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# Bodo´s Power Systems®

Electronics in Motion and Conversion

May 2019

# Leading-Edge Power Modules for the New Era in Traction Converters

› Infineon at PCIM in hall 9

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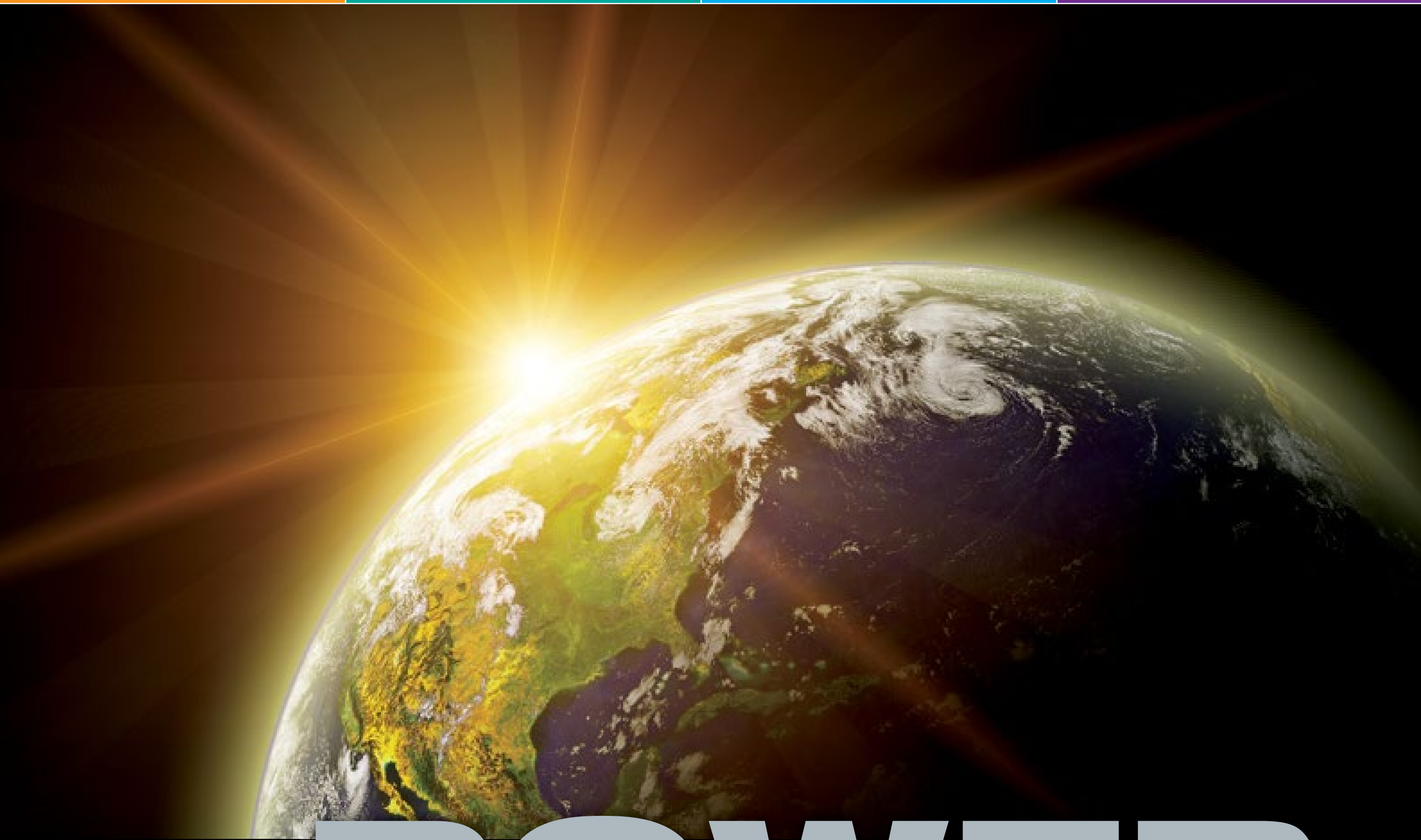

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GvA Power Electronics

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CONTENT

# The Gallery


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**PCIM Europe Hall 7 Booth 229**

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For further information, please visit: **www.we-online.com/coupled**

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- Large portfolio

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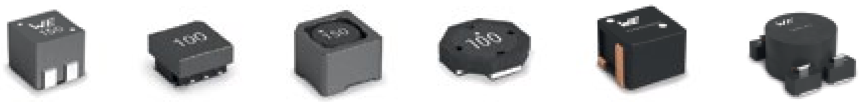

WE-MCRI | WE-CPIB HV | WE-EHPI | WE-TDC | WE-CFWI | WE-DCT

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www.bodospower.com

# Asparagus Time Again!

The weather is friendly and the asparagus is growing just fine
- we had our first meal last week -

PCIM must be just around the corner ! For the last thirty years the conference and show have been hosted in Nuremberg. Before that, PCIM Europe was in a different location every year. I remember one of the early conferences in Munich - with table top booths for companies in the parking lot of the hotel. That was back in the late 80s, with Gerd and Christine presiding.

Unfortunately, my trip to APEC at Anaheim was interrupted by an infection that put me in the hotel bed after only the first half-day. The great thing is that Holger took care of all my customer appointments during the show. I owe him my thanks. Back home in Laboe, I have made a full recovery and expect to be in Nuremberg at PCIM. The nice warm weather of California is always a reason to return, so my next plan is to be at SEMICON West in San Francisco in July.

It is always great getting experts together to work on Power Electronics – making progress in reducing power consumption. The semiconductor industry is the key technology. Wide band gap devices have been taking over more and more of the applications once served by silicon. So I will continue the tradition of a podium discussion with industrial leading experts in wide band gap technology.

This will be held on Wednesday, 8th of May at PCIM, Hall 7, Booth 543
SIC – Devices are Mature, 13:30 to 14:30
GaN – Devices are Mature, 14:30 to 15:30

Next to the podium at Hall 7, is the “Meet the Speakers Lounge”, (7-546). This is a new service where visitors can have discussions in more detail after the presentations.

I am looking forward to meeting you there.

And around the corner you will find my booth 7-540 for chatting during the show. So, I look forward to meeting next week in Nuremberg during PCIM Europe – just in time for more asparagus.

Bodo’s magazine is delivered by postal service to all places in the world. It is the only magazine that spreads technical information on power electronics globally. We have EETech as a partner to serve North America efficiently. If you are using any kind of tablet or smart phone, you will find all of our content on the website www.eepower.com. If you speak the language, or just want to have a look, don’t miss our Chinese version: www.bodospowerchina.com

**My Green Power Tip for the Month:**
Walking to the nearby beach with your grandchildren and building sand castles with them is much better than driving in the car to reach other attractions, and less pollution in the air.

Best Regards

## Events

**Battery Show Europe 2019**
Stuttgart, Germany, May 7-9
www.thebatteryshow.eu

**PCIM Europe 2019**
Nuremberg, Germany, May 7-9
www.mesago.de/en/PCIM

**SMTconnect 2019**
Nuremberg, Germany, May 7-9
www.mesago.de/en/SMT

**SCAPE 2019**
Stockholm, Sweden, May 13-14
www.ri.se/en/scape-2019

**The Smarter E 2019**
Munich, Germany, May 14-17
www.thesmartere.de

**ISPSD Conference 2019**
Shanghai, China, May 19-24
www.ispsd2019.com

**CWIEME Berlin 2019**
Berlin, Germany, May 21-23
www.coilwindingexpo.com/berlin

**Fortronic 2019**
Modena, Italy, June 19-20
www.fortronic.it

**Sensor+Test 2019**
Nuremberg, Germany, June 25-27
www.sensor-test.de

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LDSR offers a competitive price, low dimensions and complies with all regulatory standards. LDSR is also an excellent alternative to expensive fluxgate solutions due to its small footprint and simple construction.

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- Single or three phase configuration

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## Announcing Strategic Investment

UnitedSiC announced a strategic investment and long-term supply agreement from Analog Devices. Terms of the investment and supply agreement were not announced.
"From our first meeting with the ADI Power team, they instantly understood the value of our SiC technology and the ease with which the devices could be scaled and utilized in their power platforms. This is a terrific time to bring such a high caliber leader like ADI on as a shareholder," said Chris Dries, President and CEO at UnitedSiC. UnitedSiC and ADI have been collaborating on SiC-based products and devices for more than two years. As wide bandgap power devices, and SiC in particular, become more mainstream and cost effective, the inclusion of these devices should further strengthen ADI's analog power portfolio.
Steve Pietkiewicz, Senior VP of Power Products at ADI said, "For the last few years, we have been actively following the development and progress of silicon carbide technology and devices. We found UnitedSiC's FET technology to be ideally suited for ADI's high performance power platforms and our pursuit of additional high voltage applications."

**www.unitedsic.com**

## Dr. Sven Schneider to Become CFO

The Supervisory Board of Infineon Technologies AG has appointed Dr. Sven Schneider to become the CFO effective 1 May 2019. His contract will initially run for three years. Dr. Schneider is moving to Infineon from Linde AG, where he is currently Board Spokesman, CFO and Labor Director. Schneider succeeds Dominik Asam, who will be moving to Airbus SE on 1 April. During the one-month transition period, the Chief Executive Officer of Infineon Technologies AG Dr. Reinhard Ploss will manage the company's finance organization. As Chief Financial Officer, Dr. Schneider will be in charge of Accounting & Reporting, Financial Controlling, Financial Planning, Investor Relations, Taxes, Treasury, Auditing, Compliance, Export Control, Risk Management, Business Continuity, and Information Technology. "I am delighted to be joining the Infineon Management Board in a few weeks' time. Microelectronics is the key to a better future, and Infineon plays a decisive role in this with its products in important growth markets. I want to continue to write this success story together with the Infineon employees," says Dr. Sven Schneider, the designated Infineon CFO.

**www.infineon.com**

## Selling the Lighting Business

Cree announces the execution of a definitive agreement to sell its Lighting Products business unit ("Cree Lighting"), which includes the LED lighting fixtures, lamps and corporate lighting solutions business for commercial, industrial and consumer applications, to IDEAL INDUSTRIES, INC. for approximately $310 million before tax impacts, including up-front and contingent consideration and the assumption of certain liabilities. Cree expects to receive an initial cash payment of $225 million, subject to purchase price adjustments, and has the potential to receive a targeted earn-out payment of approximately $85 million based on an adjusted EBITDA metric for Cree Lighting over a 12-month period beginning two years after the transaction closes.
The agreement continues Cree's strategy, announced in February 2018, to create a more focused, powerhouse semiconductor company, providing growth capital for Wolfspeed, its core Power and RF business, and equips Cree with additional resources to expand its semiconductor operations. The deal also enables Cree Lighting to gain additional global focus, channel support and investment as it becomes a growth engine for the IDEAL team.
"Cree has made significant progress over the last 18 months in sharpening the focus of our business to become a semiconductor powerhouse in Silicon Carbide and GaN technologies. Over that time frame, we have grown Wolfspeed by more than 100%, acquired the Infineon RF business, more than doubled our manufacturing capacity of Silicon Carbide materials, and signed multiple long-term supply agreements" said Gregg Lowe, CEO of Cree.

**www.cree.com**

## Plant in Czech Republic to Produce Motors and Inverters

Mitsubishi Electric Corporation announced that it would start construction of a new plant on the premises of its subsidiary Mitsubishi Electric Automotive Czech s.r.o (MEAC) in Slaný, Czech Republic. The factory will enable MEAC to increase its mass production of motor and inverter systems for electric vehicles, such as the company's integrated starter-generator (ISG) systems for 48V hybrid vehicles*, which are expected to see rapid growth in demand, especially in Europe.
Aiming to expand the scale of its automotive equipment business, Mitsubishi Electric is developing a range of advanced automotive products by applying its extensive proprietary technologies in the fields of power electronics, vehicle integration control and high-density coil winding for motors.

**www.MitsubishiElectric.com**

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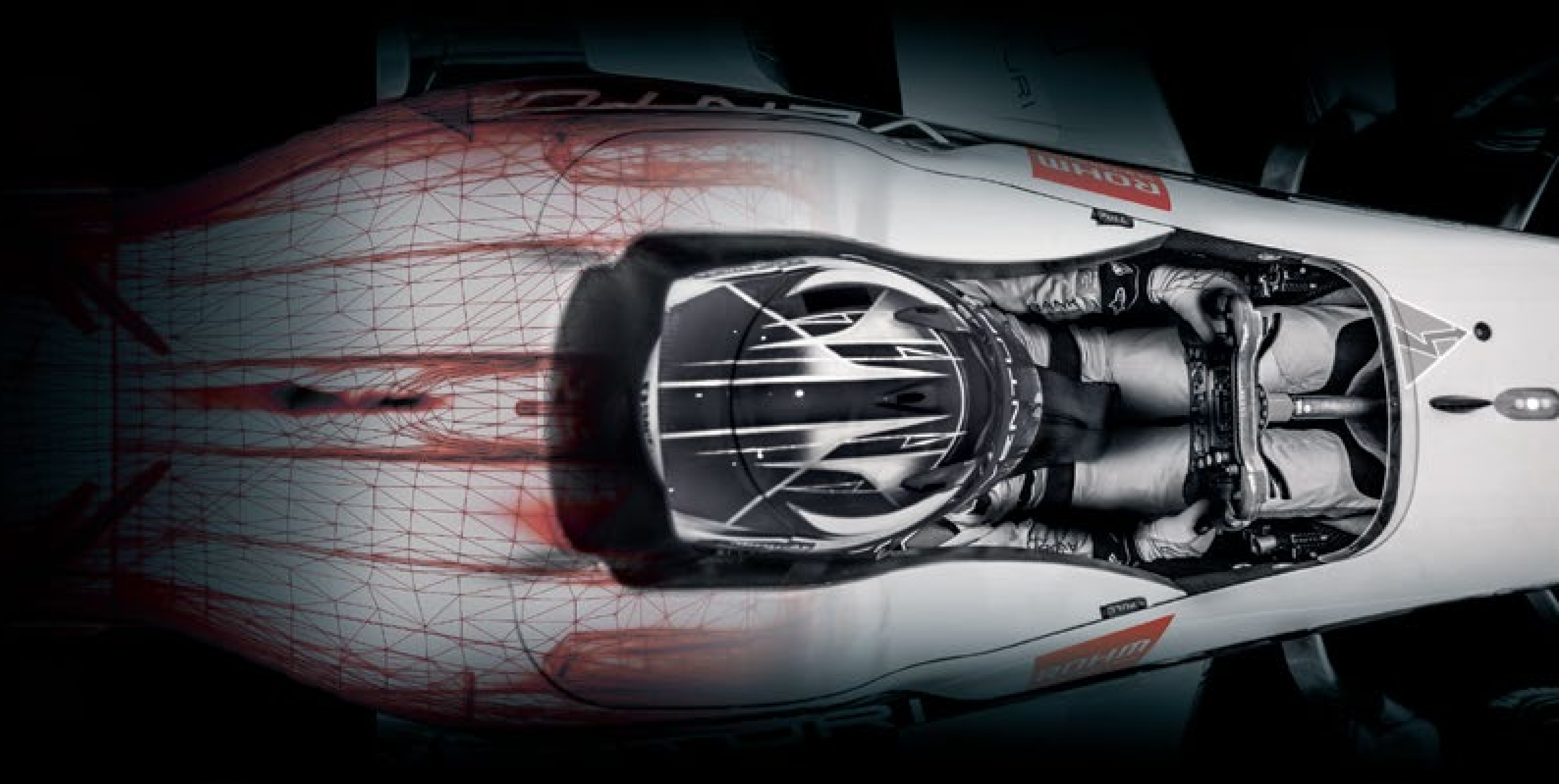

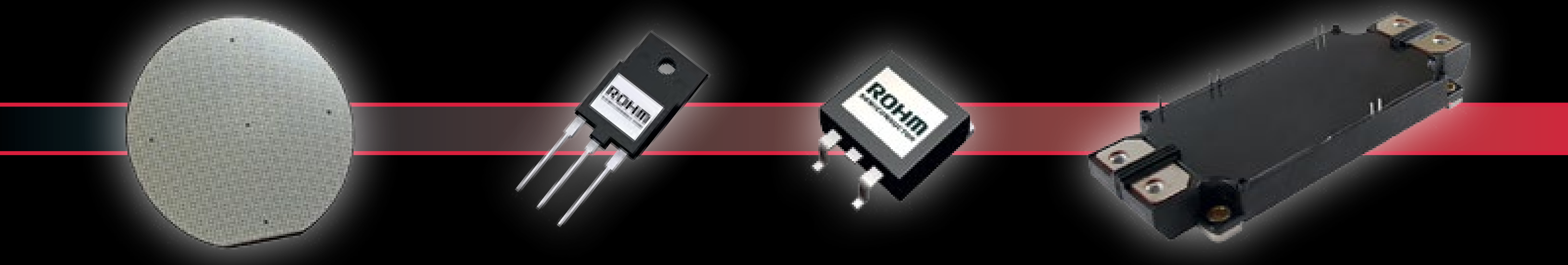

# FROM THE RACETRACK TO THE ROAD

VENTURI Formula E team has adopted ROHM's full SiC power modules for its fully electric racing cars. ROHM's innovative products power the implementation of e-mobility by delivering the next generation of power semiconductor devices. Our unique vertically integrated in-house manufacturing guarantees high quality and a consistent supply to the market.

SiC technology enables **SMALLER** inverter designs in terms of volume and weight.

SiC can achieve higher power density for **STRONGER** performance.

SiC helps vehicles to cross the finish line **FASTER** and supports fast-charging solutions.

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# Inductors Learning Kit Available

The TI-PMLK (Texas Instruments Power Management Lab Kit) Würth Elektronik Edition, developed in collaboration with Texas Instruments, is a learning kit that helps engineering students and electrical engineers to study and understand the impact of magnetics on a buck power supply. “Most universities don’t have the resources to provide specific courses in the area of power management, especially those that address the challenges associated with design and optimization of the magnetics in a power supply, which is a key component in any electronic system,” said Alexander Gerfer, CTO at Würth Elektronik eiSos. “The kit has been developed in collaboration with Professor Nicola Femia, from the University of Salerno, Italy, who has been teaching power board design for the past 25 years. This learning kit is accessible for autonomous learning to most students and engineers, and includes a mix of theoretical learning and hands-on training using real-world application scenarios.”

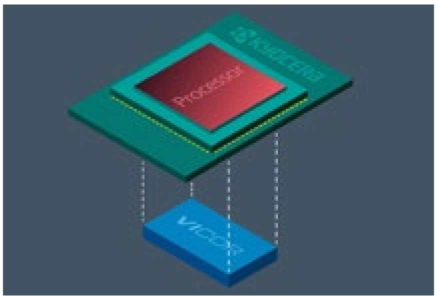

The TI-PMLK Würth Elektronik Edition comprises a buck board and a free editable experiment book.

The board consists of two independent buck circuits with six different inductors that can be individually selected. The hands-on kit allows the users to investigate the performances of inductors with different core materials, inductance, and size to analyze their impact on the static and dynamic performance of regulators.

**www.we-online.com/pmlk**

# Collaboration on Advanced Power-on-Package Solutions

Kyocera Corporation and Vicor Corporation will collaborate on next-generation Power-on-Package (PoP) solutions to maximise performance and minimise time-to-market for emerging processor technologies, the companies have announced. As a part of the collaboration between the two technology leaders, Kyocera will provide the integration of power and data delivery to the processor with organic packages, module substrates and motherboard designs. Vicor will provide Power-on-Package current multipliers enabling high density, high current delivery to processors. This collaboration will address the rapid growth of higher performing processors, which has created proportionate growth




and complexity in high-speed I/Os and high current consumption demands. Vicor’s Power-on-Package technology enables current multiplication within the processor package, allowing for higher efficiency, density, and bandwidth. Providing current multiplication within the package can reduce interconnect losses by up to 90 percent, while allowing processor package pins, typically required for high current delivery, to be reclaimed for expanded I/O functionality. Vicor’s Power-on-Package solutions were featured at the NVIDIA GPU Technology Conference 2018 and China ODCC 2018 Summit. The Vicor advanced Power-on-Package technology enables Vertical Power Delivery (VPD) from the bottom side of the processor. VPD virtually eliminates Power Delivery Network (PDN) losses while maximizing I/O capability and design flexibility.

