).

$$L_{boost}(fs) := \frac{V_{in} \cdot \sqrt{2} \cdot D}{dI \cdot fs} \qquad 1)$$

From the graph, the inductance can swing from 5.1 mH to 0.86 mH depending on frequency. The inductance value with respect to current required for the application will have a direct relationship to the cost of the inductor.

As an example, using the Magnetics Inc. software, and standardizing on the 55438 MPP core, a 25 kHz design, a 5.6 mH inductor requires 3 cores and 112 turns of 18 AWG, where a 150 kHz design, a 0.56 mH requires a single core 51 turns and there is room to use 14 AWG wire.

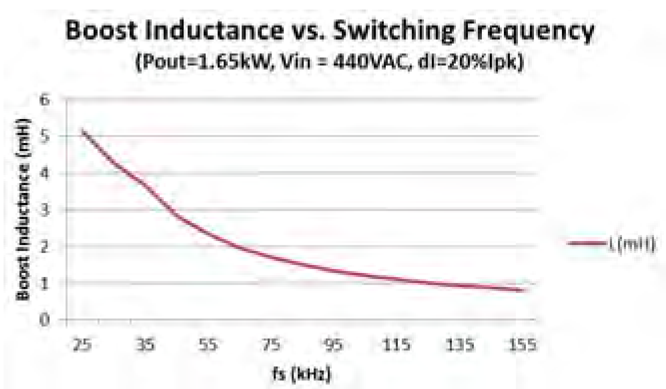

Figure 3: Boost Inductor vs. Switching Frequency

From a magnetics perspective it is clear that that moving to higher frequency / lower inductance one can produce a lower cost, more efficient inductor.

3.0 Switching Frequency

The inductance calculations highlight the advantages of increasing switching frequency, but the other side of the equation is that switching losses will be going up with frequency. A PFC test board (Figure 5) based on the UCC3818 current average controller was designed along the same criteria as the previous example: 440 to 480 VAC input, 800 VDC output with an output power of 1.65 kW(~ 5 kW in a three phase system). The initial design will be for a lower switching frequency converter, and then higher frequency will be investigated. Note: 1.65 kW was chosen as it still allows for stepping up 440 VAC from a standard 110 VAC line.

Figure 4: MPP Cores, 55438

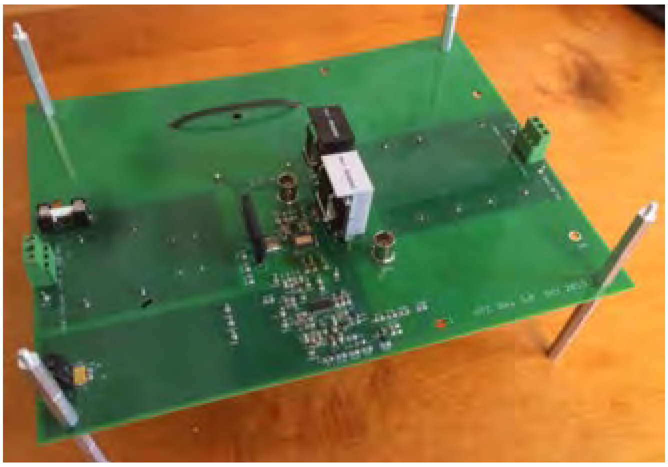

Figure 5: UCC3818 PFC Test Board

The Power Switch and Boost Diodes are the UJC1210K Cascode (1.2 kV, 100 mOhm max). The advantage of the UJC1210K is not only its fast switching capability, but that it can also be driven with standard gate drive. Its performance capability allows it to compete economically against silicon solutions. Note: all test results shown in this paper will use a V_{GS} drive of 0 to 14 Volts.

An USCi Silicon Carbide Diode, UJ2D1205T (1.2 kV, 5 A) with a QC of 14 nC will be the boost diode. Once the R_{G_L} and R_{G_H} are fixed, the only variables in the data will be the switching frequency, and the inductor design. A complete list of components can be found in the appendix. A Mathcad file based on Texas Instruments calculation is available upon request. This by no means a fully optimized design, but it is meant to highlight the relative tradeoffs between inductance and switching frequency with respect to efficiency and power factor.

Optimizing Gate Drive

As the UJC1210K is a cascode device, it is recommended to use the drive configuration shown in Figure 6. This allows control of the turn on and turn off behavior. As silicon carbide is inherently faster than silicon, and it is recommended to start with higher R_g values than silicon. In cascode, the R_{g_L} will typically be higher than the R_{g_H} value. It is recommended to start with an R_{g_H} of 10 Ohms and an Rg_L of 20 Ohms. These values can be swept +/- with selection determined by efficiency and EMI considerations.

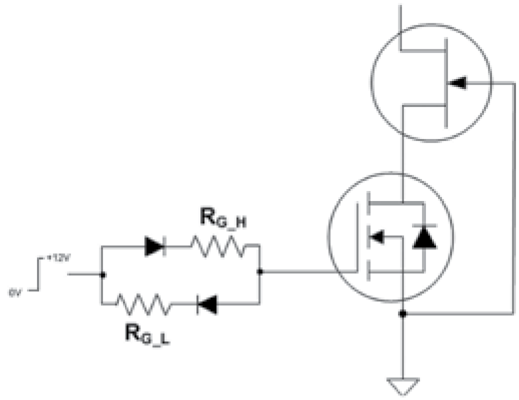

Figure 6: Cascode R_{g_H} and R_{g_L} Configuration

In figure 7, such a process was undergone. A switching frequency of 130 kHz was chosen to accentuate the performance differences. An R_{g_H} at 7.5 Ohm and an R_{g_L} of 15 Ohms were determined to give acceptable results.

In Figure 8, the corresponding waveforms associated with these Rg values are shown. All waveforms appear well controlled with minimal ringing. An R_{g_H} of 7.5 Ohm and an $R_{g_}$L of 15 Ohms will be used in all measurements with the UJC1210K.

Baseline Efficiency Curve

An Inductor was designed to generate good power factor down to switching frequency of 25 kHz. This curve will be used as a baseline to compare results against future optimizations, especially at higher frequencies. The inductor was wound using three 55438 MPP cores

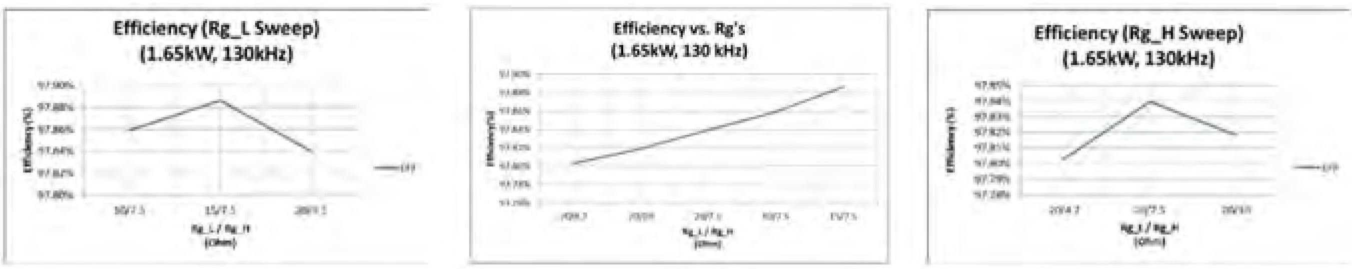

Figure 7: R_{g_H} and R_{g_L} Selection

with 87 turns of 18 AWG, (3.9mH at the 1.65kW output power), which meets the criteria set in the graph of figure 1.

For measurement purposes, the input power and power factor are measured using a Tektronix PA 1000 Power Analyzer. The output power and 14V Controller/Driver Supply power are measured using Keysight 34465A 6.5 digit multi-meters. The lab power supply and the AC input power are added together for input power when calculating efficiency.

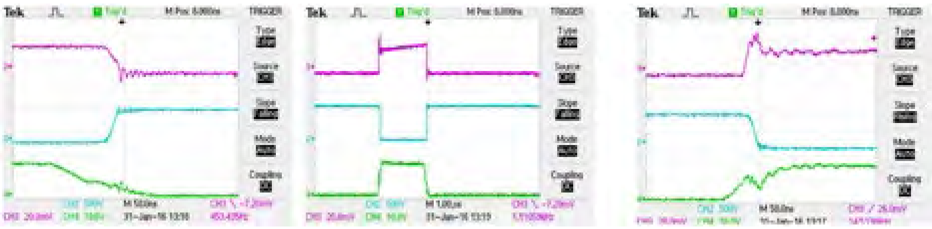

Figure 8: Turn Off, Full Period and Turn On (R_{g_H}=7.5 Ohm, R_{g_L}=15 Ohm)

In figure 9 the UJC1210K efficiency curve is plotted with respect to switching frequency and power factor. As calculated, the power factor is well above 0.990 across all load and switching frequency conditions.

Per the data, the efficiency of the silicon carbide UJC1210K cascode (VGS: 0 to 12 V) from 25 kHz to 150 kHz (98.55% @ 25 kHz / 97.87% @ 150 kHz) has a delta of 0.68%.

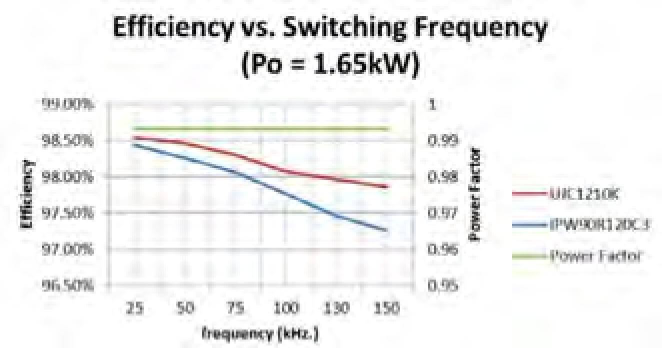

Figure 9: Efficiency vs. Switching Frequency

For a reference, this curve is compared against a similarly rated 900V super junction silicon MOSFET. The delta between efficiency across the same frequency spread is 1.19 percent. The efficiency delta grows between the two curves due switching losses as well as gate drive loss. A 6.9 Ohm gate resistor is used with the Silicon MOSFET, as compared to the 7.5 / 15 Ohm combination on the cascode.

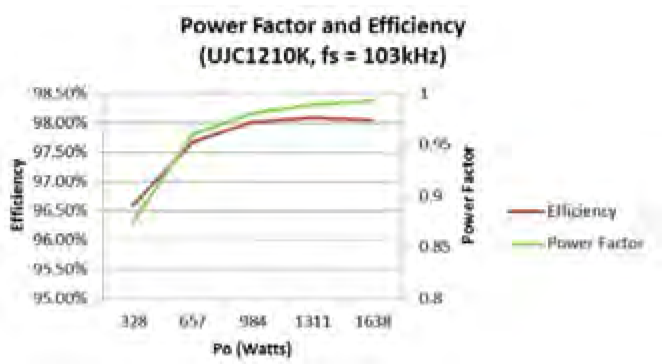

Figure 10: Efficiency vs. Load

Translating the efficiency comparison into actual loss, the cascode “loss delta” by increasing switching frequency from 25kHz to 150 kHz is 11.6 Watts, where the 900V, switching optimized MOSFET dissipates almost twice that amount at 20.3 Watts. By not dissipating the power in the first place, the SiC solution lowers the system thermal budget, and opens up the opportunity for higher switching frequency and lower inductor values.

In figure 10, the frequency is fixed at 103 kHz, and the load is swept from 328 Watts to 1.6 kW. It is noted that power factor with the given inductor begins to significantly roll off at 66% of load. The good news in this is that the peaks of the harmonics will also be dropping with power, so it is still possible to meet the line harmonic regulations with such a curve.

Lowering the Cost

In the previous example, the inductor was designed for low frequency operation (3.9 mH), and it still delivered reasonable results at 100 kHz and higher, but the goal in going to high frequency operation is to lower system cost with minimal impact to efficiency. A second inductor was designed to be optimized for 100 kHz operation, and only a single core (55438 MPP) is used. This design requires 68 turns of 14 AWG wire, to produce 1 mH inductance at load, which generates an inductor cost that is 30% of the previous example.

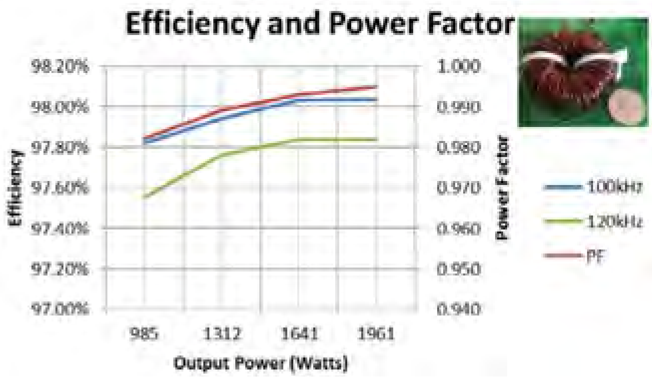

Figure 11: Boost Inductor (1 mH, 55438 MPP)

Per figure 11, the efficiency at 100 kHz exceeds 98% with an inductor 1/3 the size of the previous design. The power level is approaching 2 kW, which translates to 6 kW in a 3 phase system.

Conclusion

This design is not the final answer on how high the efficiency can be produced at 100 kHz., but are examples that illustrate that one can take a low frequency design with standard drive (0 to 14V), and by substituting a silicon carbide device (UJC1210K), and by increasing the switching frequency >> 75 kHz, one can reduce the inductor cost down to 30% of a low frequency design and still produce efficiency performance in excess of 98% and power factor ≥ 99.0%.

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Important Dates

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July 1, 2016
Final manuscript submission

August 6, 2016
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Announcement

ECCE is the foremost IEEE conference in the field of electrical and electromechanical energy conversion. ECCE2016, to be held in Milwaukee, the heartland of the North America energy conversion industry, will provide researchers, engineers and professionals from industry and academia a convivial and innovative atmosphere for interaction and networking.

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- "Future of the Smartgrid" by Prof. Massoud Amin, Minnesota University.
- "Intelligent Motor Control in a Connected Enterprise" by Mr. Blake Moret, Senior Vice President, Control Products & Solutions, Rockwell Automation
- "Optimized Power Management Using Data Analytics", by Mr. Michael Regelski, SVP and Chief Technology Officer Electrical Sector, Eaton
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Comparison of Silicon and GaN Transistors Leads to an Optimized Inverter Design

By re-designing IGBT and MOSFET solutions with GaN-based FETs, DRS optimized vehicle inverter performance, increased switching frequency by a factor of four, reduced size and weight, while achieving 98.5% efficiency.

By Scott Ramsay, Technical Director, DRS - Consolidated Controls, Inc.

At DRS, we set a goal to design an improved generation of our 2kVI vehicle inverter. During our development process we compared the performance of silicon-based IGBT and MOSFET solutions versus the recent emergence of normally-off, E-HEMT GaN devices. This paper describes how GaN devices allowed us to alter our design approach with the result of increasing switching frequency by a factor of four and the added advantage of producing significantly smaller inductors. We were also able to deliver 98.5% efficiency over a wide operating range, enabling us to reduce the overall cooling system. In the end, for the same cost, we were able to deliver a significantly smaller and lighter unit with higher efficiency than ever.

Topologies

Two common inverter topologies were considered, Dual Buck and Full Bridge. Figure 1 demonstrates a Dual Buck Inverter topology with silicon-based MOSFETs and SiC diodes, while Figure 2 demonstrates a standard Full Bridge Inverter with GaN devices.

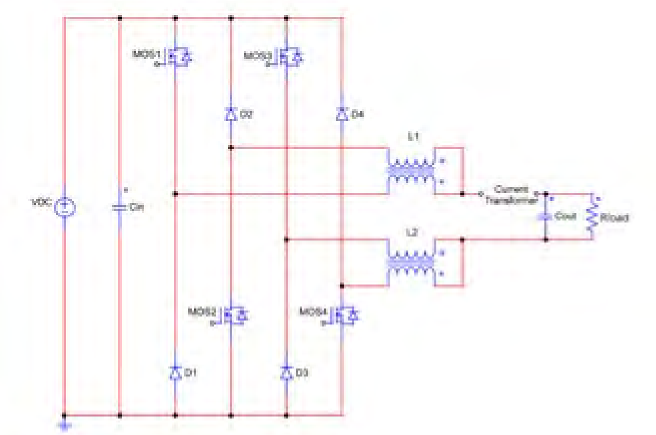

Figure 1: Dual Buck Inverter (Si MOSFETs and SiC Diodes)

A traditional single phase inverter would likely use a Full Bridge Inverter topology. In traditional inverters using this topology, either IGBTs with fast anti-parallel diodes, or silicon MOSFETs can be used for the switching devices. The IGBT solution is popular in many applications due to its low cost and minimization of the diode recovery current that would otherwise be experienced with MOSFETs. However, IGBTs cannot operate efficiently at high frequencies, nor can they achieve extremely low conduction loss conditions because they are junction devices and will always exhibit a forward voltage drop (or offset) when conducting. This limits the minimum losses that can be obtained. However, if silicon MOSFETs are used, then the forward voltage drop is replaced by a resistive element which can be progressively lowered by adding more devices in parallel. But the Achilles heel for MOSFETs in this topology is the presence of a body diode and associated reverse recovery currents and losses that will occur as devices hard switch and forcefully commutate the associated conducting body diode. In summary, the use of the traditional topology with only silicon technology is limited by both maximum attainable frequency and efficiency.

The most critical design requirement we identified when we set out to develop our ruggedized 2kVI vehicle inverter was efficiency. We knew that in order to develop a product that would be reliable in rugged vehicle applications, it would need to be fully sealed and able to function at high temperatures without significant air flow. We also did not want the product to be liquid cooled since this would constrain the end user's ability to deploy the product. These design constraints demanded a product of the highest practically attainable efficiency. Given these constraints and the state of transistor technology at the time, we used the Dual Buck Inverter topology with silicon MOSFETs and SiC diodes as the switching elements. This topology functions identically to the traditional Full Bridge topology. However it effectively isolates the MOSFET body diode from the scene, thus eliminating the efficiency limiting reverse recovery losses. We also chose MOSFETs instead of IGBTs in this application so that we could parallel the MOSFETs, thus reducing the switch resistance and lowering the losses in the device. This topology provided very good performance, and generally achieved above 98.5% efficiency over a wide operating range. However, this high-end efficiency performance did not come

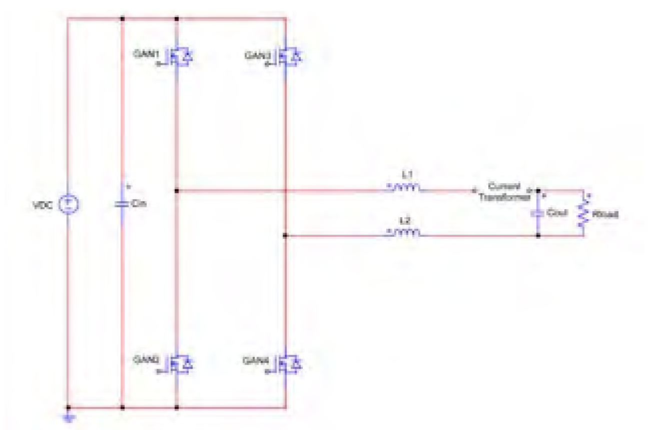

Figure 2: Full Bridge Inverter with GaN

without a penalty. As is obvious in the two simplified schematics, the Dual Buck topology is considerably more complex, requires more power components, occupies more space, and costs more than the traditional solution.

Despite achieving ultra-high inverter efficiency, we came to a juncture in our product development where we were able to re-evaluate our development plans against recent technology trends and product releases. At that time, it became clear that GaN devices were the real deal. They were reliable and available to be considered for this product's development. So we changed our development plans to use the latest GaN devices with the traditional Full Bridge topology. Since GaN devices are not junction devices, they exhibit the same resistive behavior as Si MOSFETs, yet they have the additional benefit of excluding a body diode, thereby enabling high efficiency with this topology. By using GaN Systems' GS66508P device we are able to achieve the same ultra-high efficiency conditions with far less complexity and components, and thereby package the power stage within a smaller printed wire board area.

Design Comparisons – IGBT vs MOSFET vs GaN
The following is a comparative summary between the three types of inverter solution designs:

- Full Bridge Inverter with silicon IGBT or silicon MOSFET
- Dual Buck Inverter with silicon MOSFETs and SiC diodes
- Full Bridge Inverter with GaN devices

Design 1: IGBT or MOSFET Full Bridge - This inverter solution can be achieved in a cost-effective manner and with a minimal number of components. However, the targeted efficiency cannot be achieved with this solution. A larger thermal solution would need to be used to dissipate the additional heat.

Design 2: MOSFET Dual Buck - The efficiency target is obtained and therefore a smaller thermal solution is usable. However, many more components are needed to implement this topology and to bring it

Figure 3: 2kVI Vehicle Inverter Using GaN Switches in a Full-Bridge Configuration

to the ultra-high efficiency range. In our original implementation, we used two MOSFETs in parallel for each switch and two SiC diodes in parallel for each diode. This translated to needing a total of 16 semiconductors, and in addition, the output inductors require a coupled inductor design which is more complex and larger than an equivalent single winding inductor used in the Full Bridge variant. The additional paralleled MOSFETs also require additional circuitry in the gate drive to allow the devices to work optimally in parallel.

Design 3: GaN Full Bridge - The GaN technology shown in Figure 3 enables this topology to achieve ultra-high efficiency with low part count. In our most recent implementation, we only needed a single GaN device per switch and no diodes to achieve the target performance level. Therefore, only four semiconductors and two simpler inductors are needed. In addition, the GaN devices can switch much faster than the silicon devices, enabling the switching frequency to be increased by a factor of four while maintaining the same ultra-efficient performance of the Dual Buck Inverter. At higher frequencies we can reduce the cost and size of the output inductors and filter capacitor by a factor of two, and the area needed to house the semiconductors by a factor of four.