**www.vicorpower.com**

# All Eyes on Africa

The sunniest regions of the world are located in Africa and the Middle East. So it’s particularly surprising that these regions are home to less than five of a total of 450 gigawatts of photovoltaics (PV) capacity worldwide. Africa holds enormous potential for renewable energies. Renowned experts will be exploring just how great this potential is with presentations at the Intersolar Europe Conference on May 14 and 15 in munich. The organizers of Intersolar Europe and the conference of the same name will also be presenting the results of their latest market study, the Intersolar Solarize Africa Market Report, which was carried out by the German Solar Association (BSW-Solar) on their behalf. In the exhibition halls themselves, visitors will also have the chance to learn everything worth knowing about solutions that are tailored to local conditions. Intersolar Europe will take place from May 15–17 at Messe München – in parallel to three other leading energy exhibitions as part of The smarter E Europe, the innovation hub for empowering new energy solutions.

**www.intersolar.de/en**

**www.TheSmarterE.de/en**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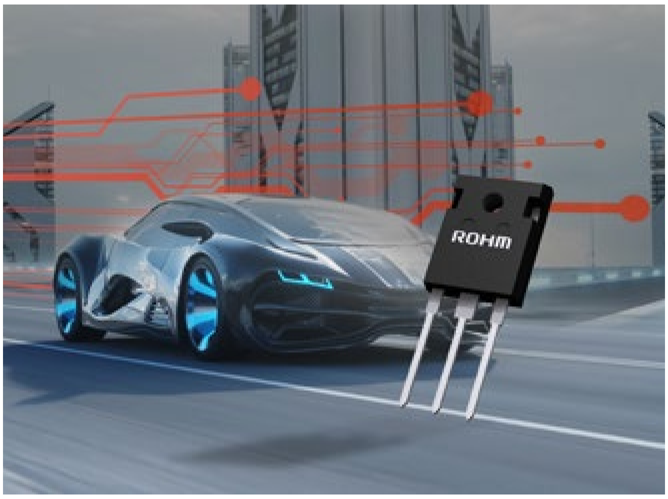
# Lineup of Automotive-Grade SiC MOSFETs

ROHM has recently announced the addition of 10 automotive-grade SiC MOSFETs. The introduction of the SCT3xxxxxHR series allows ROHM to offer the industry's largest lineup of AEC-Q101 qualified SiC MOSFETs that provide the high reliability necessary for automotive on board chargers and DC/DC converters. In recent years an increasing number of automotive makers are offering electric vehicles in response to growing environmental awareness and rising fuel costs. However, although EVs are becoming more widespread, their relatively short driving range remains problematic. To improve driving distance, batteries are trending towards larger battery capacities with shorter charging times. This, in turn, demands high power and efficiency on board chargers such as 11kW and 22kW, leading to increased adoption of SiC MOSFETs. In addition, higher voltage batteries (800V) require power devices featuring low loss and higher withstand voltages. To meet these needs, ROHM added 10 new models to its lineup of AEC-Q101 qualified MOSFETs that utilizes a trench gate structure. The result is the industry's largest portfolio, available in both 650V and 1200V variants. And going forward, ROHM will strive to further improve quality and strengthen its lineup to increase device performance, reduce power consumption, and achieve greater miniaturization.




www.rohm.com/eu

# Technical Seminars in Russia

**On March 12, 2019 Proton-Electrotex held a technical seminar for its partners in Saint-Petersburg.**

Several researchers of the company presented their reports at the seminar:

- "General presentation of the company. Basic principles of work" by A. Stavtsev
- "Modern technical solutions in the design of power semiconductor devices" by K. Volobuev
- "Current and future research projects of Proton-Electrotex" D. Malyy
- "Complete solutions for power electronics" with E. Gostenkov
- "WEB application for calculation of IGBT power converters" by T. Fedorov

Participation in such events is a unique opportunity to follow the trends in power electronics by introducing new designs, technologies, promising projects and innovative products. Participants noted in their feedback the seminar was well organized and held at a high level.

**On April 8–9, 2019 Proton-Electrotex held a technical seminar in Moscow, Hotel Vega.**

The opening ceremony was attended by the first persons of Proton-Electrotex. In particular, the Technical Director A. Stavtsev in his speech noted the importance of developing modern and competitive domestic products. The seminar included discussions of the industry prospects, potential projects and trends in the use of power electronics. The event was actively supported by partners of Proton-Electrotex. It was attended by professionals from more than 40 research, manufacturing and technical companies, including Limited Liability Company «Transconverter», «Benning Power Electronics», «Orion-R». «Ruselprom» and several others.

The technical seminar was based on the following five reports by Proton-Electrotex:

- "General presentation of the company. Foundations of business" by A. Stavtsev
- "Modern technical solutions used in design of field-controlled power semiconductors" by K. Volobuev
- "Integrated solutions for power electronics by Proton-Electrotex" by E. Gostenkov
- "Ongoing and future research projects of Proton-Electrotex" by D. Malyy
- "WEB application for calculation of IGBT converter modes" by T. Fedorov

Each report was then open for discussion by all participants. Designers of Proton-Electrotex have over 20 years of experience in researching and developing new successful technologies, allowing the company to achieve great results in the power semiconductors industry.

www.proton-electrotex.com

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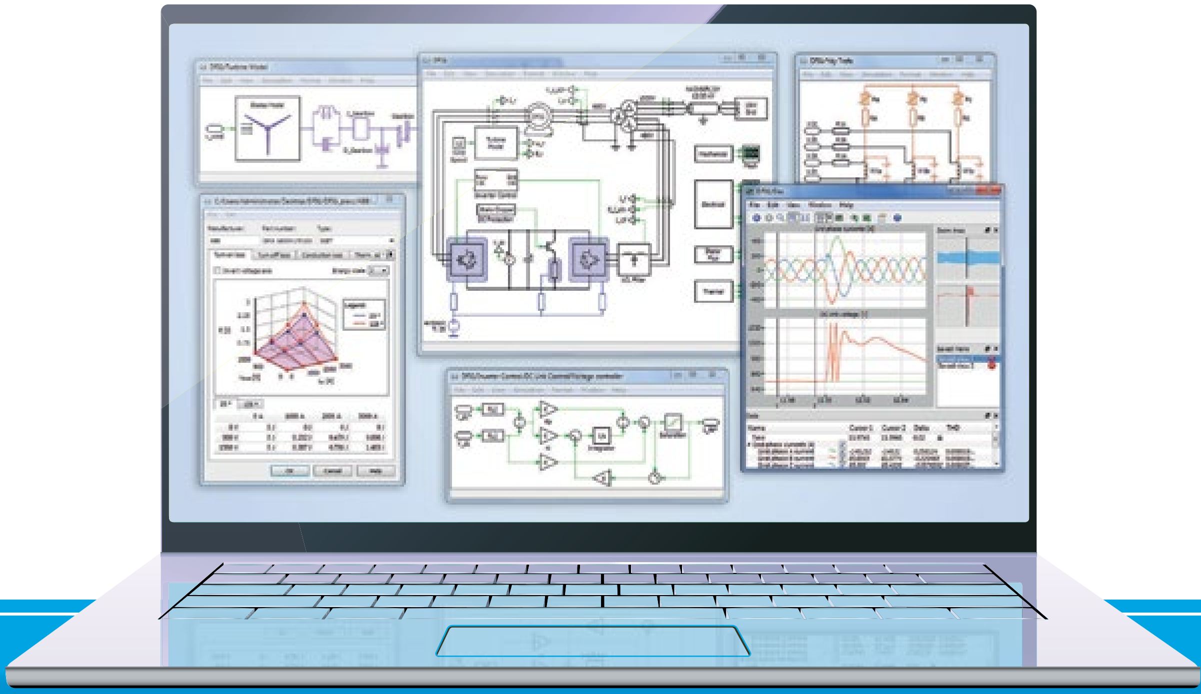

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# A New Proposal to Boost the Reliability of Coil Windings

*HIOKI has announced the ST4030 Impulse Winding Tester, featuring next-generation technology ideal for the electric motor and inductor/coil markets.*

By digitizing response waveforms captured during impulse tests, users can manage inspection data in a quantifiable way offering precise detection performance that distinguishes it from competitors.
With the ST4030, HIOKI is now positioned to provide solutions for all of the inspection requirements encountered on coil winding manufacturing lines or in servicing:

- Analyzing impulse response waveforms and quantifying judgment criteria
- Detection of even minor layer shorts
- Impulse testing of motors without any dismantling
- Detecting partial discharges caused by pseudo-shorts

**Precise detection even of miniscule defects**
By analyzing and quantifying the response current waveform obtained when a voltage is applied to the winding under test, the ST4030 simplifies judgement and makes it possible to precisely detect layer shorts even on a single turn. Such miniscule defects would go unnoticed by the conventional approach of comparing waveform area values.

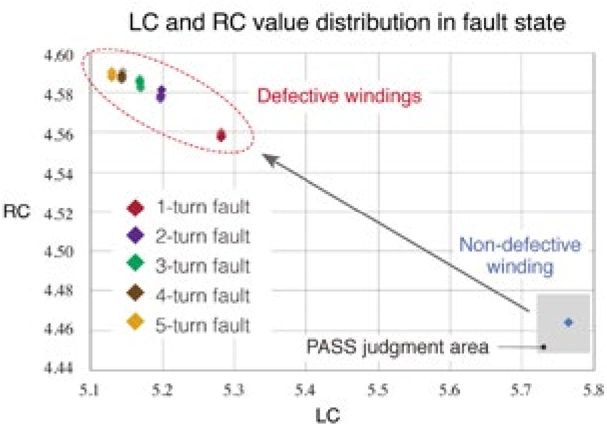


*Figure 1: Example layer short judgment screen*

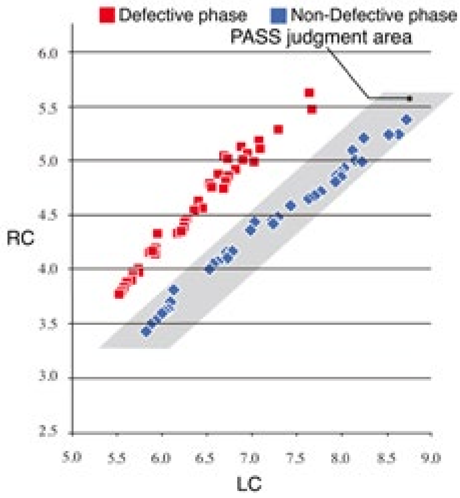


*Figure 2: Example judgment screen for windings with rotor and stator*

**Impulse testing of motors without dismantling**
A great advantage for manufacturing and servicing alike is the possibility to utilize this quantified data to test fully assembled motors by applying previously defined judgment areas.

In addition, accumulated data can be statistically analyzed and provided as feedback for upstream manufacturing processes to predict and prevent initial or future insulation failures.

**Lower voltage testing safeguards DUTs**
The ST4030 can also detect defects at ½ to ⅓ the voltages applied under conventional methods thanks to high-precision waveform detection technology and HIOKI's proprietary algorithm. Conventional methods apply a high voltage to facilitate detection of defects as discharge is typically more likely to occur this way. However, high voltage meant putting more strain and a higher risk of damage on the DUT.
The Discharge Detection Upgrade ST9000 further allows to readily detect partial discharges that are obscured by noise, which has been an issue with conventional testing methods (e.g. flutter and Laplacian methods, use of an antenna to detect discharges).
HIOKI is confident that the revolutionary technologies of the ST4030 will contribute greatly to improving high quality coil windings and advancement of the global power electronics industry. HIOKI EUROPE's expanding distributor network further ensures immediate market availability all over Europe.

The ST4030 will be on display:
- PCIM Nuremberg, Hall 6, Booth #448, May 7-9
- Coilwinding Berlin, Hall 2, B37, May 21-23

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# PrimePACK™ 7G IGBT Modules

## Upgrading to 1200 A in PP2, 1800 A in PP3 & new PP3 with additional AC-terminal

series 7G

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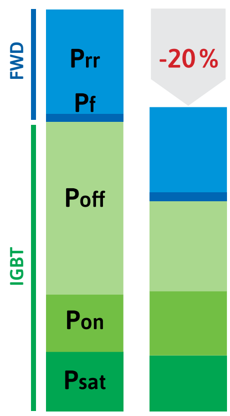
- Higher lifetime at same ΔTj
- Increased output power
- Higher power cycling capability
- Lower conducting and switching losses
- 2nd label with $V_{CE(sat)}$ and $V_F$ classification for easier paralleling

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Innovating Energy Technology

# PowerForge "Your" Power Converters Designs

*You have electricity to convert? Think about PowerForge!*


*Power Design Technologies and its unique software solution were created to meet the unfulfilled industrial needs and are aimed at you, who face increasing challenges when designing and upgrading power converters.*

Power Design Technologies is a French company proposing an innovative software for engineers working in naval, wind, photovoltaic, manufacturing, shipping, electric cars, aeronautic, storage systems… who have to be more competitive: more cost efficient and more performant. Indeed, the market is getting even more fast paced while expecting a higher performance from your converters, in a short time.

How can you optimize your time & technico-economic performance trade-off?

**ARE YOU CAUGHT BETWEEN THE HAMMER AND THE ANVIL?**

Designing performing power converters has become increasingly challenging in the last years and this trend is peeking up speed. On the one hand, power designers need to master a wide set of skills: topologies, component selection, inductor sizing and thermal evaluation among others. On the other hand, competition at international level drives the entire industry toward product differentiation, shorter development cycles and reduced costs. Don't you feel or experience that finding the product-price-market fit has never been so challenging?

*"We spoke with hundreds of engineers to understand their needs and constraints. We developed the most advanced research and know-how to help them design and compare standard and multilevel power converters in a unique Software in no time", says Dr. Thierry Meynard, scientific advisor and co-founder of Power Design Technologies.*

**YOU'RE THE EXPERT, REGAIN CONTROL! POWERFORGE!**

PowerForge is the most powerful software for designing, exploring and comparing power converter designs. Centered around your engineer's workflow, our tool offers a seamless experience from product specification stages to trade-off of most advanced multilevel topologies and sizing of passive and active components.

Thanks to multidisciplinary integration of electric, magnetic and thermal aspects early in the design process, PowerForge empowers your development teams with a unique tool for designing lighter, smaller, more cost-efficient and more efficient converters in record time.

The combination of deep power electronics knowledge with proprietary fast steady-state calculation algorithms built into PowerForge enables the fast comparison of solutions as well as the exploration of cutting-edge multilevel conversion stages in unprecedented short time.

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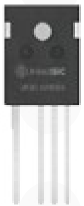

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# Applied Power Electronics Conference and Exposition – APEC 2019

*APEC, the premier annual event in applied power electronics provides technical information of interest to everyone involved in the power electronics community*

*By Gary M. Dolny, US-Correspondent Bodo's Power Systems*

The 2019 Applied Power Electronics Conference and Exhibition (APEC) was held from March 17-March 22 at the Anaheim Convention Center, Anaheim, CA, USA. The conference, which is jointly sponsored by the IEEE Power Electronics Society (PELS), the IEEE Industry Applications Society (IAS) and the Power Sources Manufacturers Association (PSMA) brings together professionals from all sectors of the power electronics industry for in-depth technical presentations and discussions that combine theory with practical applications. The conference provides numerous learning opportunities for the attendees. These include Professional Education Seminars, technical papers presented in both lecture and poster format, application-oriented industry sessions, an extensive exhibition accompanied by exhibitor seminars, and the popular "Rap Sessions" in a panel discussion format that allows open interactions between the audience and industry experts. As a result of this comprehensive program, APEC has become recognized as the premier event in the field of applied power electronics.

This year's technical program consisted of over 500 papers covering all aspects of applied power electronics. The accepted papers were thoroughly peer-reviewed for both technical innovation and to ensure the highest technical quality. Papers with broad appeal were scheduled for oral presentation during one of the forty technical sessions. Papers with a more specialized focus were presented in poster format at the dialog sessions. This allowed conference participants and presenters to discuss the work at a level of depth and detail not possible in a standard oral presentation. The Dialog Session papers underwent the same rigorous peer-review process as the Technical Session papers and both appear in the conference proceedings. The APEC Industry Sessions run in parallel with the technical track and this year expanded to 23 separate sessions on a wide variety of topics. The industry sessions consist solely of invited presentations; speakers make an oral presentation only, without submission of a formal manuscript to the conference proceedings. This enables presenters to cover current topics that would not otherwise be publicly presented at a professional conference. In addition, the conference featured a series of Exhibitor Seminars. The exhibitor seminars were a series of half-hour presentations highlighting new products and services and enabling more in-depth discussion than could be obtained by a visit to their booth.

The conference was preceded by two daylong technical workshops on Saturday sponsored by PSMA. The first of these, titled "Power Magnetics at High Frequency", was aimed at designers, manufacturers, and fabricators of magnetic components and materials interested in achieving higher power densities, reduced aspect ratios, higher efficiencies, and improved thermal performance. The second titled "The Impact of Wide bandgap Technologies on Application of Capacitors", discussed technical options available for capacitor technologies to meet the challenges driven by the increased power densities and switching frequencies enabled by the wide bandgap semiconductor devices. All day Sunday and Monday morning prior to the opening of the conference APEC presented a series of eighteen Professional Education Seminars. The Professional Education Seminars address the need for in-depth coverage of important and complex power electronics topics. Each seminar combined practical applications with theory designed to further educate both working professionals and students in power electronics and related fields. The Professional Education Seminars at APEC are three-and-one-half hours (including breaks) in length, range from broad to narrow in scope, and can vary from introductory to advanced in technical level. The 18 seminars covered a wide range of topics including wide bandgap devices, magnetics, converter and PCB design, thermal design, and digital control.

In addition to the extensive technical program, APEC 2019 offered numerous opportunities for networking and professional interactions. Key among these were the Monday evening opening reception in the exhibit hall and the Wednesday night social event featuring food, friendly-competition games, caricaturists and musical entertainment. The conference formally opened on Monday afternoon with five plenary presentations from industry leaders. The topics included the future of power electronics in robotic applications, an overview of university research in power electronics, flywheel energy storage at the utility scale, fuel cells for enabling zero emission transportation, and power electronics for space exploration.

Yole Development presented a thorough assessment of what the power electronics industry can expect from SiC and GaN in the next several years. They noted that the market share for wide bandgap devices is still small compared to the total power semiconductor market of $30B US. However, GaN was identified as having enormous potential in high performance and high frequency systems. While SiC is more mature, it has the potential for high growth in high density and high efficiency applications. By 2023 they project the WBG market to grow to about $1.5B US, which is about 5% of the total market. Other direct evidence of the growing maturity of the wide bandgap materials was provided in a joint presentation by J. Cassady of Wolfspeed and S. Watts-Butler of Texas instruments. They provided an update on GaN and SiC activities within the JEDEC standards committee. Their goals are to enable market growth, and accelerate industry-wide adoption of the WBG devices. This will be enabled by creating consistency across the supplier base through development of accepted industry standards. These include reliability verification and qualification procedures, test methodologies, and data sheet elements. The JEDEC JC-70 committee began in October of 2017 with 23 member

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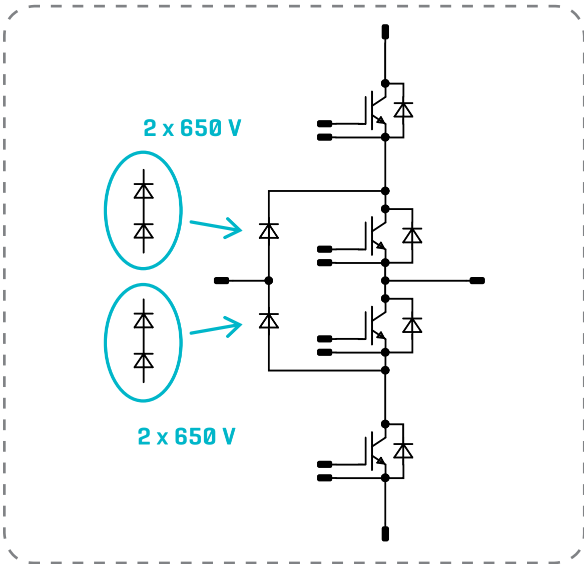


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companies and has now grown to over 50 members worldwide including semiconductor manufacturers, users of wide bandgap power devices and test and measurement equipment suppliers. Interested companies are invited to join JEDEC to participate in this important standardization effort. Information is available on the JEDEC website at https://www.jedec.org/join-jedec. Similarly, a presentation from ABB discussed WBG device needs from an end user perspective. They identified three necessary drivers for WBG adoption. These included improved technology enabled by advanced packaging and device protection techniques, demonstrated reliability from both standardized testing and field experience, and reduced costs brought about by process improvements, increased wafer size and increased production volumes.

A number of presentations from Navitas Semiconductor highlighted their efforts to develop GaN Power ICs for the fast charger market. Their technology is based on lateral enhancement mode p-GaN gate technology with high breakdown field and high carrier mobility. The devices are manufactured in an established CMOS processing line to achieve high yield and high capacity and employ multi-level metallization. A monolithic half-bridge GaN power IC consisting of two 650V enhancement-mode GaN FETs, gate drivers, regulators level-shifters and GaN logic was demonstrated in a 2 MHz soft-switching application. A number of presentations by Efficient Power Conversion Corporation (EPC) addressed the advantages of GaN-on-Si technology in a variety of applications especially high-step-down-ratio DC/DC converters. The GaN based converters were shown to offer reduced device losses compared to conventional solutions. They also presented a detailed study of GaN reliability for automotive applications. They noted that AEC Q101 qualification is an important milestone but additional application-based testing including hard/soft switching and in-circuit reliability testing is required to address customer concerns. Several presentations from Infineon discussed advances in GaN and SiC and drew comparisons against conventional Si CoolMOS devices. They stressed the crucial importance of quality and reliability when considering the wide bandgap materials in customer designs. GaN Systems, with the aid of several technology partners discussed GaN performance and reliability in datacenter, solar and wireless power production systems. The use of GaN devices in a commercial energy storage system was demonstrated to offer a 4% increase in energy efficiency, 8% cost savings in bill-of-materials cost and a 30% reduction in system size. Transphorm Corp. presented a study of the use of GaN devices in systems that are currently in commercial production. They cited various power supply applications ranging from 500W to 3 kW, as well as industrial applications such as battery chargers and inverters.

GaNPower International Inc. presented the first discreet GaN devices rated at 1200V using single-die enhancement mode technology. The lateral devices, which are released and production ready, have an actual breakdown voltage greater than 1500V and are being rated at 1200V to guarantee sufficient safety margin. They noted that all previous GaN devices with BV higher than 600V were made with depletion mode devices in a cascode configuration with two or more chips co-packaged, resulting in compromised performance.
Two presentations addressed novel technologies for GaN integration. A team from IBM and MIT presented a fully integrated GaN-on-Si technology for 48V power conversion. Their goal was to optimize conversion efficiency from 48V to <1V in point-of-load applications without an intermediate 12V bus. The process monolithically integrates GaN power switching devices with conventional silicon CMOS on a single die. Their novel technical approach is based on the selective epitaxial growth of GaN on etched areas of a silicon-on-insulator (SOI) starting wafer. SiN spacers are employed along the etched silicon sidewalls to serve as a diffusion barrier and also to prevent spurious epitaxial GaN growth from the etched sidewalls. The primary switching device is a depletion-mode GaN HEMT in a cascode configuration. An alternative approach was discussed by MinDCet NV. They developed a monolithic GaN integrated circuit using a SOI starting wafer. A buffer layer is first grown on the superficial silicon above the buried oxide. This is followed by the deposition of an epitaxial GaN layer in which p-GaN HEMTs are subsequently formed. Deep, oxide-filled trenches provide full dielectric isolation and allow for the use of local substrate contracts. Both 200V and 650V versions of the technology have been prototyped and tested.

There was also considerable interest in SiC particularly in applications such as electric vehicles (EV), industrial motor drives and high-power inverters. A presentation from ST Microelectronics discussed how SiC MOSFETs could enhance performance and reliability in an EV traction application. They emphasized that the Rds of SiC MOSFETs increases by only 30% as the operating temperature increases from room temperature to 150° C, presenting a significant advantage over Si. They demonstrated a 50% module package size reduction, an 80% cooling system size reduction, and a 1% increase in overall efficiency compared to a Si-IGBT solution in an 80 kW traction system. Similarly, a presentation from John Deere Inc. discussed a 200 kW SiC inverter operating from a 1050V DC bus for heavy duty vehicles. They demonstrated a number of advantages compared to an earlier Si-IGBT approach including increased switching frequency (15 kHz vs 7 kHz), higher power density (25kW/L vs 17 kW/L), as well as enabling a smaller DC bus capacitor (400 uF vs 1500 uF). Wolfspeed discussed a 60 kW SiC boost converter for use with solar power generation. They focused on both new packages designed to reduce switching loss through the use of a Kelvin connection to minimize dI/dt losses as well as board design techniques to optimize circuit board layout to reduce gate resistance and improve switching frequency. A four-channel boost inverter with 99.5% efficiency was demonstrated. United Silicon Carbide discussed techniques for designing with high-performance SiC-JFETs co-packaged with silicon MOSFETs in a cascode configuration with four-lead Kelvin packages. They noted that such combinations are compatible with a wide range of commercial gate drivers with no need for negative gate drive at turn-off. They also stated that because of the very low output capacitance of the cascode, snubber circuits are desirable to control voltage overshoot and output ringing. However, the required snubber capacitance values are small, and the associated energy loss is only 1-5% of the total switching energy. General Electric discussed their power overlay (POL) packaging technology with regard to SiC power modules.
The POL technology is a differentiated packaging technology that combines flex, PCB, and wafer level processes to reduce size and improve performance. The technique enables direct pad interconnects using micro-vias to reduce parasitic resistance and inductance. They note that this system can support SiC applications at 1700V, currents in the range of hundreds of amps, and temperatures up to 175°C. Semikron presented a study of SiC modules without external diodes. They showed that combining optimal switching to reduce dead time with SiC MOSFET third quadrant operation using the inherent body diode can result in a 20% increase in power density compared to solutions using external diodes. The technique is applicable for three-phase AD/DC and DC/AC converters.

Next year's APEC will be held from March 15-19, 2020 at the Ernest N. Morial Convention Center, New Orleans, LA, USA.

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# EMV 2019: International Trade Fair with Workshops

## *First-Class Business and Networking Platform for EMC*

*EMV 2019, the 31-year-old international trade fair with workshops for electromagnetic compatibility, was once again proving to be a pioneering platform for the industry in Stuttgart. The event from 19 - 21 March 2019 convinced with a broad product and service portfolio at the trade fair, a multi-faceted forum program as well as state-of-the-art, practice-oriented expert knowledge in the workshops.*

*By Roland R. Ackermann, Correspondent Editor Bodo's Power Systems*

For the first time, the organiser, Mesago Messe Frankfurt, also launched a so-called Career Center - a platform for jobs and careers where exhibitors presented their current job offers and visitors to the fair had the opportunity to take advantage of individual career advice. "EMV" is rightly regarded as the leading trade fair for electromagnetic compatibility. This was once again underlined at the Stuttgart venue this year. A total of 121 German and (more than one third) international exhibiting companies presented their products and services on an exhibition area of more than 4,200 square metres and were extremely satisfied. In 2019, EMV was once again the meeting place for EMC specialists with the power to make decisions. 2,779 trade visitors informed themselves about the latest developments in the field of EMC laboratories, measuring and testing systems, simulation software and high-frequency technology. In addition to long-standing exhibitors such as AR Deutschland GmbH, EMCO Elektronik GmbH, Gauss Instruments GmbH, Phoenix Testlab GmbH and Rohde & Schwarz GmbH & Co KG, visitors also found several newcomers, including Acal BFi Germany GmbH, Audivo GmbH, Kreutz EMC and Ntrium Inc.

**Plenary lecture on the topic "Radio Technologies in the Smart Home"**

This year's plenary lecture, which was open to all visitors free of charge, was given by Kai Kreuzer, Developer Evangelist in the Connected Home area at Deutsche Telekom AG. In his lecture, the founder and head of the open source projects openHAB and Eclipse SmartHome highlighted the possibilities and challenges of wireless technologies in the Smart Home. In addition to an overview of the various approaches, he gave detailed examples of some solutions. Authentication mechanisms were examined as well as possible attack scenarios. Integration with IP-based and other networks also played a central role.

Anyone who wanted to gain an overview of the innovations on offer could obtain specific information at the trade fair forum. The 20-minute product presentations by exhibitors and compact seminars, too, were open to all visitors and workshop participants. "EMV is a win-win situation for me. The fair is compact and everyone knows what the other companies offer. In combination with the workshops, the event is characterised by three components: Networking, further training and new trends", is how Jens Greiner, Managing Director of aktivEngineering GmbH and visitor of EMV, sums up the event.


**Comprehensive range of further training courses with practical relevance**

In parallel to the trade fair, 40 workshops with a total of 1,043 bookings took place, 29 of them in German and eleven in English. The workshops served as an individual training platform and offered the participants a varied and high-calibre programme with practical examples from everyday work in three-hour presentations, covering both basic and specialist knowledge. They dealt with topics such as legal requirements, modern analysis and measurement tools, physical fundamentals, measures to ensure EMC, technological trends and the resulting EMC requirements. The target groups for the workshops were mainly engineers in development and production, sales specialists and management as well as service providers in test laboratories. The following workshops were particularly popular:

- "EMC knowledge for New Entrants and Career Changers", Prof. Dr. Matthias Richter, Westsaechsische Hochschule Zwickau
- "Determination of Uncertainty of Measurement Balances for Immunity Tests", Dr. Bernd Jaekel, Siemens AG
- "Electromagnetics and Compatibility Made Simple - Part 2: Power Distribution Design on Printed Circuit Boards", Mark Montrose, Montrose Compliance Serv., Inc.

Overall, EMV 2019 once again proved to be the ideal platform for dialogue between users and experts. The trade fair confirmed its position as one of the leading European events in the field of electromagnetic compatibility.

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# Oscilloscopes are Heavy-Duty Signal Processing Machines

*VIP-Interview with Dr. Markus Herdin, Market Segment Manager Industry, Components and Research, Rohde & Schwarz, about the company's expertise in oscilloscopes for power electronic designs.*

*By Henning Wriedt, US-Correspondent Bodo's Power Systems*

**Henning Wriedt:** Dr. Herdin, which role does the oscilloscope play in modern electronic design and test?

**Markus Herdin:** Oscilloscopes are the Swiss Army Knife of modern electronics design. They act as a troubleshooting, verification, and production test tool. Due to their ability to capture almost any kind of waveforms and their post-processing capabilities, there are only a few things that, today, cannot be done with an oscilloscope.

**Henning Wriedt:** How did the oscilloscope evolve during the last ten years and how is your product portfolio currently structured?

**Markus Herdin:** The last ten years have brought many innovations to the oscilloscope business. From general-purpose electronics debug tools, oscilloscopes have evolved into heavy-duty signal processing machines that allow very fast and convenient analysis. One example is the acquisition speed modern oscilloscopes provide. It is possible to capture up to 1 million waveforms per second and display them on the screen. This allows capturing of rare events, which would have been previously missed. Other examples are the fast Fourier transform (FFT) based spectrum analysis capabilities, which allow the user to perform EMI debugging tasks already at the engineer's desk – and help save a lot of money due to less iterations with in-house testing. Not to forget new concepts like real-time de-embedding, which we introduced about a year ago, with the R&S®RTP oscilloscope (Figure 1).

*Figure 1: RTP oscilloscope. Key facts: Bandwidth 4 GHz to 8 GHz; max. sample rate: 20 Gsample/s; max. memory depth: 2 Gsample; all trigger events at full bandwidth; up to 16-bit resolution; signal integrity in realtime.*

**Henning Wriedt:** How important is a scope in automotive, communication, medical and IoT?

**Markus Herdin:** Automotive, communication, and medical products rely increasingly on high-performance computing systems. This makes digital design critical and verification of corresponding systems incredibly important. This is particularly true for automotive and medical applications because of the very high standards regarding product reliability they demand.

A big change happening in the automotive industry is the trend towards E-Mobility. Automotive companies and their suppliers are strongly investing into test and measurement solutions for power electronics design – and an oscilloscope with probes is the key instrument for this.

IoT is a different story. Companies developing IoT solutions are often small, innovative teams. For them, an oscilloscope has to cover as many use cases as possible. Modern oscilloscopes can cope with this pressure because of the trend that more and more analysis functions are constantly being added to them.

**Henning Wriedt:** Mobile electronic systems with and without battery are all around us with sometimes extreme low voltages and low power consumption. Can a modern oscilloscope cope with that situation?

**Markus Herdin:** Yes, but only with the right probing solutions. Actually, the dynamic range of an oscilloscope is limited by the A/D converter. Even though signal processing allows for the trade between bandwidth and resolution, there is a limit to it. This is where probing solutions come into play, which actually implement their own acquisition system. The RT-ZVC probe is such an example. It is an 18-bit acquisition system that was developed particularly for applications where a high dynamic range for current measurements is required – like in IoT battery life debugging. The digital data is then transferred to the oscilloscope via digital ports, where the data is aligned with the signals captured by the oscilloscope and displayed on the screen. This is a unique solution that allows users to correlate power consumption with any other activity of the device under test. As a side effect, this probing solution also allows for measurements of extremely low voltages, lower than what any oscilloscope can do.

However, I do also want to mention power supplies in this context. Measuring power consumption requires particularly "clear" power supplies. If the power supply is noisy, it is very difficult to measure sleep-mode currents, as ripple on the power supply will directly translate into ripple in the current and therefore influence the current measurement. The R&S®NGL200 power supply is very well suited for this application due to its linear regulation and therefore very low ripple. In some applications, it is actually a great standalone solution for power consumption testing, as it features 6 ½ digit resolution voltage and current measurement.


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**Henning Wriedt:** What kind of checklist would you recommend for a circuit designer, before he/she uses a scope for measurements and tests in power electronics (SiC/GaN semiconductors)?

**Markus Herdin:** It is important for them to understand their real measurement needs. Silicon carbide (SiC) and gallium nitride (GaN) semiconductors allow for very fast switching speeds. Theoretically, this requires very expensive probing solutions in the order of 4-5 times greater than a regular oscilloscope with significant drawbacks regarding analog signal quality and usability. However, looking at the real demand, one can see that customers choose to operate these semiconductors at only moderate speeds in order to avoid excessive radiated or conducted emissions, and expensive shielding solutions.

Therefore, traditional probing concepts work very well. We recommend that our customers look at their real needs and then choose their probes accordingly - in order to save their money.

**Henning Wriedt:** Faster power electronics means more EMI. How does a scope detect, localize and analyze these emissions? How do you see EMI-Debugging?

**Markus Herdin:** I see EMI debugging as an increasingly important application area for oscilloscopes. While, in the past, their FFT capabilities were limited and usability was not great, this has changed a lot. Today, they provide us with the capability for efficient debugging of EMI problems, both for conducted as well as radiated emissions, especially for power electronics engineers – and they are convenient to use. Well, and since engineers, anyway, always have an oscilloscope available on their desk then no other equipment is needed for these additional tasks.

The scope performs this task by calculating the FFT in order to determine the spectrum; this has been the case for a long time. The innovation, however, comes in when this is done in an intelligent way, by making use of powerful signal processing hardware and algorithms.

The big advantage for conducted emissions and debugging in the case of power supplies is that the scope can analyze the effect of EMI filters on the emission and at the same time look at the stability using the Bode plot feature, for example, with the R&S®RTM3000 (Figure 2). This is very helpful as the EMI filter influences the stability of switched mode power supplies; hence, optimizing EMI filters also requires verifying control loop stability. So, one gets all those things in just one instrument.

*Figure 2: RTM3000 oscilloscope. Key facts: Bandwidth: 100 MHz to 1 GHz; Sample rate: up to 5 Gsample/s; Memory depth: up to 80 Msample; ADC resolution: 10-bit; Display: 10.1” capacitive touchscreen.*

For debugging radiated emissions, the scope captures the emission with a near-field probe. Here, sensitivity and speed of the FFT are essential, as the customer has to move the near-field probe over the device under test to understand where the noise is coming from. The R&S®RTO2000 (Figure 3) is a great instrument for these tasks; many of our customers love it because it is so simple to use.

*Figure 3: RTO2000 oscilloscope. Key facts: Bandwidth 600 MHz to 6 GHz; max. sample rate: 20 Gsample/s; max. memory depth: 2 Gsample; up to 16-bit vertical resolution; MSO: 16 digital channels.*

**Henning Wriedt:** Can I reconfigure a scope for different applications without compromising its performance?

**Markus Herdin:** Yes, you can actually; oscilloscopes use the latest field-programmable gate array (FPGA) technology like dynamic reconfiguration. This means that the signal processing chain can be reprogrammed dynamically according to the application running on the oscilloscope. A typical example is the protocol decode operation. There, the corresponding protocol decoder is only loaded into the FPGA if it is used, which saves FPGA resources and, therefore, costs. This translates for the customer into more functionality at the same price.

**Henning Wriedt:** How can an engineer detect sporadic emissions and single events? And run tests under hazardous conditions?

**Markus Herdin:** The trigger functionality of oscilloscopes is the essential principle of capturing specific, but also sporadic or single events. This is a feature as old as the oscilloscopes – but only available in the time domain. The novelty is that this principle can also be applied to signals that are calculated out of the captured signal. One example is the FFT where, for example, spectral masks can be set in order to capture just the signal that contains a specified frequency content. Another example is a trigger event derived from the real-time protocol decoder, which allows capturing only events where a specific digital signal was present.

A user can join this capability with something called history mode, which is, basically, an automatic memory for consecutive acquisitions. Because of this, the user can “move back in time” to review thousands of acquisitions that have happened. This is very useful in combination with dedicated trigger conditions. A customer can capture all events that contain the specified signal content and later review when they happened and how they looked like.

**Henning Wriedt:** What advantages has a FFT analysis for a circuit designer?

**Markus Herdin:** The FFT analysis provides a different view of the signals under test. While in EMI debugging applications, the spec-

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**North America:** sales@ecicaps.com **Europe:** sales@ecicaps.ie trum itself is what the customer wants to see; for general-purpose signal analysis, the FFT allows identifying signal components that are otherwise hidden in the time-domain waveform. A good example are power integrity measurements. One of our customers had difficulties with the signal integrity of his digital design but he did not know the reason behind it. We approached the problem by looking at the power rail with a dedicated probing solution: a power rail probe. This enabled us to capture the problem: noise that was coupled onto the power rail. Going into the frequency domain with the FFT function revealed the root cause - a Wi-Fi RF signal got coupled onto the power rail. This, of course, deteriorated the quality of the power supply and led to signal integrity problems of his digital design.

The other advantage is that, today, using an FFT is no longer complicated. An oscilloscope allows us to directly set the essential parameters like start and stop frequencies, as well as resolution bandwidth, so the customer does not have to think about the exact relationship between time domain and frequency domain.
The oscilloscope does that in the background.

**Henning Wriedt:** The probe between the scope and the DUT must not only meet safety standards but also ensure precise test results and shouldn't interfere with the DUT. In general: What is your take on probes?

**Markus Herdin:** Probes are the most important element when it comes to measurements. As they pick up the signal from the device under test, they directly influence the quality of the measurement itself. Often, standard passive probes are used to perform high-quality measurements, which can lead to wrong conclusions and a lot of extra work. A good example of this are power integrity probes. They are optimized for power integrity measurements, and using a standard passive probe for such a measurement can result in way too high peak to peak voltage measurements and wrong conclusions about the quality of the power rail.

**Henning Wriedt:** Which probes are especially helpful in fast switching power electronics?

**Markus Herdin:** High-voltage differential probes are the right solution to choose. They have a very good common-mode rejection ratio and allow for safe and convenient measurements.

**Henning Wriedt:** Which are the benefits of Power Integrity Testing?

**Markus Herdin:** Power integrity testing becomes increasingly important as high-speed electronic designs find their way into many applications. As the designs become more sensitive to noise, the requirements for DC power supplies also become more stringent. The real problem is that noisy DC power rails do not necessarily lead to an immediate product failure, but increase the likelihood of a failure in the, not-so-well controlled, real world where the products are actually being used. The noise level of a DC power rail has a direct influence on e.g. the jitter of digital clocks, which increases the likelihood of bit errors in digital data transmissions inside of a high-speed design. Another regular issue is that the IoT devices show coupling of RF antenna signals to power rails, which leads to product failures as well. These things are taken into consideration when testing for power integrity.

**Henning Wriedt:** What are the main advantages of a modern Power Analyzer?

**Markus Herdin:** Power analyzers are typically used if particularly high measurement accuracy is needed, or conformance to specific standards has to be tested. In contrast to oscilloscopes, they use a high-resolution AD converter running at much lower speeds and integrate limit testing according to pre-defined standards. An example is energy label testing. For consumer products, it is required to show the energy consumption according to the energy label standards. This is a typical measurement of the R&S®HMC8015 (Figure 4) power analyzer by Rohde & Schwarz.


*Figure 4: HMC8015 Power Analyzer. Key Facts: Power measurement range: 50 µW to 12 kW, analog bandwidth: DC to 100 kHz; Sampling rate: 500  ksample/s; 16 bit resolution for current and voltage; basic accuracy: 0.05 %.*

**Henning Wriedt:**  Circuit designers need sophisticated and reliable power supplies. What can they expect from R&S?

**Markus Herdin:** Rohde & Schwarz offers a wide portfolio of power supplies to meet the requirements of different applications, reaching from basic benchtop to performance and specialty power supplies. For example, the power supplies for educational purposes focus on stability and simple operation, while other models are tailored to specific applications and have advanced features. Our portfolio is constantly growing and you can expect new and interesting product introduction by Rohde & Schwarz in the product category of power supplies.