At higher frequencies, we can reduce the cost and size of the output inductors and filter capacitor by a factor of two, and the area needed to house the semiconductors by a factor of four.

Even with the added cost of GaN devices versus silicon devices, and when considered with the downward pricing trend GaN devices are already exhibiting, the cost to implement an ultra-high efficiency inverter is really no higher for the GAN-enabled Full Bridge compared to the Si/SIC-enabled Dual Buck Inverter.

Summary and Commentary

During the development of the DRS 2kVI Ruggedized Vehicle Inverter, we compared conventional silicon-based IGBT and MOSFET solutions with GaN E-HEMT transistors from GaN Systems. As summarized in Table 1, the GaN E-HEMT transistors clearly exhibited superior performance while imparting supplemental advantages associated with size, efficiency and cost.

Inverter Topology	Transistor	Inductor	Relative Complexity	Relative # Components	Relative Space	Relative Cost	>98.5% Efficiency
Full Bridge	Si IGBTs or Si MOSFETs	Single Winding	Low	Low	High	Low	No
Dual Buck	Si MOSFETs	Coupled	High	High	High	High	Yes
Full Bridge	GaN on Si	Single Winding	V. Low	V. Low	V. Low	Low	Yes

Table 1: Comparison of Silicon and Gallium Nitride in Inverter Topologies

In addition to ruggedized vehicle inverters, other products will also benefit from the use of GaN devices. Any application that needs a bipolar switching operation where a reverse conducting diode comes into play will do well by applying GaN technology. Specifically, this is true for any high power, galvanically isolated power conversion stage, especially if bidirectional power flow is needed. These applications can capitalize on GaN transistors and, thereby, reduce the size and weight of the transformers and the input and output filter stages and also eliminate the reverse conducting diodes.

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Discharger for Ultra-Capacitor Modules and Assemblies

Ultra-capacitor modules and assemblies are increasing in use for many industrial applications. This has provided many advancements to customer's applications but also challenges for use and service. Specifically discharging of these modules and assemblies has created need to reduce discharge time for safe handling of storage systems for companies. Innovation Plus Power Systems USA, a Maxwell Certified Integrator, has introduced a family of fast dischargers to address these needs.

By Dan Stanton and Mark Shulski, Innovation Plus Power Systems USA

Principle of Operation:
Typical discharging of an ultra-capacitor assembly is done with constant resistance using a power resistor, heatsink and two wire connection. For a fairly high starting voltage this can be a long duration until discharged to a low enough voltage for application of a shorting strap and safe handling, taking hours or even overnight. The Innovation Plus USA dischargers use five resistance levels switched at specific percentages of rated voltage to discharge systems or modules to final discharge completion of 1 volt.

The discharger family is designed to dissipate 1000W at rated voltage, 1200W at 110% of rated voltage. Each unit has simple front panel features:

- DC circuit breaker/switch to disconnect and protect discharger
- On/Off momentary switch
- AC power On/Off switch for fan, control and display circuitry
- DMM panel jacks for monitoring ultra-capacitor assembly voltage
- LED display for operating status

Discharger Features:
The Discharger family consists of 8 units designed for different voltage levels. The voltage ratings with discharge rate (100% rated voltage to 1V) and maximum current are as follows:

- IPA-UCD25010 - 250VDC, 82 second per farad, 10A maximum
- IPA-UCD16010 - 160VDC, 32 second per farad, 10A maximum
- IPA-UCD125013 - 125VDC, 19 second per farad, 13A maximum
- IPA-UCD10016 - 100VDC, 12 second per farad, 16A maximum
- IPA-UCD08020 - 80VDC, 8 second per farad, 20A maximum
- IPA-UCD06025 - 60VDC, 5 second per farad, 25A maximum
- IPA-UCD04830 - 48VDC, 3 second per farad, 30A maximum
- IPA-UCD02030 - 20VDC, 1 second per farad, 30A maximum

The voltage ratings were chosen to optimize discharge time for each voltage rating while utilizing many common components. Higher voltage rated units can be used for a broader range of applications.

All units have a voltage withstand of +/- 300 VDC and isolated from chassis ground. Front panel LEDs will report faults:

- Reverse voltage - blocking rectifier is used to prevent damage
- Overvoltage – voltage above 110% of unit rating
- Overtemperature – unit will cease discharging until heatsink below thermal limit

The input voltage range for operating the fan, control and display circuitry is 100 – 240 VAC and 50-60 Hz.

Thermal management of the discharger is provided by high CFM fan and power module heatsinks can we change to high capacity extruded heatsinks. The fan operation is temperature controlled to

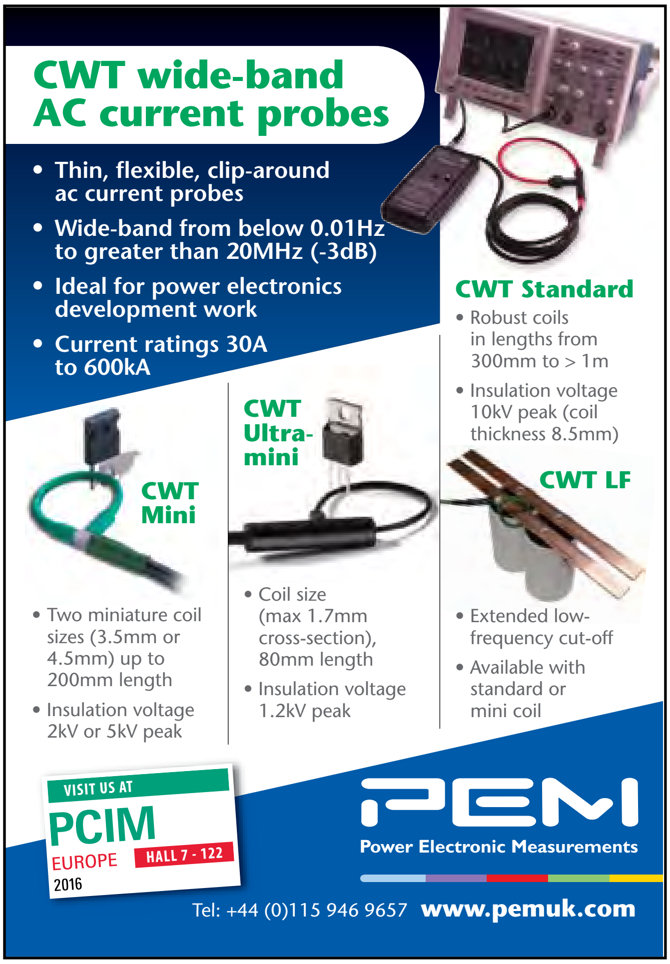
turn-on at a pre-set temperature to reduce noise and extend fan life. Output cables are twist-lock connection 8 AWG, 600 Volt, flexible in Red and Black. Custom mating connectors can be applied to customer end to mate to their module or system. The unit is designed for use in the lab or field and weighs 40 pounds. Internal PC boards are conformal coated. The size of the unit is 11 inches wide by 9-1/4" tall by 16-1/4" long.

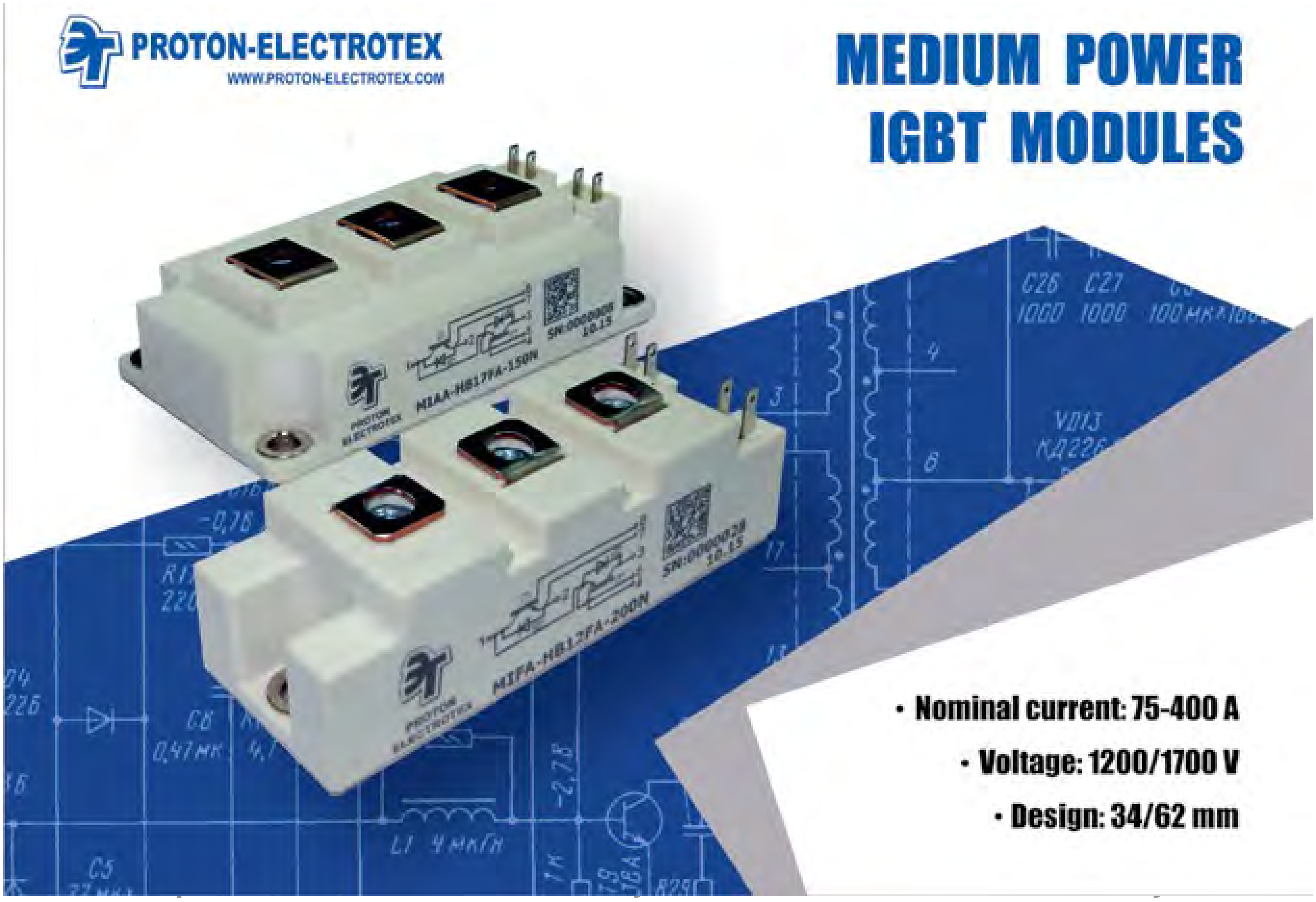
Applications:
The Discharger is designed to be used for production testing of systems utilizing ultra-capacitor technology or field service work for field personnel. Also individual module testing may be performed with the discharger for production or field work.

An example application for sizing would be discharging the Maxwell BMOD0165P048, 165F, 48V module. The 48V discharger can be used (or higher voltage rated discharger). 30A maximum discharge current will result in less than 15 degree C thermal rise within the module – very low thermal rise. 48V discharger will discharge up to 52.8V, which is below the 51V absolute maximum rating of the module. This should be above the 51V absolute maximum rating 165F x 3 sec/F = 8.25 minutes for discharge from 48V to 1V.

Conclusion:
The Innovation Plus USA Discharger is built to provide companies a solution for reliable and safe discharging of ultra-capacitor modules and systems. The five resistance level discharging saves companies time in production as well as field service work. The unit is customizable for output connectors to make easy transition to their system or production needs. Display features keep the user informed of system status and access to safe handling of the ultra-capacitors.

www.innovationplususa.com





Rectiverter Creates New Category of Power System

There are many applications in a variety of industries where there are requirements for both AC and DC power systems. Typically, this has meant customers must source separate power systems from different vendors complete with separate back up systems.

By Gunnar Hedlund, Eltek Rectiverter Product Manager

In other high power density applications – like data centers – operators are looking to be as energy efficient as possible and are transitioning from AC to DC power systems, resulting in a need for both power types.

In these applications, customers want a smaller power system footprint and high efficiency, which makes power density a critical issue. For years, power systems manufacturers have responded to this need by incrementally increasing power conversion efficiency in their own AC and DC systems. The new efficiency standard is 96%, set by Eltek in 2008 with the debut of the Flatpack2 HE system.

This has done a lot to make smaller, more reliable power systems, but has still left customers to manage separate power and backup systems.

Now there's a more revolutionary way to meet the increasing power needs of these applications: the Rectiverter a breakthrough power system that combines a rectifier, inverter and static transfer switch. All of this fits into the current Flatpack2 power shelf, but replaces multiple separate systems that need multiple monitoring systems.

The Rectiverter arguably represents one of the biggest developments in the power electronics industry in many years and offers new levels of design simplicity, flexibility and cost effectiveness.

How a new category of power modules was developed
The Rectiverter came into being quite by accident. My colleague Nils Bäckman, Eltek's R&D manager in Stockholm, tells the story of how his team was tasked with developing a high-efficiency inverter. While working on this task, one of his engineers shared an idea he had for the Rectiverter and that shifted the focus of the entire team and, following that idea, they had a working prototype within several weeks.

Figure 1: Rectifier Image

What they developed was a module with one AC input port, one AC output port and one bi-directional DC port that can accept power input from a battery, charge the battery and also provide power output to the load. In normal operation, the Rectiverter module provides up to 2000W of AC and DC power output. The AC input power is first rectified and then sent either to an inverter to be turned back into AC power, or to a DC/DC converter to be changed to the proper output for the load and the batteries.

The first available Rectiverter module delivers 1500 VA at 230 V AC and 1200 W at 48 V DC. The total capacity of the module is 2000 VA (combined AC and DC). The module achieves >96% efficiency when operating in the mains mode (AC-AC and AC-DC) or >94% efficiency when operating in the inverter mode (DC-AC). Rectiverter systems are available as single-phase or three-phase, input and output.

Bidirectionality is a key breakthrough
The insight that brought about the Rectiverter was the concept of a bidirectional power flow between the three functions inside the module. This capability means that it can control the conversion process in reverse and forward mode and can also can switch instantaneously between either mode of operation.

That's how the module can provide both AC and DC outputs at the same time operating with a single input and a single back up battery plant. In the event of a mains failure, the back up power is seamlessly triggered and the power flow from the DC port is reversed and fed through the inverter to maintain the AC load, while the DC load is fed straight from the batteries.

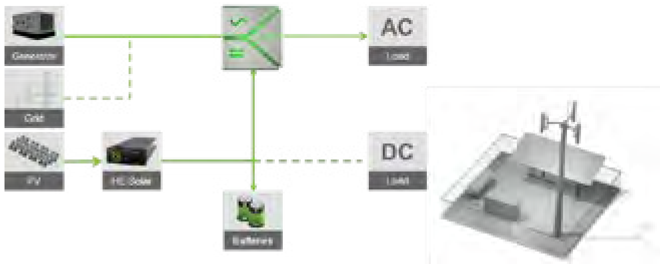


Figure 2: Bidirectionality

From module to system
The Rectiverter module is designed to operate in a redundant configuration in its own power shelves. The 6kVA single-phase power core takes up to four Rectiverter modules, where as the 18kVA 3-phase power core can hold up to 12 modules. The chassis dimensions are very similar to Eltek's existing products so that they have conventional depth and width to be installed in a 19-inch telecom rack. Systems

can contain up to 96 Rectiverter modules and can also be combined with other Eltek power conversion modules with the same DC voltage.

Both power cores also leverage Eltek's Smartpack 2 and Smartpack S controllers that provide advanced management of operational health of all of the modules and of the back-up batteries. In fact, the advanced battery management can help to remotely manage and predict battery capacity loss to ensure the maximum lifetime of each battery. These controllers also monitor other Eltek systems, which provides the ability to combine rectifier, converter and inverter systems with the Rectiverter in flexible ways.

Rectiverter applications
The dual power outputs of the Rectiverter offer exceptional powering flexibility in mixed AC and DC environments. The system can be configured for any power level combination (within the Rectiverter's output capacity). This can save a lot of space in many applications and ultimately reduce the cost of the power system and the ongoing cost of managing the power system.

While the Rectiverter has many markets in which it can add value, some of the initial applications include:

Telecom: Most telecom network locations have a requirement for both AC and DC supply with battery back up to meet laws aimed at maintaining phone service when power is down. The solution in most cases is to install separate DC systems with either inverters or separate AC-UPS'. This is especially true in wireless applications and even emerging small cell and remote radio head applications where space is at a premium, but some key pieces of equipment are AC-based. In these telecom applications, the Rectiverter is both less expensive to purchase and to operate, compared to separate systems, and offers the unified management to simplify monitoring of the power system.

Rail & Metro: In a modern rail system, there are many applications where AC and DC are required. One unique rail application is the level crossing where power systems must include large battery back up capacity to power the crossing during an extended mains outage. Most equipment in these locations is AC, but the batteries need to be charged from a DC system. The system redundancy of the Rectiverter is very attractive in this application, because it can deliver N+1 redundancy compared to the current monolithic UPS alternative that provides only 1+1 redundancy. Here the Rectiverter provides system simplification, improved reliability and reduced total cost of ownership.

Power Utilities: There are many applications in this industry, including powering switchgear, communications, safety and emergency, and automation equipment, where providing a mix of different electricity types and voltage levels is required. In these applications, the Rectiverter system significantly reduces complexity and provides a new level of flexibility for AC and DC output power. By combining the Rectiverter with other DC/DC converters in the same chassis, a single system can be built for these applications that is all controlled by a single system controller.

Marine & Offshore: In a marine application, space is at a premium and so the high power density and combined AC/DC output capabilities of the Rectiverter are very important. A ship can be outfitted differently for each voyage; with the modular Rectiverter system, the load can be scaled up through the hot-swap installation of new modules. This compares with the traditional monoblock UPS, which is not incrementally scalable - the whole system must be duplicated or replaced with a higher output replacement. Another benefit for space-constrained applications is that Rectiverter sparing involves just the modules and not an entire replacement power shelf.

Rectiverter changes the industry
As these examples demonstrate, the Rectiverter is really a breakthrough new product for the power industry. By harnessing the capability for bidirectional power flow, the Rectiverter delivers new flexibility, design simplicity and lower cost for today's applications. But the future impact of bidirectional power technology can only now be imagined in terms of future systems that optimize the energy flow and energy storage to facilitate much smarter and effective power distribution.

http://www.eltek.com/

Neo-Iso™ Power Switch Enables IoT and Industrial Systems Better than Mechanical and Solid State Relays

The electronic and wireless technology market is growing dramatically because of the success of the Internet of Things (IoT). Every day, more systems and electronic devices are now connected to either the Internet or to some kind of communication hub.

By Francois Ricodeau, Semtech

These devices are becoming smarter and are now capable of controlling other systems and loads. A smart thermostat can control the temperature in a building, a security system can unlock a door remotely, or a smart plug can turn on a lamp, a blind actuator, or an industrial tool. These are all examples of IoT with the capability to transduce a command to a load, or more simply said, to drive loads.

Often the load is controlled by a low-power, intelligent system relying on a processor or microcontroller, and often some sort of communication network, either wired, like power line communications, or wireless like WiFi, Z-wave or LoRa®.

These processing and communication systems are designed to be very low energy and need to be protected and electrically isolated from the high-power, high-voltage side of the system with various voltage levels of isolation rating. This is called galvanic isolation, meaning there is no direct electrical connection between the low power control side and the high power side of the system. The isolation is needed for several reasons, but the main idea is to protect the low power side from being damaged by transient voltage from the high power side. Other applications for galvanic isolation are used to protect humans from electric shocks that can result from a component failure. In this case the isolation needs to be rated by IEC standards to several kilo-Volts of isolation.

Emerging IoT applications are driving demand for a new way to protect these devices that is faster, quieter, smaller, more energy efficient and more reliable than today's mechanical relays and opto-couplers. One new innovation that has been developed for these applications is called Neo-Iso™ (TS13101), and it is expected to have a significant impact on IoT and industrial markets.

Electromechanical Relays

The challenge with IoT applications that use high power drive systems is that a galvanic isolation is required between the high power side and the low power side. Before Neo-Iso, systems mainly used legacy technologies like mechanical relays or opto-couplers. They are widely used today to implement isolated power switches of all types, and can range in cost from 20 cents each to much higher depending on the load.

A relay or electromechanical relay makes use of a coil to close or open a switch. The mechanical movement is a source of wear and tear. Additionally, the physical movement of the contact piece creates sparks and carbon deposits leading to a relatively short lifetime for relays. This electromechanical technology is not a fit for today's high-integration and high-reliability needs. Compared to a semiconductor integrated circuit (IC), the size of relays is significantly bigger in all three dimensions, especially in Z-height, preventing integration in low profile products.

Figure 1: Neo-iso-graphic

The relay's power consumption is also too high to meet today's energy efficiency standards and can often drain a system's battery in a short amount of time. Some relays are non-latching and have to continuously be energized with a significant amount of current in order to counteract the spring and maintain the switch in closed position. Some relays address this issue by implementing a bi-stable mechanical system, but it requires the addition of a reset circuitry that increases the cost of the system.

Another issue with using relays is that the slow switching speed of a relay could result in damage to the system before the relay can react to a fault. Also, switching noise generated by relays is rarely desirable in today's modern systems.

While relays have been in use for a long time, they are not so easy to source, especially lately. The scarcity of rare earth materials used in relay construction has created many delivery issues, and significantly increased the lead-time for sourcing relays. In fact, some relays have reached up to one year of lead-time due to the issues sourcing the rare earth material.

Solid-State Relays

Solid-state relays (SSRs) were developed to address the drawbacks of mechanical relays. Because the communication in a SSR is realized by light – through the communication between an LED and a phototransistor – these devices are also called photo couplers. The biggest improvement over a mechanical relay is device size. SSRs can fit in a typical semiconductor package and reduce the Z profile of the end product significantly. SSRs also address the noise issue heard from the mechanical counterpart, and they require relatively short lead-time as they do not rely on scarce materials.