Markus Herdin (PhD), Market Segment Manager Industry, Components and Research, Rohde & Schwarz

Markus Herdin is a seasoned market development professional at Rohde & Schwarz with a focus on power electronics test & measurement applications. His previous experience at Rohde & Schwarz includes roles in product management, product development and corporate business development. Herdin holds a PhD in Electrical Engineering as well as an MBA from the University of Chicago Booth.

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# 8th ECPE SiC & GaN User Forum

## *Potential of Wide Bandgap Semiconductors in Power Electronic Applications*

*Since more than 12 years the biannual ECPE Wide Bandgap User Forum has given advise and support to the introduction and the usage of SiC and GaN devices in power electronic systems. Major progress has been achieved, with today a multitude of SiC diodes and transistors being available and used in series products.*

*By Andreas Lindemann, Otto-von-Guericke-University Magdeburg, Chair for Power Electronics*

For those, special aspects gain importance, such as robustness or qualification when exposed to demanding mission profiles. On the other hand ongoing research and development work is dedicated e. g. to increase voltage and current ratings of SiC devices, to GaN devices including their integration, the respective packaging technology and of course to the applications. Some main topics of this year's ECPE wide bandgap user forum 26 - 27 March 2019, Erding/Munich are summarised in the following:

**State of the Art and Trends**

Several international research programmes and centres have been introduced, contributing to the progress in SiC and GaN devices and systems making use of those. SiC devices have been found to be beneficial for applications in transportation - in particular automobiles with electric drive, and on a higher power level railway - as they permit to increase efficiency and power density.

SiC transistors and diodes may serve in traction converters or power supplies there. Photovoltaic inverters constitute another important application. Besides, also special applications have been addressed, e. g. high frequency induction heating - remarkably with resonant switching - or converters in the medium voltage grid as currently investigated as a future option. GaN transistors will mainly be rated up to 650V and used up to voltage levels as supplied by the 230V single phase grid, e. g. for hard switching power factor correction and similar power supply applications. Obviously the usage of wide bandgap devices requires more than just replacing silicon devices; instead only an appropriate circuit and system design will allow to fully exploit the wide bandgap devices' potential. This e. g. concerns aspects like the cooling concept, partially permitting to replace fluid by air cooling, or the isolation within the converter and beyond, e. g. in an electrical machine, taking into account the applied voltages and their high change rates.

Obviously the passives shall be chosen appropriately as well which in most cases seems possible but will not always rely on standard components. Careful parallel connection of relatively small wide bandgap devices may be required to achieve a high current capability.

With regard to SiC, devices and the related packaging technology have been addressed where advanced modules and embedding play an increasing role. Drivers dedicated to the transistors are sufficiently fast and make sure good electromagnetic compatibility taking into account the fast switching slopes and the need to maintain controllability. The devices have reached a high degree of maturity, providing good ruggedness e. g. under surge current or avalanche conditions.

Their reliability e. g. with respect to gate oxide stability, humidity and load cycles has been qualified; it should however be noted that the applicable test methods partially differ from what has been established for silicon devices and that the respective device modelling to understand failure mechanisms still is subject to research. With respect to GaN research activities aiming at an optimisation of material and the several types of transistors have been reported. Integration on chip level has been presented as well as hybrid integration and various packaging technologies, ranging from pre-packages e.g. for embedding via chip-scale packages up to more conventional solutions with minimised parasitics. Besides the aspects already mentioned with respect to SiC drivers, GaN drivers need to comply with the different driving conditions or voltages respectively of the devices, maintaining a standard interface towards the control unit. Major progress has been reported considering parasitic effects like dynamic on-state resistance and current collapse, further also considering breakdown towards the silicon substrate in integrated lateral GaN devices.

**Conclusion and Outlook**

The findings as briefly summarised above illustrate the fast development of wide bandgap power semiconductors. This is beneficial for power electronics as a key technology in various areas, such as energy efficiency, usage of renewable sources for electric energy supply, electromobility or also automation. Both, SiC and GaN devices are available and in particular SiC devices are well qualified and widely applied in commercial products. Nevertheless, research, development and also standardisation are ongoing to further explore the possibilities of wide bandgap devices in power electronics. The European Center for Power Electronics (ECPE) is a stakeholder in this area, bringing together industrial partners and research institutions. After the major interest of more than 300 participants in this year, ECPE will anounce the next SiC & GaN User Forum in conjunction with its annual event in spring 2021, where the progress achieved since today will be reported.

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# Leading-Edge Power Modules for the New Era in Traction Converters

*Today, 55 percent of the world's population live in urban areas, a proportion that is expected to increase to 68 percent by 2050 [1]. With this ever-increasing urban population, in combination with an increasing number of commuters on public transport, and a growing awareness of energy-efficiency and emission-free transportation systems, traction application is back in the limelight. A megatrend like urbanization provides a tailwind to improve, enhance and innovate today's traction converters and components within its ecosystem. Power semiconductors, which are core components of traction converters enhancing their reliability, efficiency and longevity, are of utmost importance.*

*By Vishal Jadhav, Wilhelm Rusche and Andre Lenze; Infineon*

Since the early 1990s, Infineon has been setting trends in developing leading-edge power semiconductor modules and technologies to facilitate innovation in converter design. Product offerings address the full spectrum of traction applications, from propulsion converters to auxiliary converters, enabling designers to achieve their design targets. Typical topologies for traction sub-applications such as trams, metros, electrical multiple units (EMU), high-speed trains and locomotives, are shown in figure 1a and 1b.

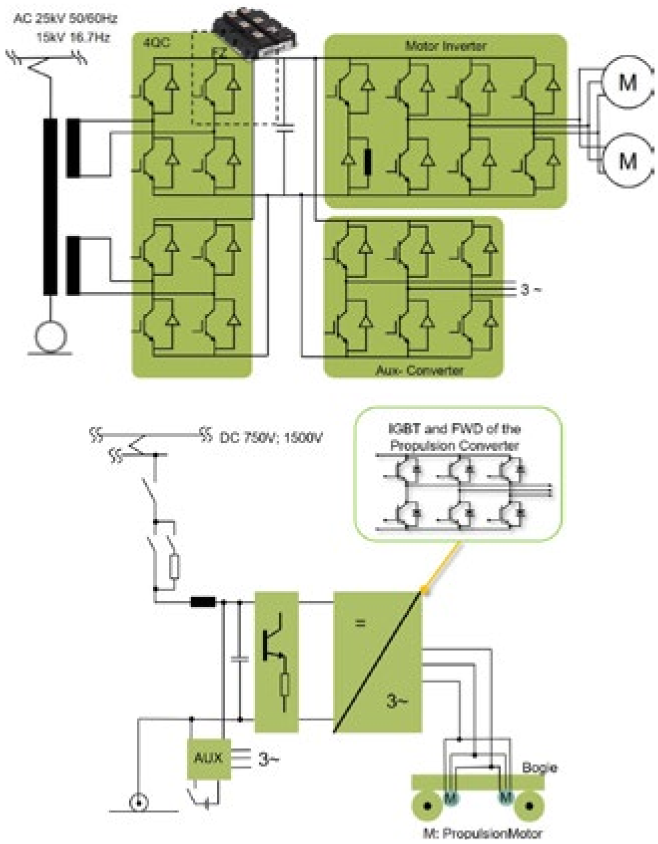


*Figure 1: Schematic depiction a typical topology in EMUs, high-speed trains & locomotives (above) and a typical topology in trams and metro applications (below)*

FZ1500R33HE3 in IHV-B 140 mm x 190 mm housing has been the basic building block in propulsion converters for applications with 1500 $V_{DC}$ – 2200 $V_{DC}$ links, i.e., metros, EMUs, high-speed trains and locomotives. 1500 A has been the preferred and most commonly available current rating; Infineon raises the bar once again with the introduction of the first 2000 A/3300 V in IHV-B package.

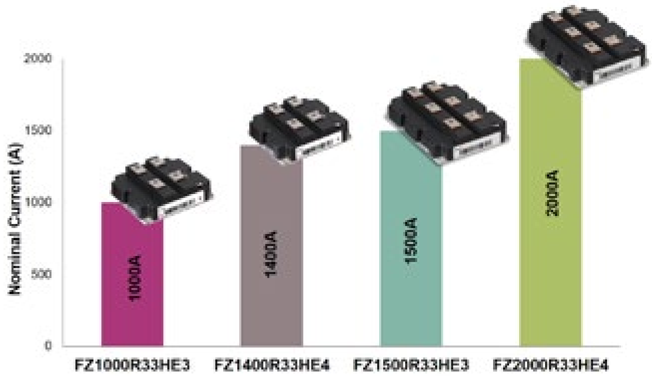


*Figure 2: Increasing nominal current in IHV modules for facilitating inverter design for traction applications*

**Boosting power density, with the first 2000 A/3300 V in IHV-B package**

Power density matters. The new 2000 A/3300 V module, the FZ2000R33HE4, offers a massive increase of 33 percent current density in comparison to the state-of-the-art 1500 A/ 3300 V module, raising the current density in IHV-B package to 7.52 $A/cm^2$. Applications such as metros, EMUs, and high-speed trains are based on today's well-established IHV modules due to its reliability, robustness, longevity and a field-proven record of accomplishment. Infineon introduced the FZ2000R33HE4 with the IGBT4 and EC4 diode in the 140 mm x 190 mm IHV-B housing to support traction converter designer can enhance existing converter platforms with a minimal design effort. Customers can easily design-in the 2000 A module without changing the DC-link and heatsink designs. A new cell structure of the IGBT4 in the FZ2000R33HE4 enables a gate charge of 40 µC, lower than the 1500 A device. This ensures that the gate driver design needs only a minor adaptation.

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Many of the existing traction designs use two modules of 1000 A in parallel, which can be replaced with one 2000 A module reducing the overall volume of the power stack. Additionally, the new 2000 A module can easily address new metro platforms with renewed motor designs requiring higher peak current, as well as EMUs and locomotives operating in high gradient areas. Infineon introduces another new module in the IHV-B package, the FZ1400R33HE4 in a 140 mm x 130 mm footprint increasing the current density to 7.69 A/$cm^2$. The 1400 A module in a 140 mm x 130 mm footprint enables customers to further optimize their existing converter designs and further improve the cost-performance ratio.

Increasing the current density of power modules leads to higher temperature ripple under cyclic load conditions, resulting in reduced lifetime. Enhanced aluminum wire-bonding technology is implemented in both new modules to increase the power cycling by a factor 2 times the standard bonding technology. The increased power-cycling factor can be further utilized to increase RMS current in applications with cyclic loads.

**XHP™ – flexible high-power platform for compact and scalable inverter designs**

Enhancing the IHV-B package satisfies the needs of today's traction converter. But, what about the requirements for a new, improved and standardized power semiconductor module which major European suppliers of traction equipment have outlined [2]? Infineon's fleXible High-power Platform (XHP™) addresses exactly this requirement.

The key motivation for introducing the XHP™ platform was to address system requirements for higher flexibility, higher current density and higher efficiency. Additionally, for clean switching, higher robustness and reliability, with a reduction of system costs. Within the XHP™ module family, the XHP™ 2 package is designed for voltage classes of 1.2 kV, 1.7 kV up to 3.3 kV, whereas the XHP™ 3 package is meant for voltage classes from 3.3 kV up to 6.5 kV. Both packages have the same footprint of 140 mm in length and 100 mm in width to facilitate the use of a common heatsink profile and homogenous converter platforms.

Sharing the same height of 40 mm for both module types ensures that standard insulators and mechanical spacers can be used. Developing both module solutions with identical dimensions supports designers' preferences for building a homogenous converter platform covering different voltage classes and power ranges. A single module becomes a building block for a converter, and higher current requirements can be fulfilled by simply building one block next to the other.

**XHP™ 3 – The high voltage module**

For the voltage classes of 3.3 kV and 6.5 kV, the XHP™ 3 module has been developed in a half-bridge configuration with an isolation voltage of up to 10.4 kV. The power terminal arrangement is further simplified with the DC terminals on one side and the AC terminal on the other side of the module. Due to the power terminal arrangement, the laminated DC-link busbar design is simplified, and thus, a low-inductive converter design is feasible. Auxiliary terminals are arranged in the area between the power terminals, this area been assigned for mounting gate driver electronics. The XHP™ 3 provides a large space of approximately 80 mm x 99 mm to mount the gate driver hardware, with or without an adapter board.

A structural comparison between two conventional IHV-B modules in half-bridge configuration and four XHP™ 3 modules results in a reduction of total commutation inductance from 90 nH down to 15 nH. This enables faster switching and lower overvoltage to achieve a reduction in switching losses. In comparison to an IHV-B, the XHP™ 3 offers easy gate driver assembly and accessibility, along with higher clearance and creepage distances.

*Figure 3: A step forward in flexibility: Infineon's high-power platform for higher power density and efficiency – XHP™ 3 (left) and XHP™ 2 (right)*

The system's stray inductance of a converter based on XHP™ 3 typically ranges from 30 nH to 40 nH, but even at similar system stray inductance, the XHP™ 3 switches faster than the IHV-B module reducing $E_{on}$ losses by roughly 21 percent. Due to the lower stray inductance of XHP™ 3 and faster switching, it is important to experimentally select the gate resistor according to the application requirements. Increasing the voltage slew rate dv/dt results in a higher turn-off di/dt, which in turn reduces the turn-off losses but generates higher voltage overshoots. At a similar dv/dt and system stray inductance, the voltage overshoot for the XHP™ 3 is reduced by 30 percent, which in turn results in a 5 percent reduction of turn-off losses [3].

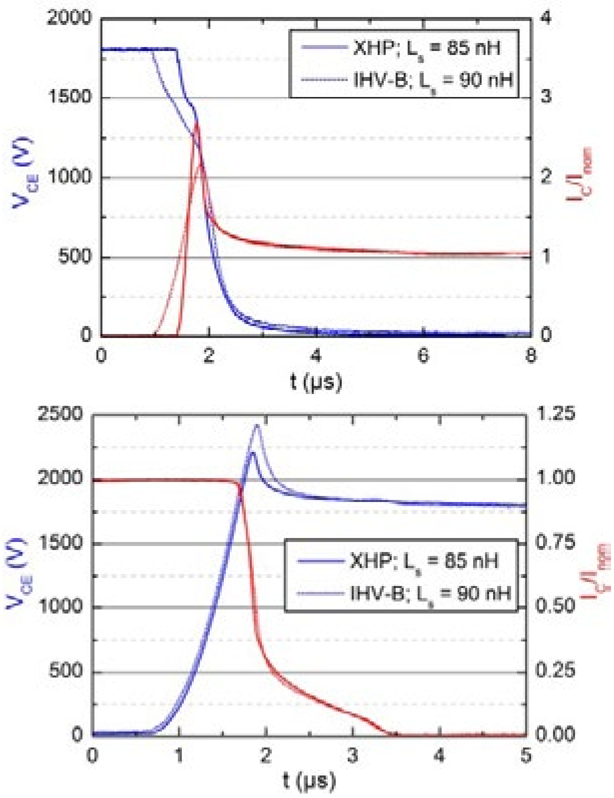


*Figure 4: Switching behavior of XHP™ 3 compared to IHV-B, above: turn-on, below: turn-off*

In traction applications, where 1500 V is a prevalent catenary, or where the intermediate circuit voltage ranges, for example, from 1800 V to 2200 V, it is customary to use 3300 kV switches in a standard 2-level topology. System complexity in 2-level converter designs can be significantly reduced by using XHP™ 3 modules, additionally


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| Part number | Package | Output current max [A] | Adjustable deadtime | Supply voltage | TTL/CMOS logic inputs [V] | Common-mode transient immunity [V/ns] | Propagation delay [ns] | Additional features | Voltage max [V] |
|---|---|---|---|---|---|---|---|---|---|
| **L6491** | SO-14 | 4 | Yes | 10-20 | 3.3, 5 | 50 | 85 | Integrated bootstrap diode, smart shutdown comparator (L6491), under-voltage lock-out, interlocking function | 600 |
| **L6494L** | | 2 | | | | | | | |
| **L6498** | SO-8 | | No | | | | | | |
| **L6498L** | SO-14 | | | | | | | | |



For further information and full design support, visit us at **www.st.com/stdrive** providing the possibility to scale the power if required. An XHP™3 package in 3.3 kV (FF450R33T3E3_B5) has an isolation of up to 10.4 kV which supports topologies like the 3-level chopper and the conventional 3-level NPC-1 topology as depicted in Figure 5, [5].

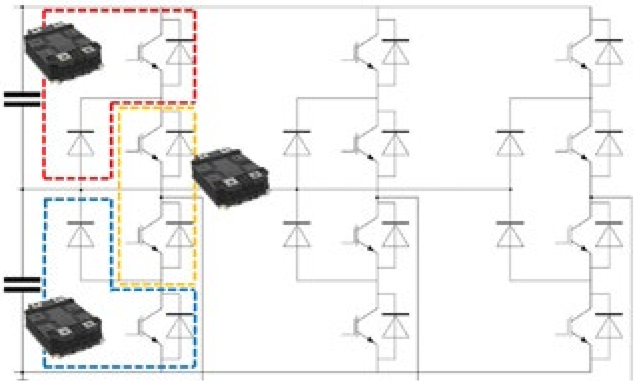

*Figure 5:*
*Schematic depiction of 3-level topologies in traction applications*

However, it is not only about power density. Applications such as metros have higher cyclic loads, which demand higher power cycling. The new FF550XTR33T3E4 module with the IGBT4 and .XT technology in XHP™ 3 package addresses such applications, which require higher power density and longer lifetimes.

**Enhancing lifetime and power density with FF550XTR33T3E4 IGBT4 and .XT technology**

The new FF550XTR33T3E4 module in the XHP™ 3 package is embedded with the new IGBT4 and EC4 diode based on the field-proven trench gate structure, in combination with an enhanced edge termination. The forward voltage drop of the EC4 diode is 200 mV lower than the EC3. The combination of enlarged chip area and the .XT technology further improves the thermal resistance $R_{thjc}$ by 20 percent. The .XT technology with enhanced aluminum bonding is implemented in this module to meet application requirements for higher power-cycling capability and higher power density. The new chip technology, reduced thermal resistance, and an enhanced bonding technology forms the new 550 A/3300 V half-bridge module to deliver an increased rms current of 30 to 40 percent. Applications like metro and EMU demand longer lifetime under cyclic load condition in combination with higher power density for their next-generation converter platforms.

**.XT technology: increased power-cycling capabilities**

.XT interconnection technology was introduced in the PrimePACK™ module to increase power-cycling capability to address higher lifetime requirements for applications like wind, special industrial servo/high-performance drives and commercial vehicles. The .XT technology in 1200 V and 1700 V extends the power-cycling capabilities by a factor of 10. With the launch of the new FF550XTR33T3E4 module, the spectrum of .XT interconnection technology has been further expanded to include 3300 V modules to extend the power-cycling capabilities by a factor of 5.

Applications like metros, EMUs, high-speed trains and locomotives have DC-link voltages in the range of 1500 V to 2200 V, which can be addressed by 3.3 KV modules in the IHV-B and XHP™ 3 package. However, some of the metro lines and trams run on 750 $V_{DC}$ catenary, which requires power semiconductors with 1700 V blocking voltage in a 2-level configuration. Infineon has introduced the new XHP™ 2 product platform equipped with the 1700 V IGBT5 .XT to meet the requirements of such applications.

**XHP™ 2 – Smart solutions for propulsion converter in urban transportation systems**

Megatrends like urbanization are driving investment in traction sub-applications such as trams and metros, which operate for short distances within the city limits. A typical tram stops after a few 100 meters, while a light rail or metro have a typical distance of 1000 m between two stops. Figure 6 depicts a generic exemplary mission profile for an electric propulsion system of a metro application.

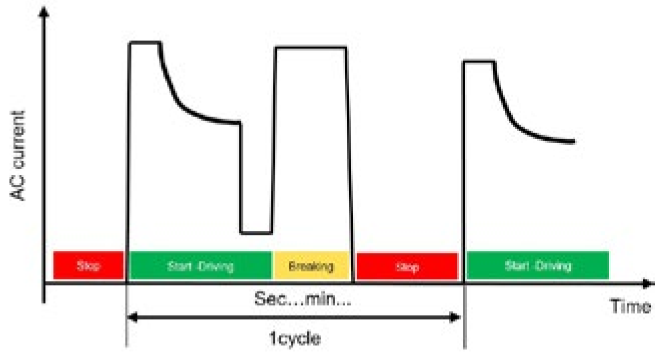


*Figure 6: Exemplary mission profile for a Metro application*

During the acceleration phase, the energy in the converter is mainly conducted by the IGBTs, and during the braking phase, the freewheeling diodes (FWD) have to conduct the generated reverse energy. These short distances performed in day-to-day operation result in enormous electrical stress, especially on the power modules. IGBT and diode chips in the power modules have to withstand this enormous electrical, mechanical and, in particular, thermal cycling stress.