But that is about the extent of SSRs advantages over mechanical relays. While failure rate over time (FIT) is slightly improved compared to a mechanical system, the opto-coupler reliability is still far from acceptable and remains the number one cause of isolated power supply failures today. The isolation rating of an opto-coupler is only slightly better to that of a relay, around 4kV. The advantages in term of performance, power consumption, switching speed, external bill of material (BOM) costs, and active protection capability are non-existent.

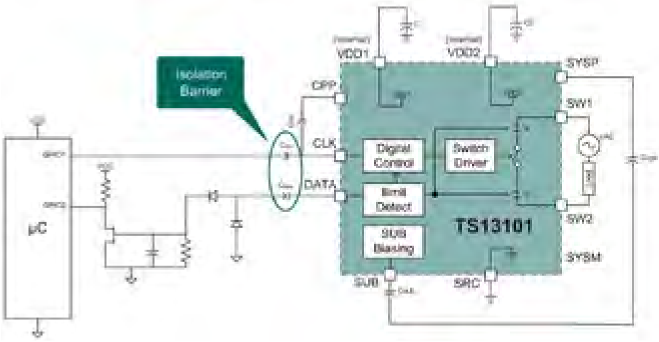


Figure 2: Latching single Channel

Neo-Iso as a New Paradigm

Semtech introduced the Neo-Iso switch to address the drawbacks of both mechanical relays and SSRs. Neo-Iso switches are available in a very small IC package and offer much higher performance than SSRs and relays. Neo-Iso technology provides silent operation. On-state drive currents are as low as 5µA and allow powering the device from a battery or can operate in power harvesting mode using only a fraction of the power from the load.

Neo-Iso solutions are silicon integrated circuits, and the silicon process that is used is not limited by any material sourcing and lead times are usually a few weeks.

The switching speed is three orders of magnitude faster than both relays and SSRs in the range of a few microseconds, delivering a much better ability to switch off a load after fault detection, which greatly improves safety. System reliability is high, as Neo-Iso has been proven on the bench to handle more than 10 million switching cycles.

Overall system reliability is even further improved with the option to switch on or off at zero cross, saving the system from harsh transients. Neo-Iso also features a patent pending bi-directional isolated communication path that provides the control system with switch status, metering and diagnostic information. There is a multitude of targeted applications, but the Neo-Iso is expected to have a significant impact on the world of IoT because of its small size and low power consumption.

Another unique feature of Neo-Iso is the capability to harvest power from the load. When a switch is open, the voltage and energy across the switch is used to power the system. In the case when all the switches in the system are closed, the Neo-Iso implements a control system called dithering during which the switch is forcefully open for a very short amount of time (25us), enough to recover energy, but not long enough to disturb the load. Some versions of the Neo-Iso family can control the dithering automatically while the system microcontroller stays asleep.

Neo-Iso integrates all the rectification and transient voltage suppression capabilities, which are designed to ultimately reduce the board component count.

The new era of wireless communications and impact of electronic systems is now being ushered in thanks to IoT systems. This is driving a fresh look at the technology used for galvanic isolation. With Neo-Iso technology, Semtech is bringing the best of semiconductor technology to what was an electromechanical device, and the features and benefits are ideally suited for this new generation of technology.

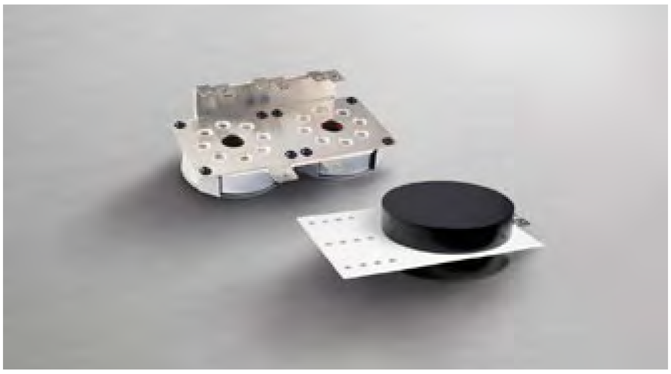
The Neo-Iso TS13101 datasheet is available online at semtech.com. Samples and evaluation boards are available on request.

www.semtech.com

Advanced ROLINX® Capacitor-Busbar Solutions

Rogers Corporation's Power Electronics Solutions group is showing examples of its latest advances in busbar power management technology at the APEC 2016 conference and exhibition (http://www.apec-conf.org).

Visitors to Rogers PES' Booth 1437 had the chance to learn more about the compact design ROLINX® CapEasy and ROLINX® Cap-Performance capacitor-busbar assemblies and their outstanding high current and low inductance capability solution. (www.rolinx.com/index.aspx).



These latest additions to Rogers ROLINX® busbar family have been combined with Power Ring Film Capacitor™ technology from SBE, Inc. (www.sbelectronics.com), resulting in capacitor-busbar assemblies with extremely low inductance and high power density capabilities. These enhanced busbar assemblies enable smaller, lighter electronic designs with higher current handling capabilities in support of a wide range of applications, from automotive electronics to solar-power and wind-power systems.

PES Design Support Hub Resource for Engineers

Rogers PES brings its 40+ years of experience together in a handy online resource that is available 24/7. The PES Design Support Hub features complete technical information on

ROLINX busbars and curamik ceramic substrates, a library of technical papers on product design and problem solving, helpful videos on products and power distribution topics, and PES University training programs. Registration for access is quick and free. The Design Support Hub helps design engineers increase power, manage heat, and ensure the quality and reliability of their devices for optimal new product design.

www.rogerscorp.com/designhub

Clamp AC Current Sensors Expanded for High Current Applications

TDK Corporation has expanded its CCT series of clamp AC current sensors with a new 600 A type. The lineup of TDK current sensors is now positioned to meet the high-current sensing needs of energy management systems (EMS) for buildings, factories, stores and communities. The new CCT406393-600-36 current sensor has a clamp inner diameter of 36 mm and external dimensions of 56 mm x 67 mm x 96 mm. With a current transformation ratio of 3000:1, the output current is 200 mA. Mass production will begin in July 2016.

The new clamp AC current sensor achieves its high current rating thanks to its optimized sensor shape and high-performance ferrite material developed especially for current sensors. Moreover, the CCT series is manufactured with automated winding and soldering processes to ensure high quality.

With the addition of this new component to a current sensor lineup that already includes a 300-A (24 mm inner diameter), 100-A (16 mm) and 30-A (6 mm) types, TDK offers a comprehensive portfolio of clamp AC current sensors for a wide range of currents.

www.global.tdk.com/

1-2W Medical DC/DC Converter G/H Series

MORNSUN recently released new 1W/2W DC/DC Converter G/ H series targeting medical, which meet medical design standard EN60601-1 and ANSI/AAMI ES60601-1 3rd Edition (1xMOPP/2xMOOP).

Both creepage and air clearance of the transformer are 5mm, and 5.5mm for PCB. The isolation voltage is as high as 4200VAC (6000VDC), which is 40% higher than standard voltage (3000VAC) of 2×MOOP. Moreover, patient leakage current is less than 2µA, which greatly ensures the patient's safety.

G/H series operate high efficiency up to 84% to save energy effectively. They have a compact dimension of SIP7(19.50*9.80*12.50mm) and provide an input voltage range of 5 to 24VDC and 5, 12, 15, ±5, ±9, ±12, ±15VDC output voltages. They are not only suitable for medical applications but also others such as power grid and IGBT driver.

Specifications:

- Isolation voltage as high as 4200VAC (6000VDC)
- Low leakage current ≤2µA
- High efficiency up to 84%
- Operating temperature range: -40°C ~ +85°C
- Meets EN60601-1, ANSI/AAMI ES60601-1 standards 3rd Edition (1xMOPP/2xMOOP)

www.mornsun-power.com

Supercapacitor-Based Energy Storage Modules

Power management company Eaton announced the XLR Supercapacitor Energy Storage Module designed to provide high reliability, long life and maintenance-free operation in systems requiring frequent high-current charge and discharge cycles in outdoor, rugged or high vibration and shock environments. As safer alternative to batteries, XLR Modules are designed for maintenance-free, up to 20-year lifespans to reduce the total cost of ownership of energy storage for applications such as microgrid systems; diesel-hybrid and electric busses, subways, trolleys and trains; hybrid power systems with fuel cells; seaport cranes and maritime equipment; forklifts, heavy construction and mining equipment.

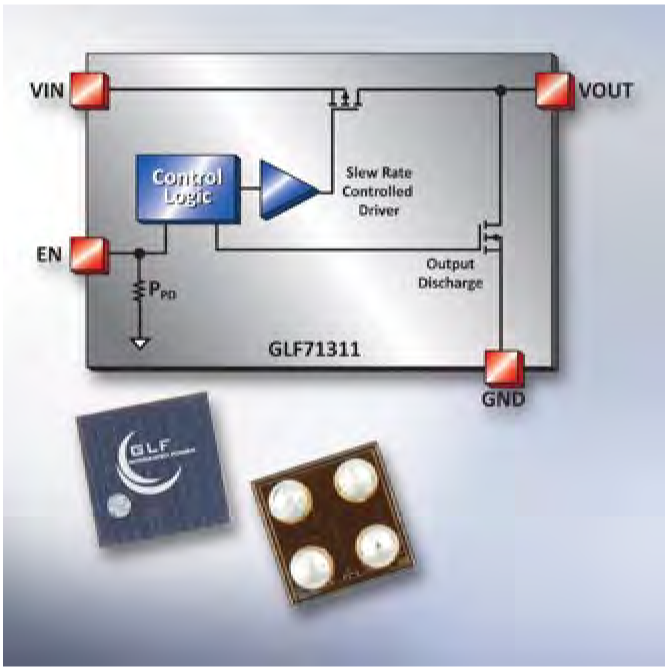
"Supercapacitor-based modules are seeing high interest in several outdoor industrial and transportation applications because system operators are averse to the high costs and safety issues associated with batteries used for energy storage," said Jason Lee, global product manager, Eaton's Electronics Division. "Eaton Supercapacitor Modules are designed to last up to 20 years, with more than one million charge and discharge cycles, thereby reducing system cost over the lifetime of the application. The XLR is specifically designed to be installed in environments with wide temperature variations and high vibrations common on vehicles and heavy equipment."

www.eaton.com/electronics

IQSmart™ Load Switches Extend Battery Life in Wearable Applications

GLF Integrated Power, Inc., an emerging leader in efficient power switch technology, announces mass market release of the first product in its IQSmart™ line of high-performance load switches. The GLF71311 load switch offers these best-in-class features: an off-state leakage current (ISD) of 5 nA, typ., at 3.3 VIN; a logic operating current (IQ) of less than 10 nA, typ., up to 5.5 V; and an on-state resistance (RON) of 34 mOhms, max, at 5.5V and 41mOhms (max) at 3.3V. Add to this a tiny 0.97 by 0.97mm form factor, and designers now have an ultra-efficient alternative for improving power efficiency in their wearables, mobile medical devices and other battery-powered devices that is significantly better than competing load switches – and dramatically better than using discrete devices.

The GLF1311 load switch's 5 nA off-state leakage is best in class. This is important since a load switch saves power by turning off power-hungry subsystems when not in use. To maximize efficiency, the system must be "really" off, and off-state leakage, or ISD, is a measure of just how off a system is. The lower the ISD, the less power is wasted in the off state. The GLF1311 load switch's typical off-state leakage is up to 50 times lower than the nearest competitive load switch device. It also has half the on-state resistance and exhibits as much as 700 times lower logic operating current. These features combine to reduce both power dissipation and battery drain compared with other fully integrated load switches.



www.glfipower.com

15 MHz Half-Bridge Development Boards Use eGaN FETs

Efficient Power Conversion Corporation Introduces the EPC9066, EPC9067, and EPC9068 development boards, which are configurable to a buck converter or as a ZVS class-D amplifier. These boards provide an easy-to-use way for power systems designers to evaluate the exceptional performance of gallium nitride transistors, enabling the designers to get their products into volume production quickly.

All three boards feature a zero reverse recovery (QRR) synchronous bootstrap rectifier augmented gate driver to increase efficiency at high frequency operation, up to 15 MHz. The boards can produce a maximum output of 2.7 A in the buck and ZVS class-D amplifier configurations. Loss reduction is realized across the entire current range.

The EPC9066/67/68 feature 40 V, 65 V, and 100 V-rated eGaN FETs respectively. These boards are 2" x 1.5" and are laid out in a half-bridge configuration. Each board uses the Texas Instruments LM5113 gate driver with supply and bypass capacitors. The gate driver has been configured with a synchronous FET bootstrap circuit featuring the 100 V, 2800 mΩ EPC2038 eGaN FET, which eliminates the driver losses induced by the reverse recovery of the internal bootstrap diode. The boards have various probe points and Kelvin measurement points for DC input and output. In addition, the boards provide the capability to install a heat sink for high power operation.

The operating load conditions, including configuration, of the development board determine the optimal design load voltage and resistance, resulting in a specific board's performance. Quick Start Guides, containing set-up procedures, circuit diagram, bill of material and Gerber files for the boards are provided on-line at http://epc-co.com/epc/Products/DemoBoards.aspx

Price and Availability The EPC9066/9067/9068 are priced at $158.13 each and are available for immediate delivery from Digi-Key at http://www.digikey.com/Suppliers/us/Efficient-Power-Conversion.page?lang=en

www.epc-co.com

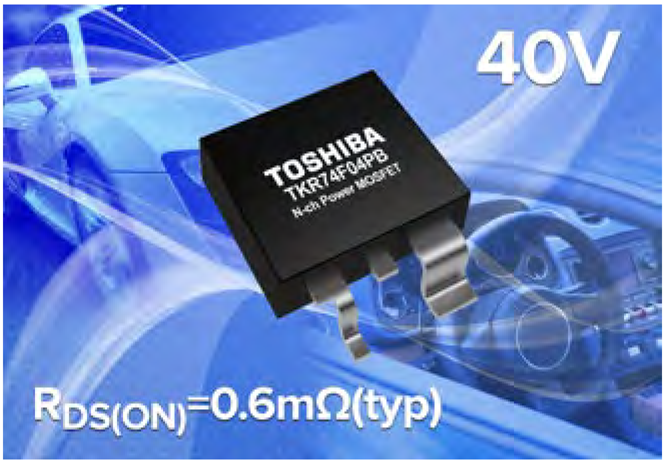
Fully-Qualified 650V GaN FET with the Lowest R(on) in a TO-247

Transphorm Inc. introduces the TPH3207WS GaN field effect transistor (FET) with the lowest on-resistance (41 mOhm) in a TO-247 package that reduces system volume as much as 50% without sacrificing efficiency. The device's low Rds(on) and ultra-low Qrr (175nC) bring the benefits of GaN to applications that previously relied on silicon, enabling engineers to achieve power-dense solutions with reduced component count and improved reliability in high-voltage power conversion applications.

The TPH3207 improves system reliability, performance and power density in an easy-to-handle cascode configuration. These advantages are being realized in hard-switched bridges and the continuous conduction mode (CCM) bridgeless totem-pole power factor correction (PFC) designs being used in on-board chargers, solar inverters, telecom power supplies and other power conversion applications. Transphorm's GaN FET portfolio is also strengthened with the introduction of the TPH3208 family (130 mOhm) in industry-standard TO-220 and PQFN packages, further enabling the GaN revolution.

www.transphormusa.com

40V N-ch Low ON-Resistance Power MOSFET for Automotive



Toshiba Electronics Europe has expanded its line-up of automotive power MOSFETs with a new 40V N-ch housed in the low on-resistance TO-220SM(W) package. The TKR74F04PB is ideal for a variety of high power automotive applications, including DC-DC converters, EPS (Electric Power Steering) and load switches.

TKR74F04PB achieves an industry-leading[1] low RDS(on) in the automotive 3-pin SMD package market. Its low RDS(on) of typ0.6 / max0.74 mohm was realised by combining Toshiba's latest 9th generation trench MOS 'U-MOS IX' process with Toshiba's unique TO-220SM(W) package. TO-220SM(W) has a wider and shorter source pin than conventional D2PAK (TO-263) packages and contributes to the PCB size reduction with a smaller foot print.

TKR74F04PB will conform to AEC-Q101 automotive level qualification requirements.

www.toshiba.semicon-storage.com

WaveRunner 8000 Oscilloscopes add OneTouch Gesture Control

Teledyne LeCroy introduces the WaveRunner 8000 oscilloscopes with bandwidths from 500 MHz to 4 GHz, which deliver an extensive toolbox coupled with a superior user experience to expedite solving debug problems. WaveRunner 8000 has the industry's widest and deepest collection of tools, making it unbelievably powerful. WaveRunner 8000 marks the debut of the next-generation MAUI advanced user interface,

bringing enhancements to the oscilloscope industry's premier UI. The addition of OneTouch to MAUI makes measurement setup incredibly easy, speeding up dramatically the time to insight into complex signal abnormalities.

The standard collection of math, measurement, debug, and documentation tools provides unsurpassed analysis capabilities. Application-specific packages enable streamlined debugging for common design/validation scenarios. Options include digital filtering, spectrum analysis, device and switching power supply analysis, and more. The advanced customization option enables user-defined parameters and math functions providing unique and limitless analysis capability. The WaveRunner 8000 has the greatest breadth and depth of tools, ensuring quick resolution of the most complicated debug tasks.

The WaveRunner 8000 and MAUI with OneTouch extends Teledyne LeCroy's long tradition of user-interface innovation. MAUI with OneTouch optimizes convenience and efficiency by enabling all common operations with a single touch of the display. MAUI with OneTouch has revolutionary drag-and-drop actions to copy and set up channels, math functions, and measurement parameters without lifting a finger. Common gestures such as drag, drop, pinch, and flick facilitate instinctive interaction with the oscilloscope. The "Add New" button quickly enables a new channel, math, or measurement while traces and parameters turn off with a flick of a finger. MAUI with OneTouch delivers a unique set of touchscreen gestures that simplifies measurement setup and brings unsurpassed efficiency and intuitiveness to oscilloscope operation.

http://teledynelecroy.com

High Frequency Motor Drive Common-Mode Currents

Accurate non-contact current measurement helps counter threat of damage to motor bearings and subsequent drive. Motor installers and design engineers can deal more effectively with high frequency (hf) common-mode currents caused by variable-frequency drives, using the latest non-contact current probes from Power Electronic Measurements (PEM) Ltd.

The new CMC series of current probes, using Rogowski technology, empower engineers to assess the magnitude of the threat posed by hf common-mode currents, that can damage motor bearings and interfere with nearby electrical equipment. The current measurements can help determine suitable corrective action, such as fitting brushes, insulated bearings, or choke coils, and with further measurements assess the effectiveness of the chosen remedy.

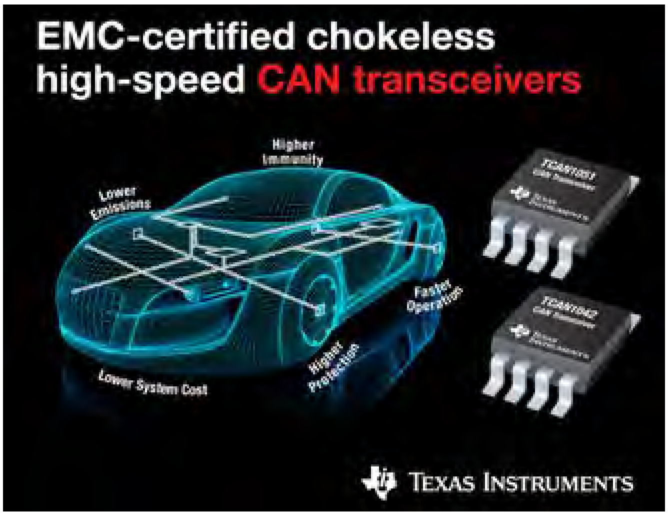
The screened coils have excellent immunity to voltage disturbances and a low frequency (-3dB) bandwidth that attenuates unwanted 50/60Hz magnetic fields while maximising the SNR of the measurement of the high frequency common mode currents. Available in coil sizes from 300 to 1000mm, and longer if required, making them ideal for use with a wide range of motor shafts. Even with a coil circumference of 1000mm the CMC probes can achieve a high frequency (-3dB) >10MHz.

The probes are available in three sensitivity grades for measuring bearing currents up to 37.5A, 75A or 150A peak. The peak detected current corresponds to a maximum output voltage of ±7.5V when connected to an oscilloscope input via the BNC output provided.

www.pemuk.com/products/cmc-probe.aspx

Chokeless High-Speed CAN Transceiver Families

Texas Instruments introduced two families of controller area network (CAN) transceivers that meet all industry requirements for electromagnetic compatibility (EMC) from U.S. and European automotive manufacturers. Delivering high bus-fault protection, fast CAN flexible data rate (FD) speeds and the industry's shortest loop delay, the TCAN1042 and TCAN1051 CAN transceiver families provide the industry's best combination of protection and high performance for a variety of automotive and industrial applications.



Compliance with EMC standards from leading international organizations: The 16 Automotive Electronics Council (AEC) Q100-qualified devices meet EMC requirements for automobile manufacturers in the United States (Society of Automotive Engineers [SAE] J2962) and Europe (Ingenieurbüro für Industrielle Elektrotechnik [IBEE]-Zwickau). The eight industrial devices meet the requirements of the Comité International Spécial des Perturbations Radioélectriques (CISPR) 22, International Electrotechnical Commission (IEC) 61000-4-6 up to 10 V, IEC 61000-4-4 Criteria A to ±4 kV, and IEC 61000-4-3 from 80 MHz to 2.7 GHz up to 100 V/meter.

The devices eliminate the need for an external noise-suppressant common-mode choke component, thereby reducing bill-of-materials cost and space in automotive and industrial designs.

High bus-fault protection up to 70 V exceeds 12-, 24- and 48-V battery requirements, in addition to protecting against 24-V DC industrial power supplies. This protects CAN bus pins against short-to-DC voltages. ESD protection up to ±15 kV eliminates the need for external transient voltage suppression (TVS) diodes, saving board space and cost.