Major criteria for the long-term reliability of power devices depend upon the power modules' capability to withstand these cyclic thermal loads. The dominant end-of-life (EOL) mechanism for standard joining technologies in such demanding applications are the degradation of solder layers and the aluminum-bond wire lift-off on the chip. These interconnections are highly stressed by the relative temperature swing $\Delta T$ at the resulting junction operating temperature $T_{vj,op}$ and by the duration of this thermal stress ($t_{on}$) [4,5]. Based on these challenging application requirements, today's power modules are typically dimensioned by selecting a higher current rated module or by paralleling smaller modules to reduce the thermal loads and fulfill the high lifetime requirement. To achieve optimized solutions in the power converter, the typical wear mechanisms must be significantly improved and shifted to a much longer running time, or if possible, eliminated.

Infineon's 5th generation chip with its .XT technology provides a considerable enhancement in terms of robustness against cycling loads [6]. In addition to the optimized chips and joining technologies, the ratio of chip sizes between IGBT and diode are balanced based on the application requirements. Figure 7 compares the results of a lifetime simulation of a metro mission profile. For addressing the requirement of 30 years of lifetime, two devices of 1200 A/1700 V IHM in parallel are required. In comparison, only one 1200 A/1700 V XHP™ 2 module with IGBT5 .XT is required.

Integrating the new 5th generation IGBT and diode technologies with operational junction temperature $T_{vj,op}$, of 175°C, the maximum module current for the 1700 V XHP™ 2 is further increased up to 1800 A. Infineon introduces two new modules in 1700 V XHP™ 2 housing, the FF1800XTR17T2P5 and the FF1200XTR17T2P5. They are equipped with 5th generation IGBT and emitter-controlled diode with .XT joining technology.

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| TPP 15A-D | 15 | | | • | | | • | • | • | • |
| TPP 15-J | 15 | | • | | | • | | • | • | • |
| TPP 15-D | 15 | | • | | | | • | • | • | • |
| TPP 30A-J | 30 | | | • | | • | | • | • | • |
| TPP 30A-D | 30 | | | • | | | • | • | • | • |
| TPP 30-J | 30 | | • | | | • | | • | • | • |
| TPP 30-D | 30 | | • | | | | • | • | • | • |
| TPP 40A-J | 40 | | | • | | • | | • | | |
| TPP 40 | 40 | • | | | • | | | • | | |
| TPP 65A-J | 65 | | | • | | • | | • | | |
| TPP 65 | 65 | • | | | • | | | • | | |
| TPP 100A-J | 100 | | | • | | • | | • | • | |
| TPP 100 | 100 | • | | | • | | | • | • | |
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Improving power density and efficiency is not only limited to propulsion converters. There have also been significant improvements in weight, volume and efficiency in auxiliary traction converters by using SiC-MOSFET devices. Here, Infineon offers a wide range of CoolSiC™ MOSFET modules to facilitate the next generation of energy-efficient auxiliary converters.

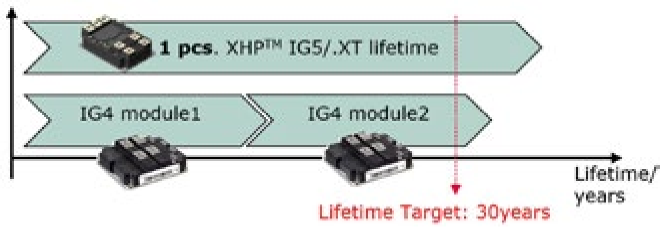


*Figure 7:*
*Comparison of lifetime for XHP™ 2 against two IHM modules*

**SiC-MOSFET to boost system efficiency and power density in auxiliary converters**

Auxiliary converters commonly known as Auxiliary Power Units (APU) are integrated into trains to isolate power lines to support electrical loads, e.g. fans, heaters, air conditioners, laptops, power sockets etc. Since weight and efficiency are the key requirements for APUs in-rail vehicles, the use of CoolSiC™ MOSFET modules show a huge benefit due to the unique performance of SiC. Compared to state-of-the-art Si solutions, CoolSiC™ MOSFET modules offer several advantages for the application including:

- Higher efficiency
- Smaller size of passive components like chokes, transformers, capacitors etc. due to operation at higher switching frequencies
- Less cooling effort to decrease weight and volume of the system
- Less audible noise.

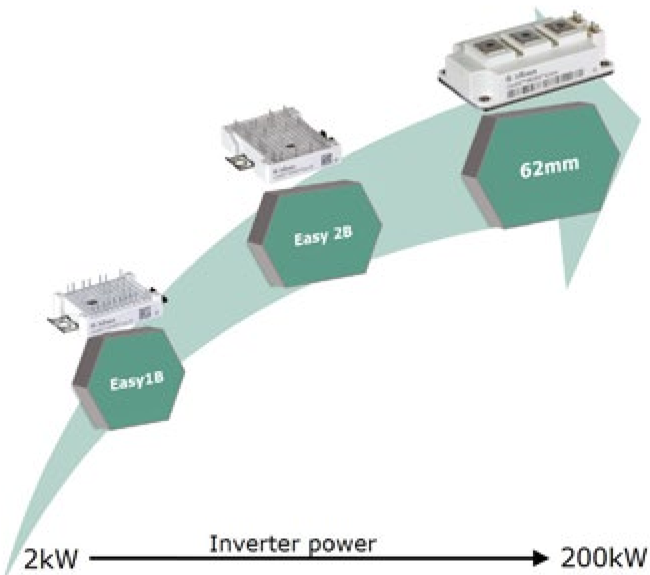


*Figure 8: Inverter power depending on SiC MOSFET module*

Infineon's CoolSiC™ MOSFET modules with an on-state resistance $R_{DS(on)}$ of between 45 mΩ and 2 mΩ are a perfect match for APU applications. The dynamic performance of the SiC-MOSFET, being a unipolar device, is mainly determined by the capacitances, and thus optimized in terms of dynamic losses. The ratio of the gate-drain reverse capacitance $C_{rss}$ compared to the input capacity $C_{iss}$ is designed to suppress parasitic turn-on events. The knee voltage-free conduction behavior offers a significant potential for loss reduction. APU generally operates under partial load conditions, resulting in considerably lower conduction losses for a majority of the operation lifespan. Additionally, positive temperature coefficients of the on-resistance makes the devices suitable for paralleling.

Electrical performance, however, is only part of the story. For fast switching of SiC devices, the package design as well as the system layout is of equal importance. For this reason, Infineon has developed a broad portfolio of packages. The popular and flexible Easy 1B / 2B as well as the 62 mm power modules are used to implement half-bridge configurations, booster solutions, H-bridges and six-packs.

The flexible pin grid of Easy modules makes the PCB layout easy and offers <10 nH stray inductance. This is a factor 5 improvement over previous solutions, and represents a valuable step in power module design. 62 mm modules provide increased clearance and creepage distances for the DC/DC converter, as well as the ISO voltage of 4 kV.

**Summary**

Infineon's product offerings address the full spectrum of traction applications, from propulsion converters to auxiliary converters, enabling designers to achieve their design targets. The focus has been to continuously enhance the IHV-B product family to enable improvement of the existing converter platform. The new 2000 A/3300 V with 33 percent higher current density addresses application requirements for more power. The 1400 A offers a better cost-performance ratio in comparison to the state-of-the-art module.

XHP™ 3 and XHP™ 2 have been developed in line with the requirement set by the European traction equipment manufacturers and will be the future building block of traction converters. The new 1800 A/1700 V in XHP™ 2 enables customers to achieve the required lifetime, and to reduce the module size at the same time for applications such as trams and metro systems with 750 $V_{DC}$ link. Infineon offers SiC-MOSFETs in the flexible Easy 1B and Easy 2B packages as well as in the field-proven, low-inductive 62-mm package. SiC-MOSFET modules provide higher system efficiency, reduce the number of passive components, and reduce the cooling efforts to decrease the weight and volume of the system. Last but not least, they also significantly reduce the audible noise. From high-power, high-voltage propulsion converters to, low-voltage auxiliary converters, Infineon is the one-stop solution provider for reliable power semiconductors.

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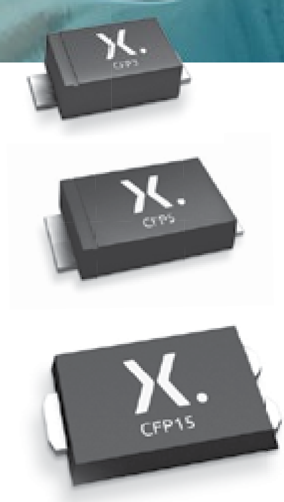


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# New Current Sensors Measure Higher Currents While Staying the Same Size

*As power electronics systems get smaller LEM is introducing 3 new families of compact open-loop current sensors which measure higher currents than earlier sensors of the same size, or similar currents with smaller size. Excellent performance is obtained using a single custom ASIC to perform all signal processing and analog correction functions. This article describes the sensors and their key electrical characteristics. It concludes with some application examples.*

*By David Barbagallo – R&D project manager, Pierre Turpin – R&D project manager and Thomas Hargé – Global Products Manager for Renewable Energies & New Markets, LEM*

**Introduction**

The current measurement trend today in for example UPS systems and in power generation from renewable sources continues towards smaller physical size, higher current ranges, faster response times that go with faster switching frequencies, and of course lower cost. The simplicity of open-loop sensors makes them an attractive solution for attaining these objectives.

In this article we present three new families of sensors which allow the nominal current to be as high as 800 Amps RMS and detection of an overcurrent up to seven times higher. The miniature HLSR xx/SP10 sensors are an extension of the existing HLSR family with an integrated primary conductor; they are mounted on a PCB and are the best choice if small physical size is important. The two other families, HOYS and HOYL are busbar mounted with new magnetic circuits optimized for weight and size. The open-loop HLSR and HO sensors introduced by LEM 5 years ago indeed meet the objectives of size, accuracy, speed and cost but the nominal primary current of the smaller HLSR is limited to about 50 Amps by saturation of the ferrite magnetic circuit. (Reference 1).

Often closed-loop sensors have been used to meet the accuracy and speed requirements of high current sensors but the secondary coil which cancels the magnetic field from the measured current adds to the device size, current consumption, complexity and cost. In high current devices the secondary must be driven from a high supply voltage or complex electronics. A preferred approach is to use an open-loop architecture in which the imperfections inherent in an open-loop system are mastered by using a complex ASIC as the magnetically sensitive element. This technique was already used in the earlier lower current sensors: any errors of sensitivity or offset, including their drift with temperature, are measured during the ASIC production test and stored in it. The corrections needed are applied continuously when it is used and most electrical parameters approach the level of the previous generation of closed-loop sensors.

Figure 1 shows one of the high current HLSR xx/SP10 sensors. It has the same small physical dimensions and footprint as the existing family members, but the maximum nominal current is extended from 50 to 120 Amps by a new FeSi magnetic circuit. In all cases the maximum current which can be measured is 2.5x the nominal current. The HLSR has an integrated primary and is mounted on a PCB. The four other connections to it are for the secondary side supply, the output voltage $V_{OUT}$ and a reference voltage $V_{REF}$. $V_{OUT} – V_{REF}$ is proportional to the measured current.

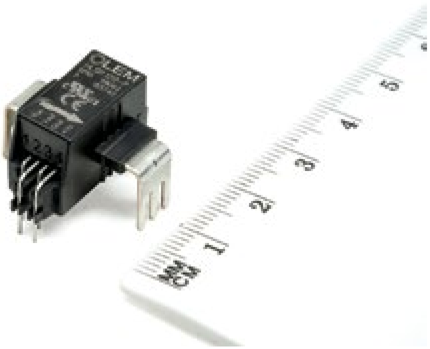

*Figure 1: an HLSR xx/SP10 sensor*

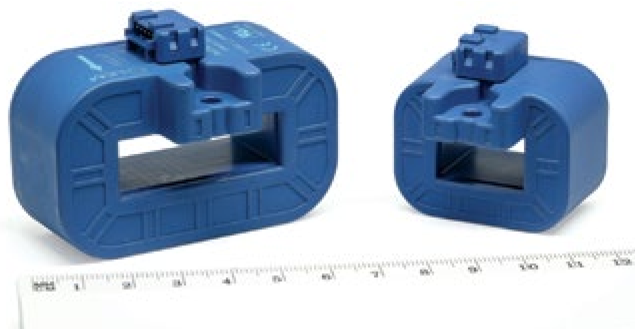

*Figure 2: HOYL (left) and HOYS (right) sensors*

Figure 2 shows the new HOYS and HOYL sensors which are respectively ‘small’ and ‘large’ devices for mounting on busbars up to 21 x 12 mm and 39 x 12 mm respectively. Together they cover the current range from 100 to 800 Amps – with a maximum measurable current of 2000 Amps. These sensors have a fifth output pin, OCD, which shows that an overcurrent condition has been detected on the primary current. Their compact size is due to the optimization of the magnetic circuit and package around the busbar and because there are no electronic components inside the sensors except the Hall effect ASIC and two decoupling capacitors.

**Sensor Performance**

The supply for the measuring (secondary) side of the sensors is 3.3 V or 5V and the output is referenced to half that value, generated by the sensor (although other reference voltage values may be forced from an external source). Apart from the variations in size and mounting arrangement the differences in performance between the HLSR and HOY families are mainly due to their magnetic circuits.

In sensor applications switching speeds are rising and therefore response times must be shorter so that unusually high current and short-circuit conditions are detected quickly. In the new sensors the CMOS ASIC contains Hall cells as the magnetically sensitive element and all the signal processing circuits. A high clock speed is used to give a fast response time, less than 3.5 us, while filters minimize the noise at the sensor output by limiting the ASIC signal path bandwidth to that needed to pass the current waveform.

Two of the most important characteristics of high current sensors are linearity and, when the primary is part of the sensor, thermal dissipation. A comprehensive series of simulations and tests has been performed to validate these aspects of the new sensors.

The capability of the HLSR xx/SP10 magnetic circuit was validated by building a test sensor with an $I_{PN}$ of 180 Amps, 50% above the highest production value, and measuring its linearity. The result for a current of $I_{PM}$ (+/-450 Amps) is shown in figure 3a. The curve shows the difference between the measured output and an ideal perfectly linear output. With a maximum of 0.5% of $I_{PN}$ it demonstrates that the linearity specification for the series sensors is attained with good margin. (Note that short current pulses were used for this test, 450 Amps is too high for a continuous current in the primary.)

The capabilities of the HOYS and HOYL sensors are shown by their linearity in figures 3b and 3c respectively. In these tests the primary current covered the range +/- $I_{PM}$, but the linearity error is expressed relative to $I_{PN}$, a more demanding specification.

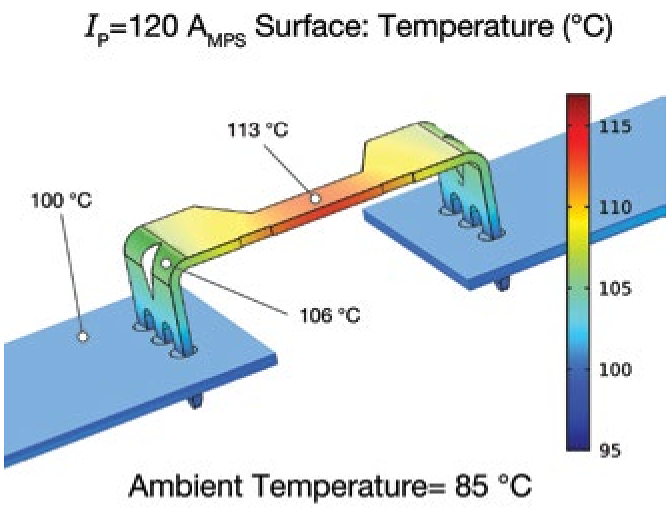


*Figure 4:*
*Thermal simulation of the primary of an HLSR xx/SP10 sensor*

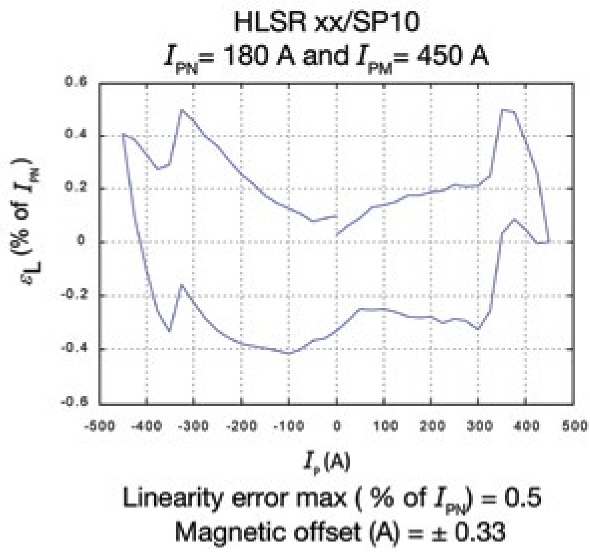


*Figure 3a:*
*example of linearity and magnetic offset of an HLSR xx/SP10 sensor*

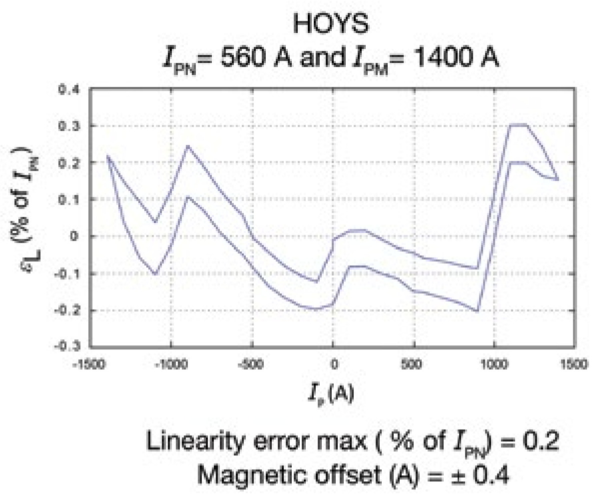


*Figure 3b:*
*example of linearity and magnetic offset of an HOYS sensor*

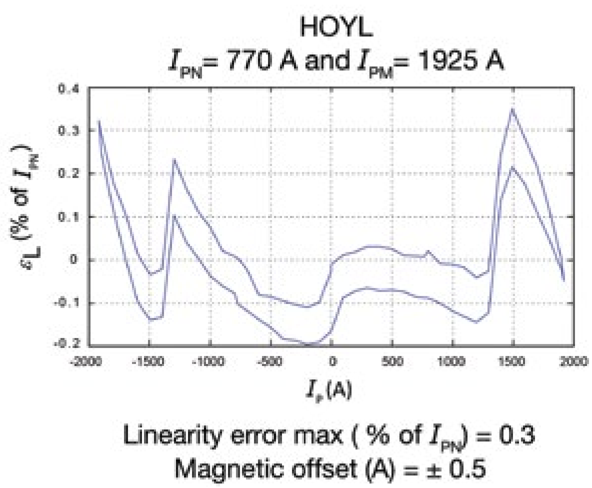


*Figure 3c:*
*example of linearity and magnetic offset of an HOYL sensor*

For the HLSR xx/SP10 sensor, whose primary is part of the device, it is important to know the thermal characteristics when a high current passes through it. Clearly the sensor heating depends on the PCB to which it is soldered as well as the sensor itself. Today's PCB technology allows for maximum currents of around 100 Amps: in the example simulated here all of the four layers of the PCB are used; its design and cooling by natural convection maintain the solder joints at 100 °C in an environment at 85 °C. Figure 4 shows the results – only the sensor primary is shown, however for the simulation it is situated as usual in the sensor housing. With a current of 120 Amps DC the hottest part of the primary stabilizes at 113 °C, just lower than the 120 °C maximum allowed.

A particularly useful feature of the HOYx sensor family is overcurrent detection (OCD). The input used for OCD detection is taken before the sensor output amplifier and filters – see the simplified block diagram of figure 5. This has two advantages: the signal here is of lower amplitude so a current level higher than that which saturates the sensor output can be detected, and the OCD response time is faster than that at the output. By default the OCD threshold is set at 2.93x $I_{PN}$ but 15 other multiples from 0.68x $I_{PN}$ to 7.06x $I_{PN}$ may be selected at the time of ordering the sensor. The exact multiples available are shown in the datasheets (Reference 2): in the most extreme case an OCD level of 5'648 Amps may be chosen for the 800 Amp version of the HOYL sensor. Note that OCD levels are accurate only to 10 or 20%, depending on the level chosen, but this is more than good enough for the fast warning function that OCD performs.

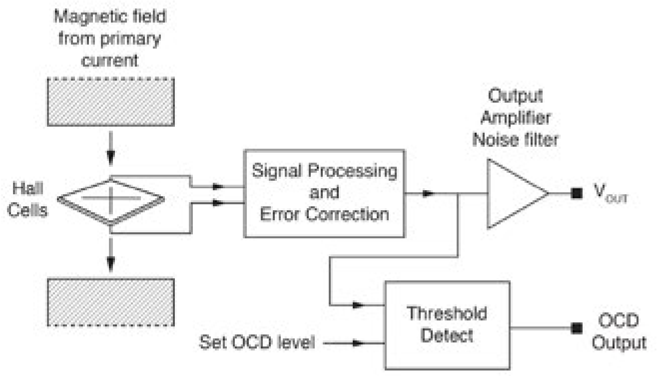


*Figure 5: the OCD system*

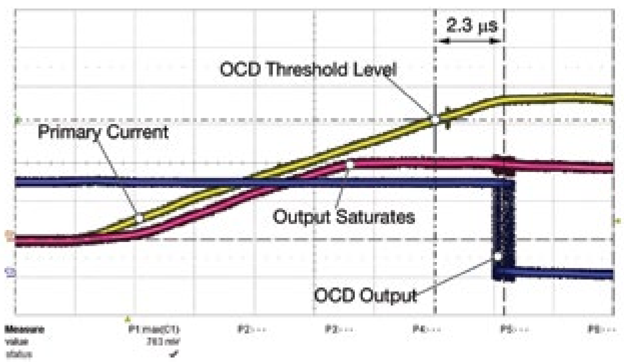


*Figure 6: current and sensor waveforms when the OCD is triggered*

Figure 6 shows an example of the OCD output: the primary current (yellow) is ramped up above the level which saturates the sensor output (red); 2.3 us after the OCD threshold is crossed its output (blue) falls to 0V. The OCD output is an open drain which allows several to be connected to a single warning line. The spread of OCD response times is due to the primary current not being synchronized with the sensor clock.

The new sensors have excellent isolation characteristics. In all of the HLSR and HOY sensors there is full galvanic separation between the primary and secondary circuits. For example, the 1.2/50 µs 'impulse withstand' insulation test allows 8 kV with the HLSR sensors and 9.6 kV with the larger HOYL family.

Sensor reliability is another important consideration: the construction of open-loop current sensors is extremely simple, with only one active component – the Hall effect ASIC – and very few solder joints (none at all in the case of the HLSR family). The reliability of this sensor type is therefore excellent, with a FIT rate of 3.4, corresponding to a MTTF of 294'170'980 hours.

Table 1 shows a summary of the principal electrical characteristics of the HLSR xx/SP10 and HOY sensors. The complete details are in the product datasheets.

| **Parameter** | **HLSR xx/ SP10** | **HOYS / HOYL** | **Comment** |
|---|---|---|---|
| Nominal Current, $I_{PN}$ (A) | 80 - 120 | 100 - 800 | |
| Maximum Current, $I_{PM}$ (A) | 200 - 300 | 250 - 2000 | |
| $V_{OUT} – V_{REF}$ (mV) | 800 | 800 | 5V supply; Input current = $I_{PN}$ |
| Response time (us) | 2.5 | 3.5 | |
| Bandwidth (-3dB) (kHz) | 250 | 180 / 140 | Small signal |
| Noise at the output (mVpp) | 8.8 | 5.8 – 8.6 | In 100 kHz bandwidth |
| OCD available | No | Yes | |
| Overall accuracy (% of $I_{PN}$) | +/-1.0 | +/-1.0 to +/-1.25 | At 25 °C |
| Overall accuracy (% of $I_{PN}$) | +/-3.8 | +/-3.8 to +/-4.0 | At 105 °C |
| Impulse withstand voltage (kV) | 8 | 9.6 | 1.2/50 us rise/fall |
| Footprint ($cm^2$) | 3.87 | 11.0 / 17.8 | |

*Table 1*

**Application Example 1: UPS Get Smaller**

Uninterruptible Power Supplies (UPS) are being driven by two technology trends: faster switching devices allow lower value reactive elements to be used; these are physically smaller so the electronics can all be PCB mounted – and of course the current sensors have to follow the same size trend so as not to dominate the PCB surface. At the same time, higher currents can be passed by using many or all of the layers on multi-layer PCBs – some layers may be thick and dedicated to high current capacity. The HLSR xx/SP10 sensor is ideally situated at the intersection of small size, high current ranges and PCB

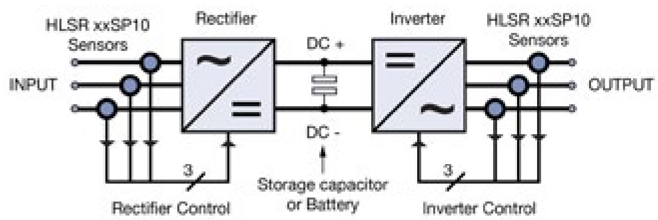


*Figure 7: HLSR xx/SP10 sensors in a UPS system*

mounting. Figure 7 shows a simplified application schematic in which HLSR xx/SP10 may be used in the control loop for the switches used both for AC to DC and DC to AC conversion.

**Application Example: Large Measuring Range and OCD for Wind Turbines**

In this application the large current measuring range and the OCD feature of the HOYx sensors can be useful. The generator driven by a wind turbine may use power from the network it drives for its stator coils. See figure 8: the AC/AC converter output when mixed with AC current from the generator creates the correct 50 Hz waveform for the network which is powered. If the network load draws too much current the power available for the generator may become insufficient, worsening the effect of the excessive load and, if there is no LVRT (Low Voltage Ride Through) capability, the failure of one generator may propagate through the network and cause others to fail. Part of the LVRT solution is to detect overcurrent on the network side, where the large HOYx measuring range is advantageous; the OCD feature is useful to decide different corrective actions and to confirm that current spikes have disappeared. The low physical size of the HOYx sensors makes them easy to deploy in these applications.

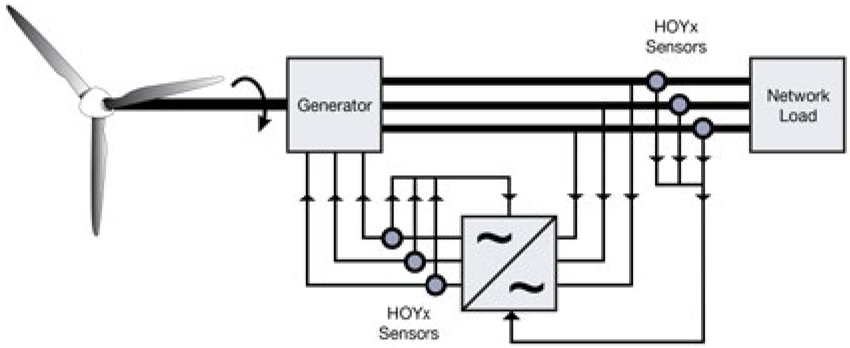


*Figure 8: HOYx sensors in a wind turbine system with LVRT*

**Conclusion**

This article has introduced new sensors allowing currents of up to 2000 Amps to be measured using a simple low cost open-loop architecture. In many cases their performance will allow them to be used instead of more complex sensors. Their compact size, low supply voltage and the HOYx OCD feature will give designers new possibilities to implement efficient and economic systems.

Reference (1): https://www.lem.com/en/file/3135/download

Reference (2): https://www.lem.com/en/product-list?keys=HOYL and https://www.lem.com/en/product-list?keys=HOYS

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# The Next Generation of High Power IGBT Modules

## *LV100 for Wind Converter, Photovoltaic Inverter and Motor Drives*

*High power applications in the fields such as renewable energy and industrial drives require reliable and scalable power modules with high power density and low stray inductances. In order to fulfill these requirements, the concept of the well-known and successful HVIGBT LV100 package has been transferred and adapted to the needs of renewable and industrial applications.*

*By Thomas Radke and Narender Lakshmanan, Mitsubishi Electric Europe B.V*

**LV100 Concept**

Applications like wind energy converters, central photovoltaic inverters and industrial drives require power modules with the highest power density, high reliability, and scalable power ranges with a standardized outline in the voltage classes of 1200V and 1700V. To fulfill such requirements, the LV100 power module is based on same outline and internal layout concept as the well-known HVIGBT LV100 module. This concept is convincing because it is based on a standardized package outline while also capable of delivering the highest power density, scalability by easy paralleling, low stray inductance, capability to operate with fast switching devices like SiC MOSFETs and having excellent current sharing balance. In combination with the latest 7$^{th}$ generation IGBT and Diode efficient chips and the thermal cycle failure free SLC-package-technology, the LV100 module provide the best overall performance. In the 1700V, a current rating of 1200A has been realized which represents an outstanding current density considering the compact package footprint of only 144x100mm².

*Figure 1: New LV100 Power Module for industrial application*

**LV100 Internal Layout**

In high power IGBT modules, multiple chips are connected in a parallel configuration because IGBT chips sizes are limited and usually the rating maximum current is in a range of ~200A for IGBT chips with blocking voltages of 1200V or 1700V. Therefore, for the realization of an IGBT module with a current rating of 1200A or more, paralleling of at least six or more IGBT chips is required. While designing the layout, the current balancing between the chips connected in parallel has to be considered. Equally shared chip currents are required for achieving homogeneous loss and heat distribution. A non-homogeneous current distribution causes a certain chip to carry the highest current and this chip will experience the highest temperature which ultimately limits the performance and life-time of the total system. The parasitic impedances of the connection to the individual chips significantly influence the current sharing between the chips operated in parallel. In case the parasitic inductances are not equally designed for all chips, a dynamic current imbalance during IGBT switching will occur. The module terminal arrangements and the chip positions are the major influencing factors for the parasitic impedances. To realize an equal impedance, the distances from the power terminals to all the chips have to be ideally the same. This can be achieved by optimizing the terminal and chip arrangement so that it is perpendicular to the current flow as shown in figure 3 [6]. In the ideal module concept, the commutation (indicated by the blue and red arrows) is only in Y-direction whereas the terminals and chips are orientated perpendicular in x-direction.

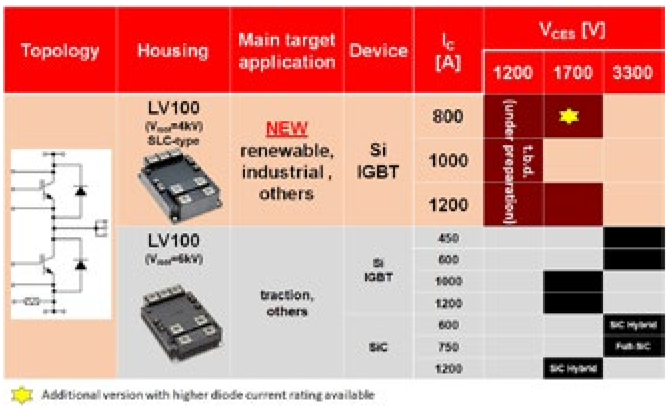


*Figure 2: LV100 product line-up plan*


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High power applications in the field of renewable energy and industry require reliable, scalable and standardized power modules. Providing optimized solutions, Mitsubishi Electric is expanding the line-up of the standardized LV100 package to 1200V and 1700V blocking voltages by utilization of proven SLC package and 7th Gen. IGBT/Diode chips technology.

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By this approach, equal parasitic impedances are achievable. This ideal concept was considered in the development of the LV100 layout and a homogenous current sharing, as shown in the simulation result in figure 4 was realized. The conventional modules available today in the field of high power industrial drives or converters for renewable energy usually have a terminal arrangement which is parallel to the chip arrangement and current flow. As a result of this conventional design, equal parasitic impedances was not be realizable and the resulting imbalance in the current sharing was an accepted feature of the conventional modules. For events such as load short circuits, due to the absence of the inductive coupling in the laminated busbars, the impact of the unequal stray inductances between different chips becomes significant for such conventional modules.

In case of fast switching semiconductor devices with high di/dt, the differences in parasitic stray inductances between the chips will influence the current sharing enormously. Therefore, if an inverter designer considers changing to SiC devices in future, the LV100 package is the right choice since the layout concept is ready for SiC [8]. As result, a potential future change from Si-IGBT to SiC-MOSFET [9] devices is feasible with less changes and redesign efforts.

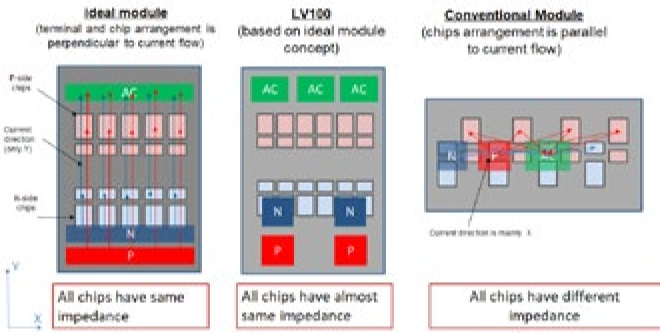



*Figure 3: Comparison of power module layout concepts*

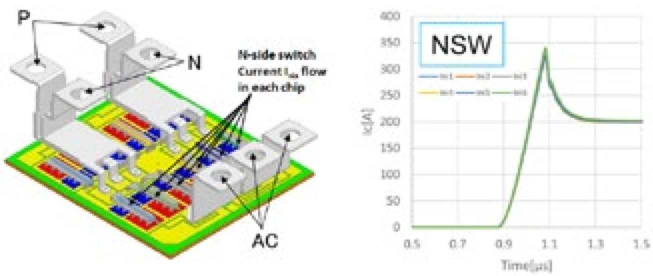



*Figure 4: Simulation result of current sharing at turn-on event in LV100 package concept.*

**Thermal cycle failure free package**

IGBT modules in high power industrial drive applications experience thermal cycling [1] in case of fluctuating (or non-continuous) loads. Wind power converters are usually liquid-cooled with the cooler having a thermal time constant of a couple of seconds. As a result, the IGBT case temperature will respond rapidly to a temperature swing by changing of load conditions. That means on days with fluctuating wind conditions the IGBT module baseplate will experience many thermal cycles. Also photovoltaic inverters experience at minimum one huge thermal cycle per day. Considering an inverter life-time of 25 years, the IGBT module have to be capable to resist several thousand thermal cycles. The thermal cycle capability of conventional industrial IGBT modules with conventional package structure (with several pieces of ceramicling substrates solder to copper baseplates), is limited. Hence thermal cycles have to be considered as lifetime limiting parameter during the converter design. To eliminate thermal cycling as lifetime limiting parameter, the SLC-Technology [2] [3] has been selected for the LV100 development for industrial application. As shown in figure 5, the conventional power module package structure is replaced by an IMB (Insulated Metal Baseplate) in combination with a direct potting resin. The thermal expansion coefficient of the insulator and the potting resin are matched with each other [4] (considering the thermal expansion of copper base- and pattern-layer. Due to this matching thermal expansion and the elimination of system solder layer, a thermal cycling failure free package structure has been realized [5].

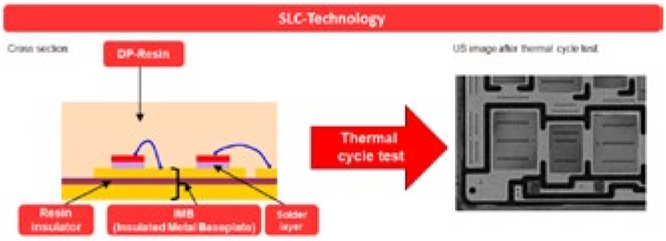
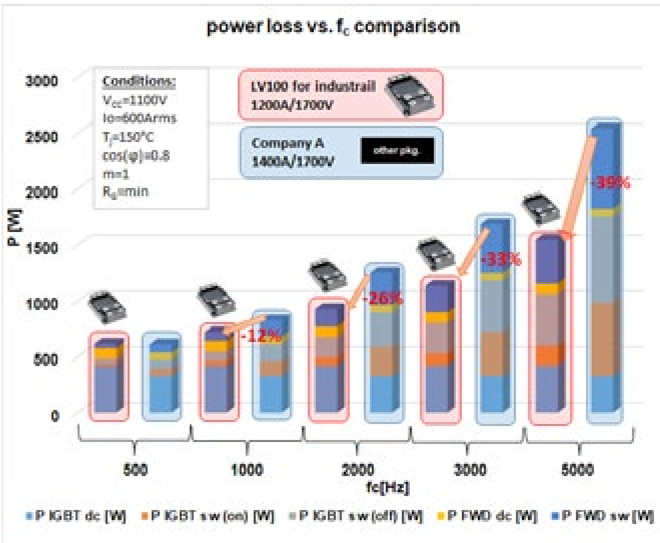



*Figure 5: SLC-Technology and thermal cycle test result*

**7th gen 1700V IGBT chip-set**

The 7th gen IGBT and diode chips possess an optimized structure and are thinner than its predecessors. Additionally, the devices have been designed by selecting an appropriate trade-off between the DC performance and the switching performance [5]. The inverter losses under typical application conditions for high power converters has been performed by Mitsubishi Electric Melcosim [7] simulation software. In figure 6 the result and comparison of 1200A/1700V LV100 vs a conventional 1400A/1700V module from company A. It is noticeable that for a switching frequency of 500Hz the total losses are comparable. However due to the appropriately selected trade-off in combination with the optimized chip structure, the diodes and the IGBTs indicate switching losses are significantly reduced. The result is that for switching frequencies higher than 500Hz, the LV100 has significantly higher efficiency. For example, at a switching frequency of 5kHz the loss reduction is 39%. This loss reduction contributes to reduce the cost of total inverter by reducing efforts for cooling and enabling to achieve higher power density of the system.




*<<Figure 6: Power loss comparison of 7th gen. IGBT chip in LV100 1200A/1700V module vs. Company A 1400A/1700V conventional module. >>*

## Conclusion

A new high power IGBT module (LV100 for industrial) is under development, which has been optimized for the requirements of high power applications in the field of renewable energy converters, and industrial drives. The outline of the module housing is same as HVIGBT LV100 and in line with the new market defacto standard. The SLC-package-technology is thermal cycling failure free and improves the reliability of the system. The 7th gen IGBT chip technology provides a significant reduction of switching losses and is beneficial considering a switching frequency from 500Hz onwards. The internal layout has a minimized stray inductance and ensures a homogenous current sharing between the chips. Therefore, it is feasible to use this layout with fast switching semiconductor.

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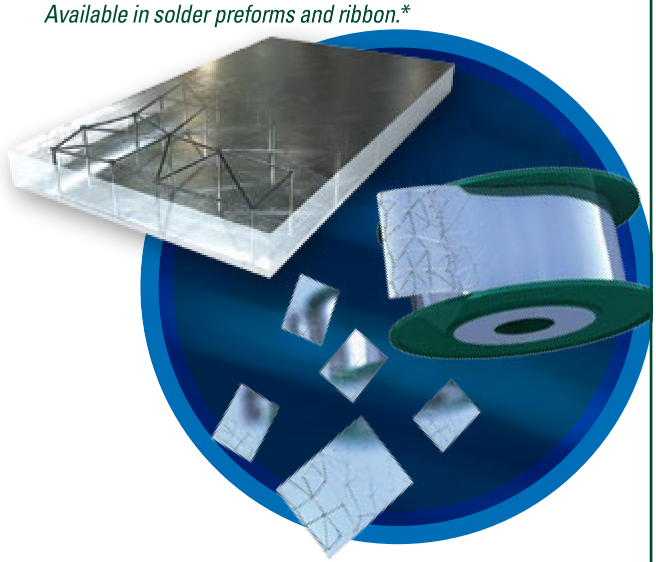

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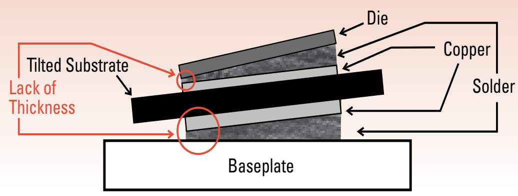


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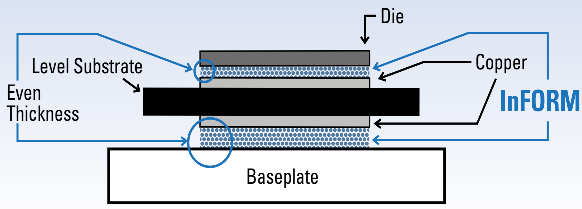


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# Benchmarking System Architectures and Topologies for DC-to-DC Converters, the Heart of Off-Board Chargers

*Electrical vehicles (EVs) pose a host of questions, challenges and problems for people seeking to put this breed of car on the road. OEMs' engineers have one set of issues to tackle, and infrastructure planners quite another, while policymakers are busy assembling the puzzle pieces of renewable energy, EVs and the smart grid. If we consider EVs in isolation, which is easily done on paper but difficult in the real world, the biggest issues are charging time and infrastructure availability.*

*By Baran Özbakir, Product Marketing Manager, and Gábor Manhertz, Sr. Development Engineer, Vincotech*

**Introduction**

These challenges will have to be mastered, for EVs are the future of transportation: As many as 120 million EVs could be up and running by 2030 [1], and the more EVs are on the road, the greater the collective fleet's appetite for energy. Today charging energy demand amounts to around 20 billion kilowatt-hours, with forecasts calling for it to rise to 100 billion kilowatt-hours by 2025 and 280 billion kilowatt-hours by 2030 [1]. This is a tall order to fill – 2030 is just ten years down the road. More efficient EV chargers could help meet rising energy demands and deliver more power, faster. This article investigates various system architectures and topologies. It trains the spotlight on the DC-DC converters that are the heart of off-board chargers.