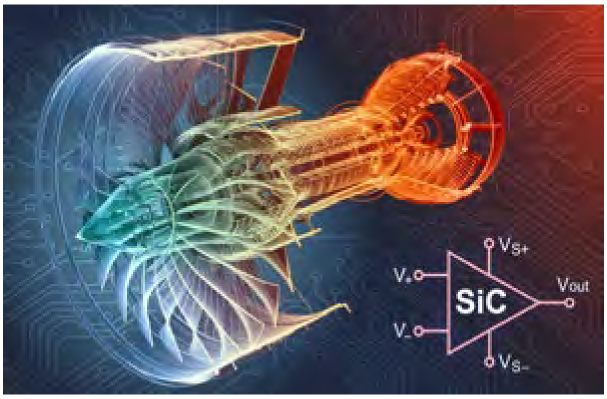
A fast CAN FD speed of up to 5 Mbps increases the communication speed and data-transfer capability between electronic control units and nodes on the CAN network.

The industry's shortest loop delay of 175 ns enables more margin in the system design, longer networks and more nodes on the CAN bus.

www.ti.com

Silicon Carbide Based Analogue Circuitry for use in High-Temperature

Raytheon UK's Semiconductor's business unit and Newcastle University's School of Electrical and Electronic Engineering have collaborated to produce Silicon Carbide based amplifier circuitry with Operational Amplifier (Op Amp) like characteristics. The amplifier, once integrated and packaged into a single device, has the potential for use in monitoring and closed-loop control circuitry applications within a variety of harsh environment industries; such as aerospace, oil and gas, geothermal energy and nuclear.



"To date, the focus on Silicon Carbide semiconductors has been power electronics and exploiting the material's ability to dissipate internally-generated heat," says Dr Alton Horsfall, the Reader in Semiconductor Technology at Newcastle University. "For this project though we've focussed on creating circuitry that can operate in high temperature and other harsh environments. This could therefore lead to condition monitoring circuitry mounted on gas turbines or within the primary coolant loop of a nuclear reactor, which runs at about 350oC."

At the heart of the amplifier circuit is a lateral small-signal Junction Field Effect Transistor (JFET). This offers a significant improvement in reliability in hostile environments, because of the lack of a gate oxide layer. This results in a greater stability in the threshold voltage and a reduction in the intrinsic noise, making these structures ideally suited for the realisation of high temperature, low noise amplifier circuits. The current circuit is a fully differential, three stage amplifier.

Laboratory tests have shown the amplifier circuit has an open circuit gain in excess of 1500 at room temperature. A high temperature gain of 200 has been recorded at 400°C, but this is limited by the passive components used in the circuit.

The recent monolithic integration of the amplifier into a single chip will deliver the kind of Op Amp capabilities with which electronics engineers the world over are familiar.

Phil Burnside, Business Development Manager of Raytheon UK's Semiconductors Business Unit, comments: "Though we're not the only ones to be exploring the suitability of Silicon Carbide for control and monitoring applications in harsh environments, we believe this amplifier circuit represents the furthest anyone has gone down the lab-to-fab route. In this instance, it is Newcastle University's design expertise and understanding of harsh environments, combined with our Silicon Carbide processing expertise, that have the potential to result in the full commercialization of a high temperature version of a fundamental electronic building block, the humble Op Amp."

A technical demonstrator of the amplifier circuit will be on Raytheon UK's stand (134 in Hall 6) at PCIM Europe - Nuremberg, 10th to 12th May. In addition, Raytheon UK is on a panel session, organised by Yole Developments, regarding the use of power electronics in high temperature applications, on 11th May (from 10:00 to 12:00) at PCIM Europe, Industry Forum Area (Hall 6, stand 248)

Raytheon UK and Newcastle University have produced Silicon Carbide based analogue circuitry for use in high-temperature and harsh environment monitoring applications.

www.raytheon.com

High-Accuracy, High-Isolation, Differential Current Sensor ICs

Allegro MicroSystems Europe announced two new current sensor ICs that are economical and precise solutions for AC or DC current sensing. These devices are ideal for use in industrial, commercial, and communication systems that require very high voltage isolation.
Both the ACS724KMA (5 V) and the ACS725KMA (3.3 V) are available in a very small package that is ideal for space-constrained applications, that also saves cost through reduced board area. They are packaged in a high-isolation SOIC16 wide body surface mount package that provides reinforced isolation. The differential sensing technology provides immunity to interfering common mode magnetic fields from adjacent current traces or motors. Typical applications include

motor control, load detection and management, switched-mode power supplies, and overcurrent fault protection.
Both devices consist of a precise, low-offset, linear Hall sensor circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage. The current is sensed differentially in order to reject common-mode fields, improving accuracy in magnetically noisy environments.
The inherent device accuracy is optimised through the close proximity of the magnetic field to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which includes Allegro's patented digital temperature compensation, resulting in extremely accurate performance over temperature.

www.allegromicro.com

Precision ALD EPAD Enhancement Mode Arrays

Advanced Linear Devices Inc. (ALD) announced the industry's first high-precision quad P-Channel EPAD® MOSFET array ALD310708A and ALD310708 designed for next-generation sensor circuits used in portable instruments. The devices enable revolutionary precision and low power operation in circuit designs for current mirrors, sources and oscillators that will greatly enhance the sensitivity and accuracy of portable test and detection equipment.

The P-Channel EPAD Enhancement Mode MOSFET Arrays are designed for the rapidly growing Internet of Things (IoT) platforms and backup power applications as well as a variety of other analog and digital electronic systems requiring ultra-precise sensing and detection abilities. These MOSFET arrays will allow highly precise circuitry needed to make portable instruments as precise and effective as much larger and more sophisticated laboratory instruments.
The A-Grade ALD310708A enables a gate threshold of -0.80V, which enables circuit designs with operating voltages as low as 0.80V. This ultra-precise grade offers a maximum offset voltage of 2 Millivolt, as opposed to the standard grade ALD310708, which has the same gate threshold but offers an offset voltage of 10 mV.

http://www.aldinc.com/

Game-Changing Highest Efficiency, Lowest Profile LED Driver ICs

Arctic Sand Technologies, the performance and space saving leader in power conversion ICs, launched its ARC1C0608 IC – a 'triple-play' delivering industry leading power conversion efficiency, in the lowest 'z' height profile and smallest footprint in the industry. The ARC1C0608 is an LED driver that is so efficient that it is able to save 0.5W (in a typical 2 W host platform) when deployed in backlights for tablets and other smart mobile devices, thus enabling a new generation of low power, long battery life, ultra-thin devices.

Arctic Sand is a spin-out of MIT with technology based on exclusively-licensed MIT patents co-authored by Arctic Sand's founder and Chief Scientist David Giuliano, as well as many new Arctic Sand-issued patents. Arctic Sand IC's feature TIPS (Transformative Integrated Power Solution) a patented 'staged pipeline' architecture that effectively reduces dependence on inductance, inherently lowers EMI and ripple and uniquely enables ultra-low profile solutions with industry-leading power conversion efficiency performance – addressing key pain points for mobile computing and data centers.

The ARC1C0608 LED driver has six integrated programmable current sinks, integrates all MOSFETs, its control and driver circuitry, and features state of the art dimming options within a tiny WLCSP-35 package. The TIPS™ boost architecture delivers LED efficiency levels of 93.5% peak for up to six LED strings at 3.8V input voltage.

www.arcticsand.com

2nd Generation of Corona-Free Custom Magnetics Solutions

Bicron Electronics Company, manufacturer of high-reliability, custom magnetics, is pleased to announce the latest advance in its line of VoltBoss™ corona-free transformers. Corona bloom, a corrosive effect of partial discharge, is a leading cause of failure in magnetics components. The new, 2nd generation of VoltBoss™ transformers have been developed to eliminate corona failure (dielectric breakdown) for voltages up to 4.5kV in a heretofore difficult to obtain 1 sq. in. footprint. This technology, frequently misunderstood as only applying to large, high voltage magnetics devices, is equally important in smaller magnetics devices in operating environments as low as 300V employed in equipment that must operate reliably over their lifetime – often decades. This new transformer platform measuring just over 2 cu. in and weighing just 2.5 oz. achieves a partial discharge specification of the unheard-of level of <10 pC @ 4.5 kV.

www.bicronusa.com

Industrial and Three-Phase Power Supply Applications with New 900 V InnoSwitch-EP ICs

Power Integrations announced the addition of a 900 V device to its InnoSwitch™-EP family of off-line CV/CC flyback switcher ICs. The new device targets power supplies operating from high-voltage DC and three-phase power sources found in industrial, motor-drive, metering and renewable energy applications, and standard mains-voltage applications where continuous operation during line swells and surges is required. The 900 V InnoSwitch-EP ICs are highly efficient – typically 85% for a dual output 18 W design – eliminating heat sinks and enabling highly compact power supply implementations.

The 900 V InnoSwitch-EP ICs feature an uprated, integrated 900 V power MOSFET which provides a significant operating margin for 450 VAC industrial systems, increasing reliability and operational life. Working continuously with an input voltage of up to 450 VAC, an optional layer of protection - line UV/OV – prevents the IC from switching and protects the circuit up to 650 VAC. This flexibility is a huge benefit for designers of power supplies that suit all worldwide conditions.

www.power.com/innoswitch-ep

Diode Phase-Leg Module with Record Current Rating

IXYS Corporation announced the expansion of its standard rectifier module portfolio for diode phase-legs in the Y4 package (34mm) outline. The Y4 (34mm) package is an IXYS DCB based module with the highest performance in thermal behavior and power density. A wide range of controlled and uncontrolled rectifiers for one and three phase applications are already provided by IXYS in that housing class.

This latest addition to the portfolio of diode phase-legs in an Y4 (34mm) package outline offers a drastic improvement in current density. Until now the most powerful diode phase-leg offered in a 34mm package type provides a permanent current of 224 Amps at a case temperature of 100 degrees C. With the new IXYS 34mm modules, this value increases by 25% to 280 Amps. This results in the highest power density in the package range of 34mm housings available in the market and can be used as an alternative to several diode phase-leg types in the next bigger package class, the Y1 (50mm).

http://www.ixys.com

Advertising Index

April 2016

Power MOSFET

Products that Reach New Efficiency Dimensions

ST's MOSFET portfolio offers a broad range of breakdown voltages from -500 V to 1700 V, with low gate charge and low on-resistance, combined with state-of-the art packaging. ST's process technology for both high-voltage MOSFETs (MDmesh™) and low-voltage MOSFETs (STripFET™) has enhanced power handling capability, resulting in high-efficiency solutions.

LV: low-voltage MOSFETs (STripFET™) – below 200 V breakdown voltage, H7 & F7 family, best in class EMI
HV: high-voltage MOSFETs (MDmesh™) – M2 family, DM2 with intrinsic fast body diode or M5 family for very low RDSon
VHV: very high-voltage (MDmesh™) – K5 family, the market reference from 800 V up to 1700 V
SiC: 1200 V, for highest efficiency applications, stable low Rdson over whole temp range till 200 degC!