**System architectures**

There are two main scenarios to ponder, public charging and home charging. Demand for each option varies by region. In view of China's infrastructural constraints and densely populated cities, public charging is likely to be the far more frequent application in that country. In much of the USA, in contrast, home charging will dominate because so many people live in single-family houses. Then there is the nature of the charging device to contemplate – is it to be a slow charger, a fast charger or a high-power charger?

| Charging Type | Level | Charger location | Current | Power |
|---|---|---|---|---|
| Slow chargers | Level 1 | On-Board | AC | <3,7 kW |
| Slow chargers | Level 2 | On-Board | AC | <3,7 kW and <22 kW |
| Fast chargers | Level 3 | On-Board | AC(3~phase) | >22 kW and <43,5 kW |
| Fast chargers | Level 3 | Off-Board | DC | >50 kW and <200 kW |
| High power chargers | Level 3 | Off-Board | DC | Currently > 200 kW |

*Figure 1: EV charger power levels*

Batteries' charging periods range from 20 minutes to 20 hours, depending on the output power of the electrical vehicle charger (EVC). Take, for example, an EV with 27.2 kWh net battery capacity. A 3-kW residential charger replenishes this battery's capacity from 0% to 80% in nine hours. A DC-DC off-board fast charger (Level 3) does this in less than 45 minutes.

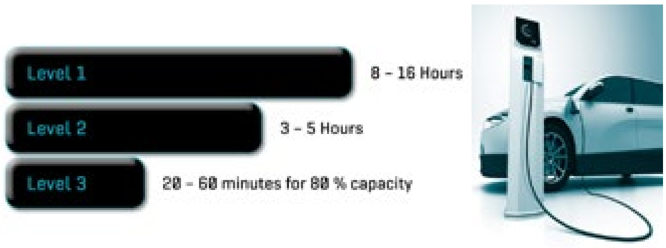


*Figure 2: Average EV charging time*

Three main system architectures were on the market at the time of writing.  A quick review of each follows.

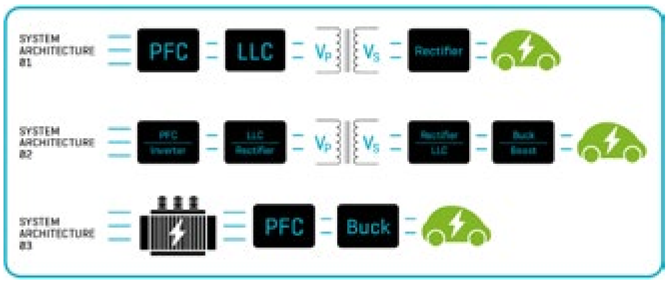


*Figure 3: System architectures*

**System architecture 1**

This is the state-of-the-art system architecture for up to 350 kW. Composed of several units, it is modular. The power level and type of power unit varies by regions. In China, for example, power units in the latest models of EV chargers are rated for 15 kW to 30 kW, and mainstream power units for 20 kW. Most are based on telecom power supplies with discrete components that still satisfy today's expectations for efficiency and reliability. Europe presents an entirely different picture, where even 20 kW power units are based on power modules to meet reliability and efficiency expectations and reduce manufacturing time. Much the same can be said of the USA.


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**System architecture 2**

This is a bidirectional vehicle-to-grid (V2G) system. It is designed mainly for residential applications where the EV serves as the storage unit. V2G is one of the key elements in smart-home applications and the smart grid. Again, it is just not feasible to consider EVs and EV chargers in isolation without factoring renewable energy and smart-grid penetration into the equation. This is why system architecture 2 is gaining ground in applications ranging up to 22 kW and higher. Take, for example, a home-charging scenario where an American mother charges her compact EV at home, overnight. In this case, her car can actually serve as a buffer or energy storage unit for the household. This type of charger will make inroads into home-charging applications as the smart grid gains ground and renewable energy becomes a bigger factor in the energy mix.

**System architecture 3**

This latest design aims to serve the higher power (>200 kW) market. A medium-voltage transformer furnishes power directly to the system. There is a good reason why this has to be a medium-voltage transformer: A highway-side charging station with ten chargers working at 350 kW each draws 3.5 MW from the grid. The power ought to be sourced from medium-voltage lines to meet this kind of demand. There are two ways of doing this. For one, we can use a conventional 50-Hz transformer to step the voltage down to 400 V (L-L) and then convert AC to DC. For the other, we can use power electronic transformer (PET) to generate medium-voltage, medium-frequency power with the power being converted within the transformer. Used for years in traction applications, PET will be vital to the smart grid. DC-to-DC conversion is the heart of the system in all architectures. To date, the transformer has converted DC to DC to provide galvanic isolation between the car and mains power. The most frequently used topology is LLC. This is a zero-voltage-switching (ZVS) technique that serves to reduce switching losses, increase efficiency and energy density, and mitigate EMI issues. The next section briefly explains LLC topology and examines the results of an effort to benchmark component technologies' cost and efficiency.

**LLC Benchmark**

A resonant LLC converter has advantages such as high efficiency, low EMI and increased power density. However, selecting the right component for the given application does require more effort.

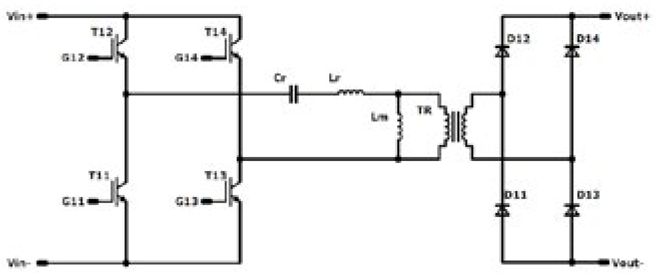


*Figure 4: Full-bridge LLC converter with a full-bridge rectifier*

DC-DC conversion gain = turn ratio of transformers * resonant tank gain * switching bridge gain where the gain of the full-bridge LLC is 1 [2].

A summary of the resonant LLC converter's design parameters follows [2]:

1-) Quality factor (Q)
2-) Reflected road resistance
3-) Resonant frequency
4-) Ratio of primary inductance to resonant inductance (k)

The resonant LLC converter discussed in this paper was benchmarked using various component technologies at different resonant frequencies to rate efficiency and costs. The transformer's conversion ratio is 1 and the maximum gain of the resonant tank is limited to 1.4. The Lr, Cr and Lm values depend on the transformer's conversion ratio, the resonant frequency and the LLC's designated power rating.

Several configurations with various component technologies are available. The double H-bridge consists of two cascaded H-bridges with 650 V components. The second configuration is an H-bridge with 1200 V components. The double H-bridge topology enables us to use 650 V components where the voltage at the PFC's output is divided in two and routed to each H-bridge [3].

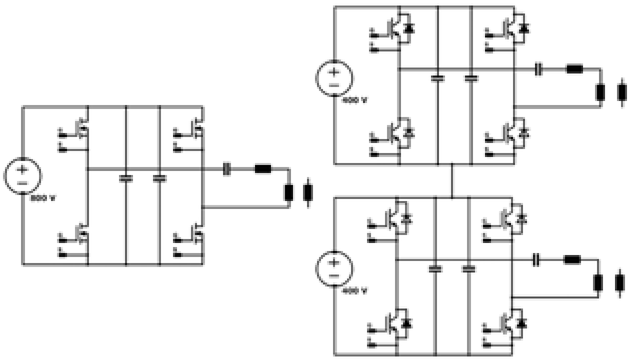


*Figure 5: H-bridge topologies*

| | |
|---|---|
| Chip set | 650V Fast IGBT - 100A |
| Topology | H-Bridge |
| Power | 12.5 kW |
| Vin | 400 V |
| Vout | 400 V |
| k factor | 9 |
| Q factor | 0.4 |
| Frequency range | 1-120 kHz |

| | |
|---|---|
| Chip set | 1200V Fast IGBT - 80A |
| Topology | H-Bridge |
| Power | 25 kW |
| Vin | 800 V |
| Vout | 800 V |
| k factor | 9 |
| Q factor | 0.4 |
| Frequency range | 1-120 kHz |

| | |
|---|---|
| Chip set | 650V Si-MOSFET - 20mOhm |
| Topology | H-Bridge |
| Power | 12.5 kW |
| Vin | 400 V |
| Vout | 400 V |
| k factor | 9 |
| Q factor | 0.4 |
| Frequency range | 1-120 kHz |

| | |
|---|---|
| Chip set | 1200V SiC-MOSFET - 20mOhm |
| Topology | H-Bridge |
| Power | 25 kW |
| Vin | 800 V |
| Vout | 800 V |
| k factor | 9 |
| Q factor | 0.4 |
| Frequency range | 1-120 kHz |

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The 1200 V SiC-MOSFET version exhibits the greatest efficiency throughout the frequency range. The 650 V Fast IGBT and 650 V Si-MOSFET solutions in double H-bridge topology exhibit similar performance beyond 100 kHz. The 650 V IGBT is more efficient at frequencies below 100 kHz. However, the Si-MOSFET solution's loss is lower than the IGBT solution's at partial loads, which is attributable to the Rdson steepness. On the other hand, the 1200 V Fast IGBT's performance dips drastically after 25 kHz. The cost benchmark provides a more complete picture. It clearly shows that the 1200 V SiC-MOSFET is the most expensive solution. The costs of the 650 V Fast IGBT and the 1200 V Fast IGBT are comparable and considered equal for the purpose of cost benchmarking. The Si-MOSFET, around twice as expensive as the Fast IGBT, falls midway between the two others in the cost ranking. Note that this cost benchmark takes the power module's price into account. This comparison assumes that the 1200 V SiC-MOSFET (single H-Bridge) comes in the Vincotech flow1 housing. The 650 V Fast-IGBT and 650 V Si-MOSFET are based on a double H-Bridge configuration, so they are taken to be housed in two Vincotech flow1 housings. Although the 1200 V Fast IGBT can come in a single module, this comparison assumes it is packaged in two Vincotech flow1 housings to distribute heat across two modules. The higher losses would otherwise make it impossible to disperse the heat from a single module. The trajectory of the efficiency curve at a partial load is a crucial issue. The graph below shows this partial load efficiency. Please note that the LLC is designed for a full load. Of course, this also determines its parameters.

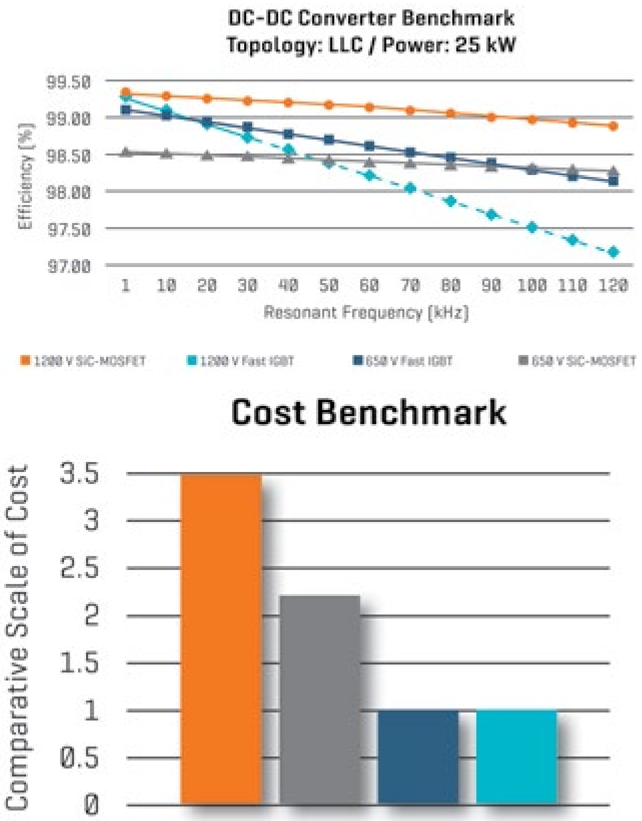


*Figure 6:*
*DC-DC converter benchmark under 25 kW full-load conditions*

This benchmark for efficiency at partial load shows the 650 V Si-MOSFET outperforming the 650 V IGBT throughout the frequency range. This is explained by the lower power level – the reduced input current causes less static loss. Static losses generally outweigh switching losses in the LLC topology. Off-board DC-DC chargers supply the energy at full load to reduce charging time, which is why the comparison at full load is more meaningful. The final question to be examined in this article is how much efficiency money can buy. We halved the 650 V Si-MOSFET's Rds(on) to investigate how this affects efficiency. The graph below provides some answers.

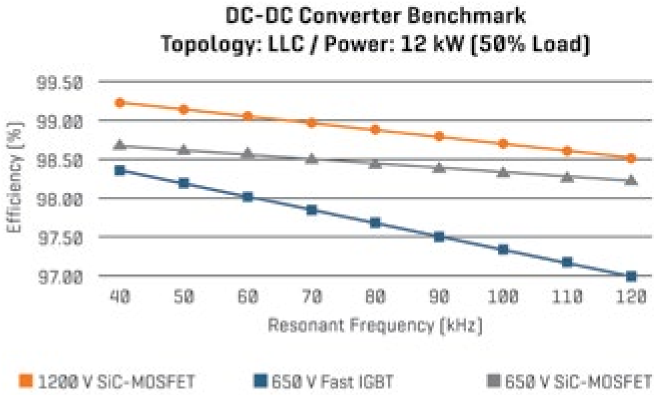


*Figure 7:*
*DC-DC converter benchmark under 12 kW partial load conditions*

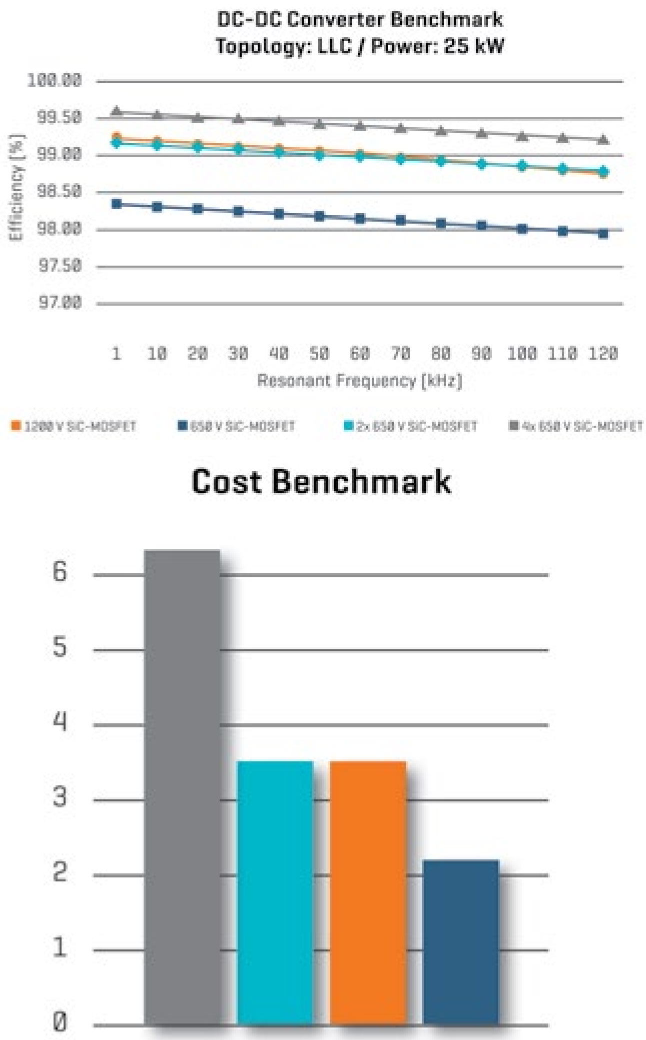


*Figure 8:*
*DC-DC converter benchmark under 25 kW full load conditions*

As the above graph shows, paralleling 650 V Si-MOSFETs reduces losses and increases efficiency. If we halve Rds(on) to 10 mΩ, the efficiency level is on par with that of 1200 V SiC-MOSFET (20 mΩ). The next step is to reduce Rds(on) to 5 mΩ, which is done by paralleling the Si-MOSFET (20 mΩ). This again raises the system's efficiency to a level beyond that of the SiC-MOSFET. As is to be expected, the modules' price rises accordingly. Note that doubling the 650 V Fast IGBT's current rating would not increase efficiency as much as halving the Si-MOSFET's Rds(on), which is why this option has not been explored. Conversely, doubling the Fast IGBT's current rating does indeed reduce $R_{th}$, which helps cut losses by bringing the junction temperature down. This, in turn, enhances component reliability and extends service life.

**Conclusion**

This article briefly reviewed current EV chargers' system architectures and zoomed in for a closer inspection of the LLC topology. The EV booming market has its challenges. As power levels increase, efficiency becomes an ever more important consideration. The resonant LLC DC-DC converter is one of the most frequently used options in charger applications, but it is vital to select the right component and configuration for the application. The double-H bridge configuration with the 650 V Fast IGBT performs well in terms of both cost and efficiency. The 1200 V SiC-MOSFET and 650 V SiC-MOSFET are good options if the application requires very high efficiency even at partial loads. Charging stations are a priority market for Vincotech. With its range of standard power modules and customer-specific solutions, the company offers the right solution to meet the demands of every customer's applications.

**References and Notes:**


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# 4500 V / 3600 A Reverse Conducting IGCT

## *Highest Power Density for Most Compact Equipment*

*With the introduction of its latest Reverse-Conducting Integrated Gate Commuted Thyristors platform (RC-IGCT), ABB sets a new benchmark in high power semiconductor device performance. The initial RC-IGCT release is a 4500 V, 3600 A device. Available in variants optimized for medium switching frequency applications found with 3-level topologies, and for low switching frequency used in Multi-Level Modular Converters (MMC). The repetitive turn-off current of 3600 A is a record value in its class.*

*By Umamaheswara Vemulapati, Tobias Wikström and Christian Winter, ABB Semiconductors*

For the converter manufacturer, it means a significantly compact converter design than previously. The device can be used in many applications including medium voltage drive (MVD), power grid compensators, wind, rail-intertie and shore-to-ship.

**Introduction**

The advance in power conversion towards high power and high current, driven by renewable energy, grid stability and industrial drives, calls for compact power semiconductors with high current capability, low losses and high reliability. IGCT, compared to the ever-maturing IGBT technology, offers the following advantages:

- Low on-state voltage, leading to lower total losses
- High current capability without paralleling
- Inherent ability to withstand large fault currents without rupturing
- Potential for stable short-circuit failure mode after failure

For this inverter type, the IGCT's low loss advantage was quantified in [1]. Depending on the inverter mode, the losses are 10 – 15 percent lower using IGCTs than IGBTs.

This new IGCT platform is the culmination of some 20 years of continuous development.

**Design**

A key requirement is to retain the current outer dimensions for compatibility with the application and integrated gate unit.

The potential to expand the existing RC-IGCT platform offers:

- Increased device diameter through efficient use of raw silicon wafer.
- Minimal gate-circuit impedance – achieved by using a gate contact infrastructure at the device's periphery and by routing the gate contact through the housing.
- Improved cooling by moving the gate contact to the periphery – now the pole piece trenches, used to convey the gate signal, are no longer needed.
- Increased maximum controllable current by adjusting the HPT+ platform [2].

The device size has been increased from 91 to 94 mm, corresponding to 7 percent more area, by improving the respective capability of the manufacturing line.

By improving the thickness tolerance of the housing wall, a larger wafer diameter can be accommodated without changing the housing's outer dimensions. As shown in Figure 1, by moving the gate contact radially outwards, its area consumption increases, provided other conditions remain the same. To counteract this effect, the device's centering tolerance is lowered by more than 50 percent. This results in a 21 percent increase in the active area available for performing the device's function. The extra area is given entirely to the diode, whereas the IGCT area was made slightly smaller than the existing platform.