30 V to 120 V	400 V to 700 V	600 V	550 V - 650 V	800 V ... 1700 V
F7 H7	M2 M2-EP M6	DM2	M5	K5
Motor Drives Sync.R/DC-DC	Flyback PFC/ LLC Resonant	ZVS / FB & HF	Hi-End PFC, Hard switching topologies Flyback / Two Transistors Forward	Flyback
Fork Lift Electric Vehicles Power Tools / Fans	Chargers / LED Lighting	Solar Inverters, UPS, HEV	Solar Inverters, UPS, HEV	LED Lighting Aux Power Supply
				LED Driver / Metering

- STH310N10F7-6
- 100 V
- RDS(on) 2.3 mΩ

- STF25N60M2-EP
- 600 V
- RDS(on) 0.188 Ω & Qg 29nC

- STY145N65M5
- 650 V
- RDS(on) 0.015 Ω

- STW21N150K5
- 800 V up to 1700 V
- RDS(on) 0.9 Ω, Qg 89nC

App Store Google play

ST MOSFET Finder APP

Get the right MOSFET for your application with a touch on your screen!

EBV University

Learn how to select easily active devices for an efficient PFC stage on this free webinar!
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Fore more information, please visit **www.ebv.com/st-power**.

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April 2016

SiC MOSFET

The Real Breakthrough in High-Voltage Switching

KEY FEATURES

- Very low switching losses
- Low power losses at high temperatures
- Higher operating temperature (200 ˚C)
- Best in class RDSon stability over full temperature range
- Easy to drive

KEY BENEFITS

- Smaller form factor and lighter systems
- Reduced size/cost of passive components
- Higher system efficiency
- Reduced cooling requirements and heatsink size

TARGETED APPLICATIONS

- Solar inverters
- High-frequency power supplies
- Motor drivers
- High Power Applications and HEV Chargers

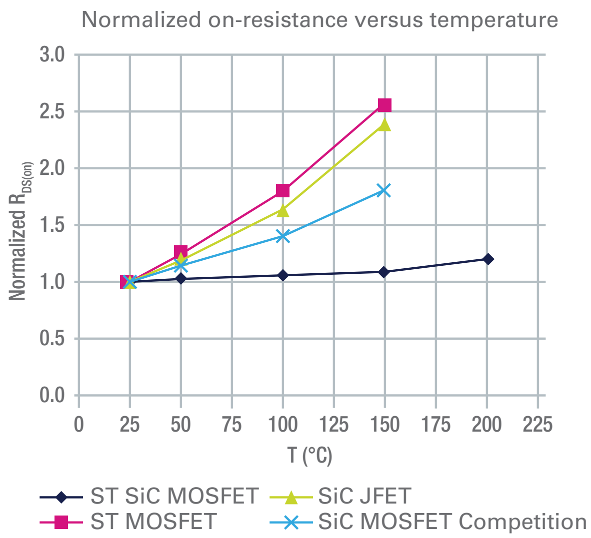
SWITCHING LOSS COMPARISON

Device	V_{ON} typ (V) @ 25 °C, 20 A	V_{ON} typ (V) @ 175 °C, 20 A	E_{ON} (µJ) @ 20 A, 900 V 25 to 175 °C	E_{OFF} (µJ) @ 20 A, 900 V 25 to 175 °C
SiC MOSFET	2	2.4	725/965(*)	245/307
IGBT	1.95	2.35	2140/3100	980/1850

Note: * E_{ON} measured using the SiC intrinsic body diode

+ 30% at 175 °C   + 90% at 175 °C

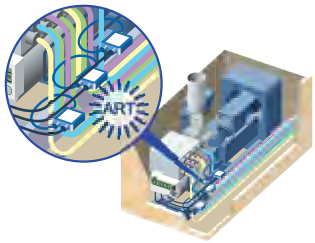
ON-RESISTANCE VARIATION VERSUS TEMPERATURE



Part number	BV_{DSS}	$I_{D(max)}$ @25 °C	$R_{DS(on)}$ (typ) @ 20 V	Total gate charge Q_g (type)	$T_{j(max)}$	Package
SCT30N120	1200 V	45 A	80 mΩ	105 nC	200 °C	HIP247™
SCT20N120	1200 V	20 A	169 mΩ	45 nC	200 °C	HIP247™
SCT50N120 *	1200 V	65 A	52 mΩ	126 nC	200 °C	HIP247™
SCT10N120 *	1200 V	12 A	520 mΩ	21 nC	200 °C	HIP247™

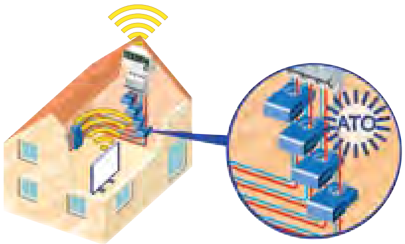
Full release in May 2016

LEM City APPLICATIONS



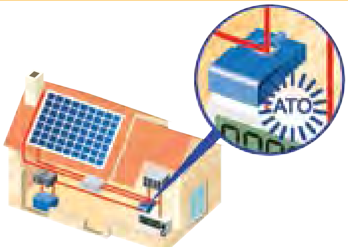
→ Power Generator

The electricity is conducted to the network and measured at the output of the generator through the ART current sensors, which are connected to the energy meter.



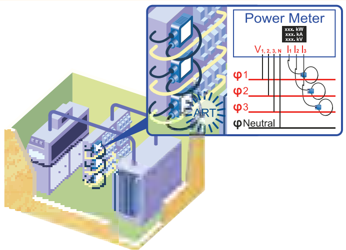
→ Home Energy Management (HEM)

HEM with ATO current sensors to inform the occupants of their energy use by displaying the result of these measurements in order to better control consumption.



→ Battery Monitoring System (BMS)

Automated, compact and simple to install, home energy storage with BMS + ATO current sensors allows independence from the grid, emergency backup and avoiding peak demand rates.



→ MV/LV Substation

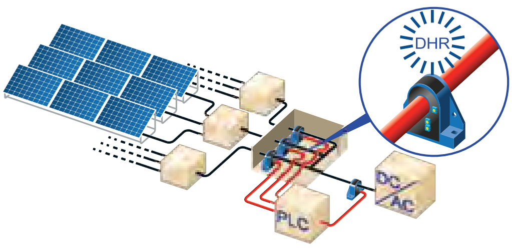
A Smart Meter installed in the LV panel measures the transformer's health with non-intrusive ART current sensors allowing safe commissioning on a "live" transformer.

→ Submetering

To reduce the electricity consumption in a building, the Wi-LEM (EMN+ATO/ART) energy solution provides site managers and users with the power consumption of equipment, departments, floors, buildings...

→ EV Charging Station

The challenge is to provide fast charging without stressing the energy grid with multiple AC-DC chargers. The charger uses the ATO sensor to measure the AC current.



→ Solar Power Plant

The detection of any defective solar string, reducing the total output of the installation, must be made in real time. A simple way to detect this is to check the current produced by each group of strings with the DHR transducer.


SENSING FOR SMARTER CITIES
LEM, at the heart of our planet's energy measurements.
LEMcity™ www.lemcity.com
www.lem.com
At the heart of power electronics.
LEM®

New Advanced High Power Thyristors

High Power, High Reliability

Utilising the latest low temperature sintering technology, IXYS UK is proud to present it's newest large area thyristors.

Comprising four phase control and one fast thyristor utilising distributed gate technology, this range is manufactured using a 96mm silicon die, alloyed to a metal disc and encapsulated in fully hermetic ceramic packages with thicknesses of 26mm or 35mm.

These new designs benefit from an increased electrical performance in a smaller package than older designs as well as improved thermal performance giving them a higher current density.

Part No.	V_{DRM}/V_{RRM} V	I_{TAV} A	I_{TSM} kA	V_{T0} @T_{JM} - 125°C V	r_T mΩ	R_{THJK} DSC K/W
N4165EE400	4000	4165	56.0	0.977	0.177	0.006
N4165EE450	4500					
N4650EA400	4000	4650	56.0	0.977	0.177	0.005
N4650EA450	4500					
N5715EE240	2400	5715	80.0	0.84	0.085	0.006
N5715EE280	2800					
N6405EA240	2400	6405	80.0	0.84	0.085	0.005
N6405EA280	2800					

Part No.	V_{DRM}/V_{RRM} V	I_{TAV} A	I_{TSM} kA	t_q µs	V_{T0} @T_{JM} - 125°C V	r_T mΩ	R_{THJK} DSC K/W
R5370EA18x	1800	5370	70.0	70-100	1.661	0.071	0.005
R5370EA22x	2200						

Typical applications for phase control thyristors include:

- Industrial drives
- Wind Power Converters
- Sort Starters
- Excitation
- Controlled rectifiers
- UPS Systems
- DC Drives

Typical applications for distributed gate thyristors include:

- Induction power supplies for:
  - Melting
  - Billet Heating
  - Surface conditioning
- Resonant power supplies
- Pulsed power

Efficiency Through Technology

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This new 3kA device maximises the current rating within the same package envelope as our existing 2.4kA device and is available as an asymmetric blocking, IGBT only device or with a fully integrated, anti-parallel diode with asymmetrical current rating.

These IGBT's are suitable for applications ranging from ten megawatts up to and above several hundred megawatts.

Typical Applications Include:

- Medium voltage drives for industrial, marine & renewable energy infrastructure applications including wind generation.
- Energy Utilities including STATCOM, FACTS, Active VAr controllers and renewable generation

	Part No.	$V_{DC\ link}$ V	$V_{CE(sat)}$ V	$I_{C(DC)}$ A	I_{CRM} A	E_{on} @I_C J	E_{off} @I_C J	Diode V_F V	R_{THJK} IGBT K/W	R_{THJK} Diode K/W	T_{JM} °C
New	T2960BJ45E	2800	4.00	2960	5920	16	16	N/A	0.0042	N/A	125
New	T1935BJ45G	2800	4.00	1935	3870	7	12	3.80	0.00645	0.0096	125
Established	T2400GB45E	2800	3.60	2400	4800	13	13	N/A	0.0052	N/A	125
Established	T1800GB45A	2800	3.60	1800	3600	11	10.5	3.90	0.0073	0.0144	125

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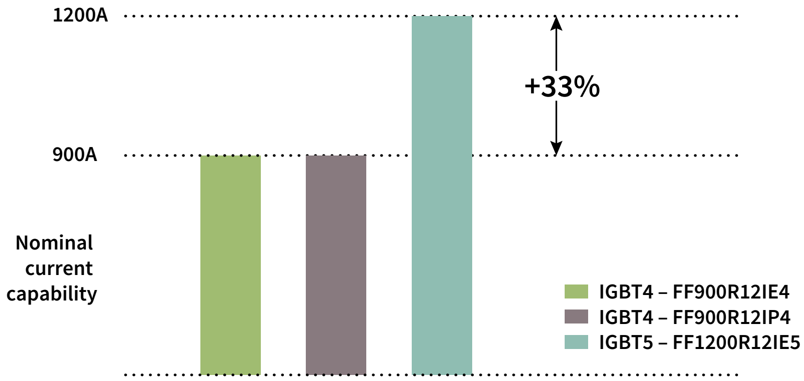

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