*Figure 1: Left: The conventional RC-IGCT wafer with the gate contact in the separation between diode- and GCT parts. Right: The newly developed RC-IGCT wafer with the outer ring gate contact.*

For turning off large currents, the IGCT is critically dependent on low gate-circuit stray impedance. The inductive impedance has three contributors: wafer, bushing and gate unit. The wafer and gate unit contributions are low in comparison to the bushing. With the new platform accommodating the peripheral gate, separation of gate and cathode can be decreased by routing the gate and cathode conductors close to each other, as shown in Figure 2.

Silicon: Factors affecting the silicon design include resilience to cosmic ray induced failures, blocking capability and switching behavior, especially of the diode. The diode turn-off behavior at low currents and high voltages – the so-called snap-off behavior – governs the device's thickness and resistivity. Being fabricated on the same silicon wafer, the thickness and resistivity cannot be optimized separately for GCT- and diode parts. The device thickness is chosen to minimize the losses both in GCT- and diode parts, while maintaining diode snap-off and cosmic ray failure rate at an acceptable level [3].

Package: The new package design (without changing the outer dimensions of the housing) has eliminated some thermal bottlenecks compared to the previous version, as shown in Figure 3. Furthermore, the GCT- and diode parts are more connected, thermally, which can be used in applications where one part is more heavily loaded.

**Optimization flexibility**

Different lifetime tuning technologies enables diverse element optimization depending on the application's needs, as shown in Figure 4. Increasing the on-state voltage usually decreases the turn-off losses, shown in Figure 5.

This gives the converter designer the flexibility to select the device best suited to the application (i.e. low or high switching frequency).

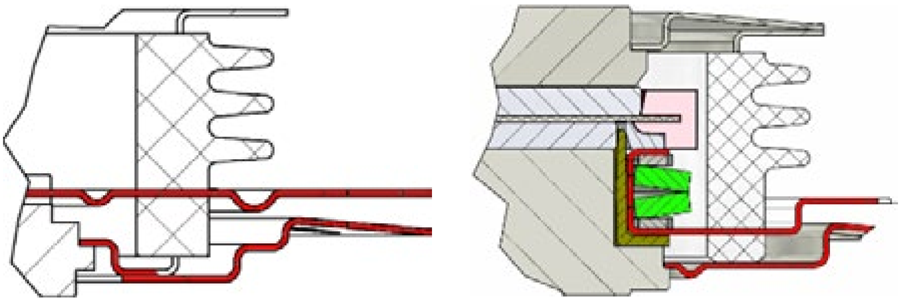

Figure 2: Cross-sections of the gate-lead bushing of the earlier (left) and new (right) IGCT housing platform. The red parts show the current paths through the hermetic housing. ABB Switzerland Ltd is an owner of the design patents for both IGCT housing platforms.

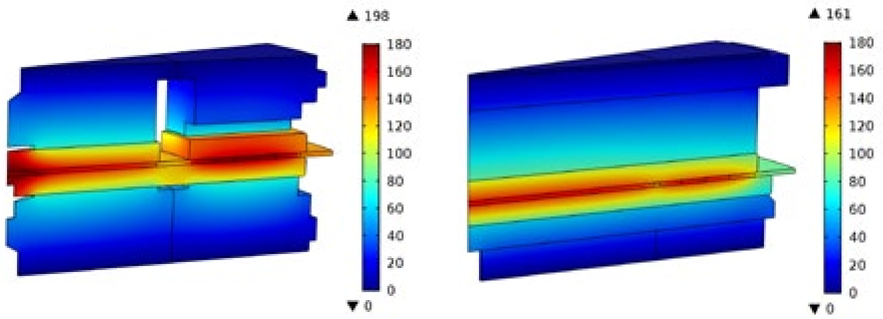


*Figure 3: Thermal simulation output of the previous housing platform (left) and of the newly developed housing (right) at the same heating power density in the silicon wafer. Both GCT- and diode parts generating losses. The color indicates the temperature in °C, in the simulation. The maximal temperature of the new housing is 15 percent or 30°C lower.*

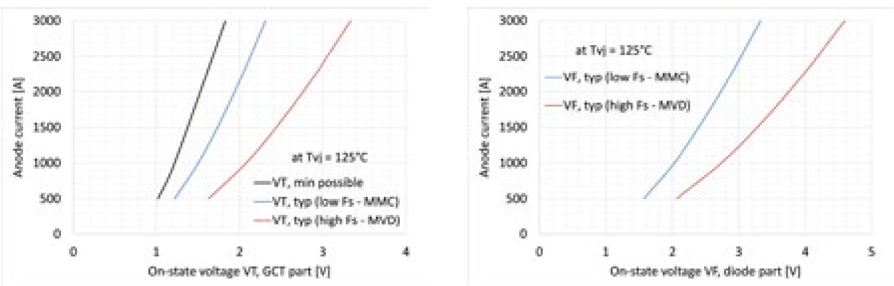


*Figure 4: (Left) On-state characteristics of the 4.5 kV device's GCT part, showing the flexibility in tuning the IGCT for different switching frequencies (Fs). (Right) The corresponding on-state characteristics for the diode part.*

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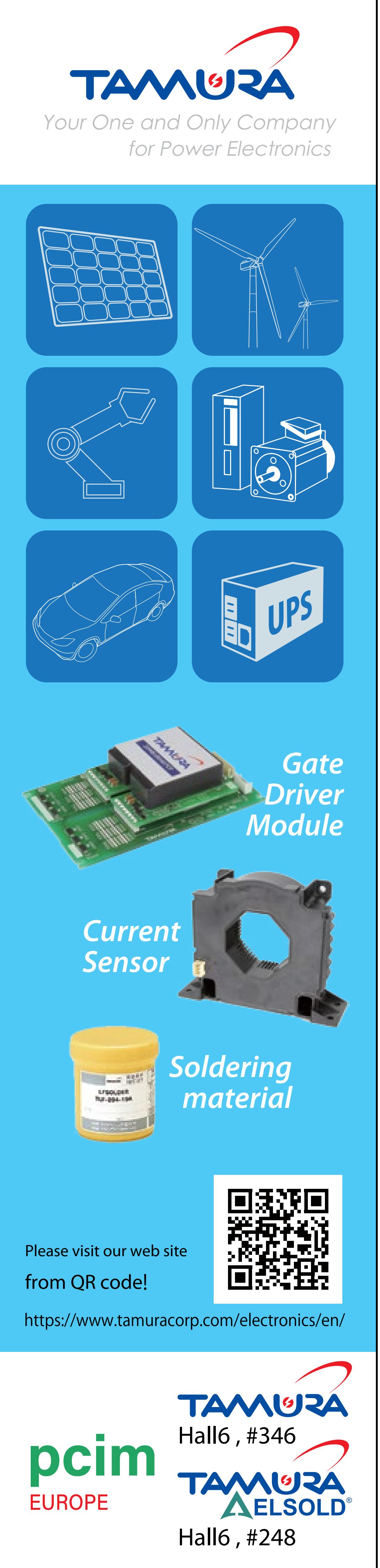


### Device performance

The developed platform is subjected to the full range of reliability and electrical qualifications. In addition to repetitive validation of the device parameters, the robustness of the switch and diode is extraordinary, for the newly developed 4500 V/3600 A device variants. Figure 6 and Figure 7 show the current handling capability of a 4.5 kV device in single pulse turn-off measurements.

### Conclusions

This paper highlights the latest developments for the Reverse-Conducting Integrated Gate Commutated Thyristors (RC-IGCTs) technology platform. The new platform offers a larger active device area and optimized gate contact design. This results in a higher controllable current over 6000 A in single pulse operation, improved diode conducting capability and improved cooling. The new technology platform further offers RC-IGCT variants, respectively optimized for medium and low switching frequency applications.

The RC-IGCT 4500 V/ 3600 A, reported in this study, could be expanded to larger area and higher voltage devices for any applications, including power grid applications based on MMC topology.

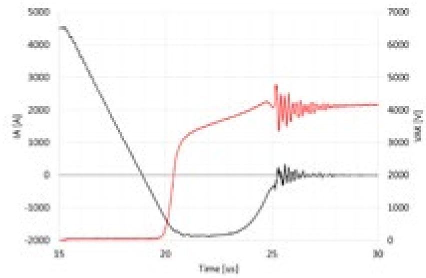


*Figure 7: Demonstration of the 4.5 kV RC-IGCT for the diode part, recovering 4.5 kA against 3.9 kV DC at 135°C.*

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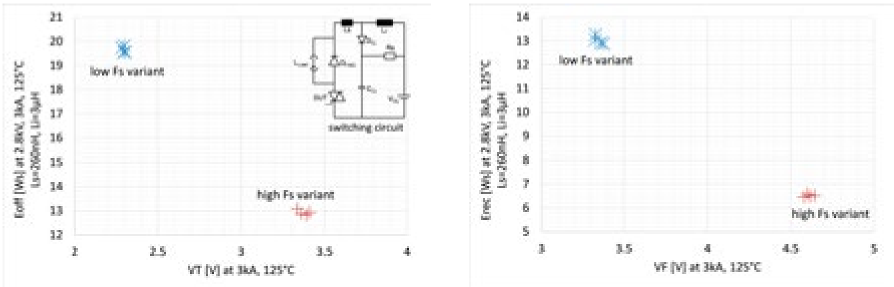


*Figure 5: Trade-off between static and dynamic losses for both low Fs and high Fs variants of the 4.5 kV RC-IGCT. (Left) GCT part. (Right) diode part.*

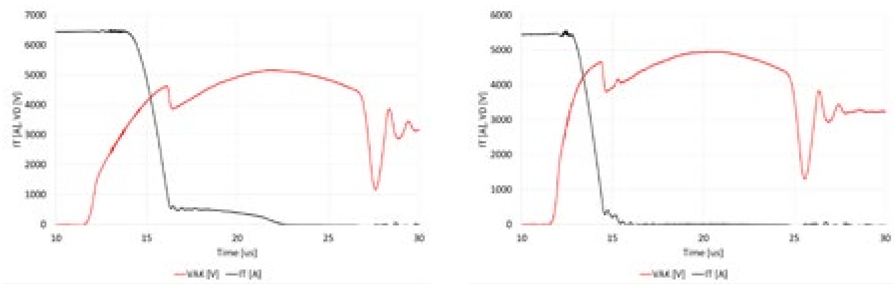


*Figure 6: SOA waveforms of the 4.5 kV RC-IGCT's GCT part at VDC = 3.2 kV. (Left) Tested up to 6.5 kA without failure at 25°C. (Right) The device controls current up to 5.5 kA at 135°C.*

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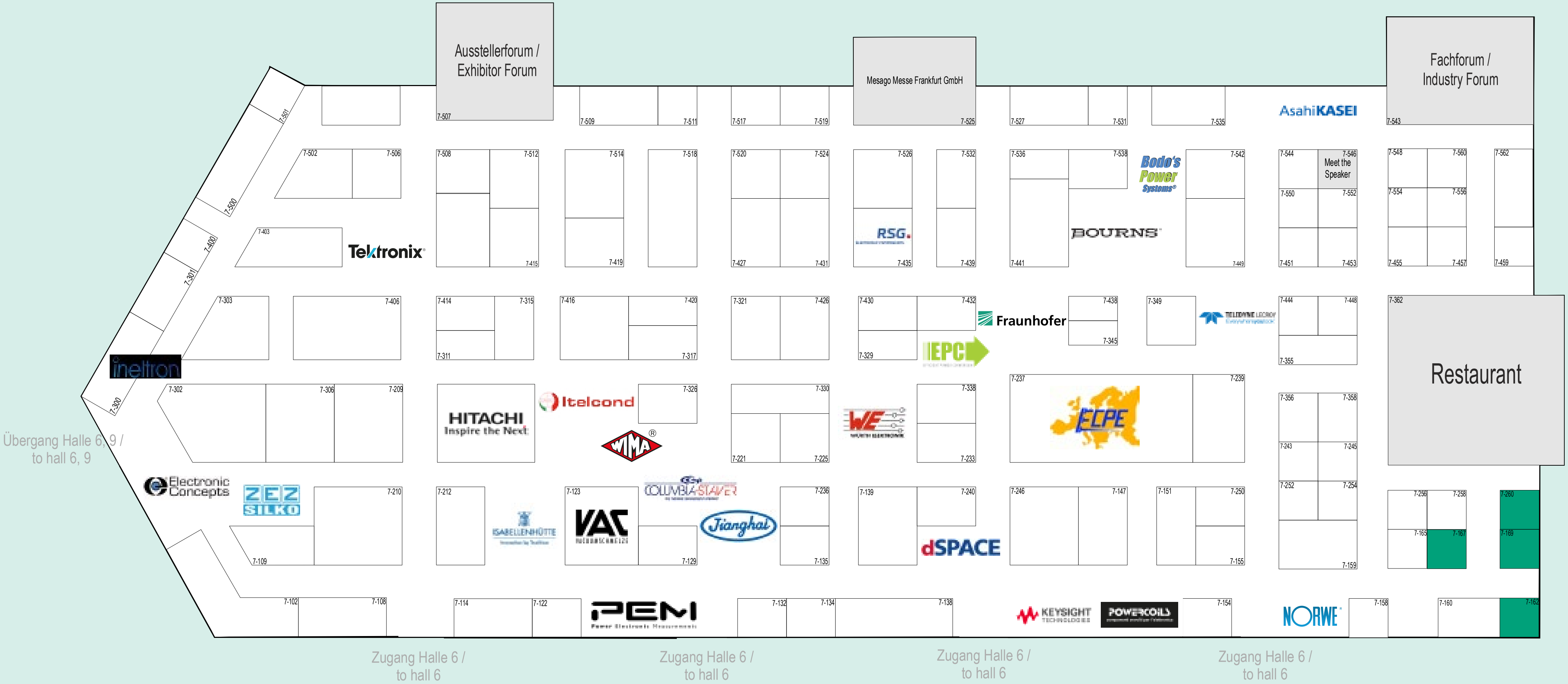


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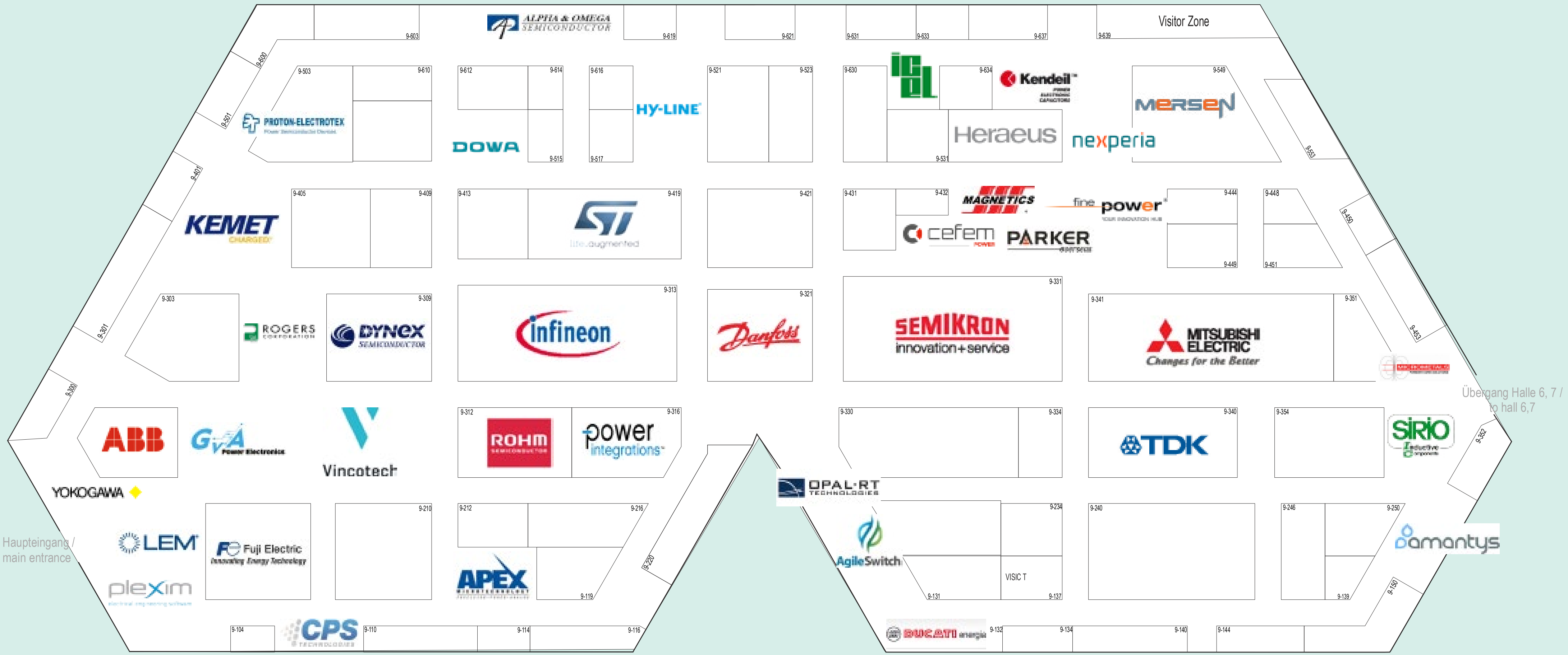


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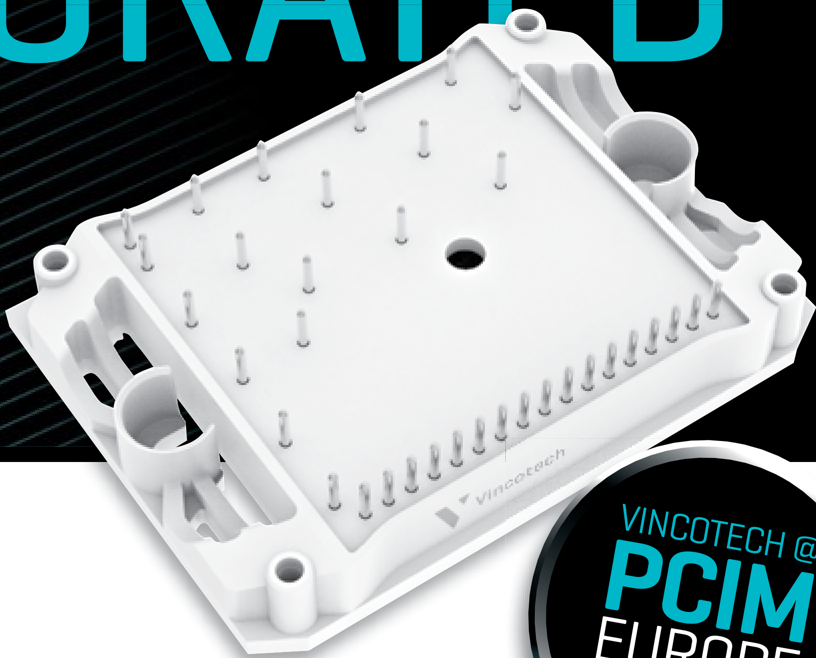

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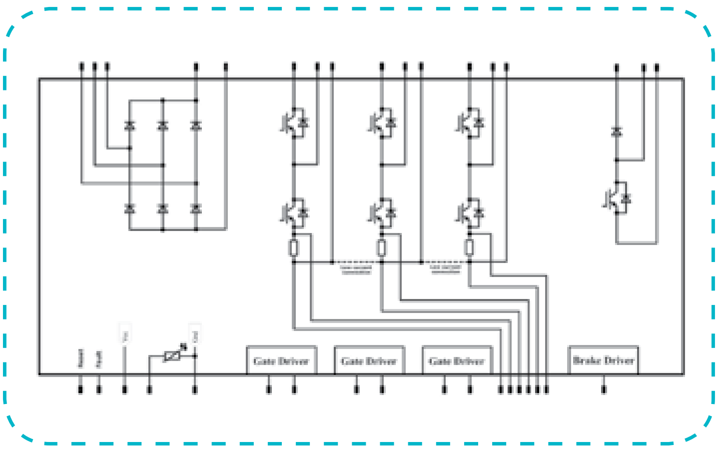


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# 11 Technical FAQs About the Danfoss DCM™ Technology Platform for Automotive Traction Inverters

*Curious about the technical details of Danfoss' DCM™ power module technology platform? Wait no longer. Our application engineers have collected the 11 most frequently asked questions from customers – and we have decided to share with you.*

*By Arne Bieler, Alexander Streibel and Martin L. Kristensen, Danfoss Silicon Power GmbH*

For decades, Danfoss has been helping top-tier automotive manufacturers meet stringent reliability, design and cost targets by developing customized IGBT and SiC power modules for automotive traction applications. With the recent launch of the new Danfoss DCM™ power module technology platform for automotive traction, Danfoss has naturally been invited to pitch to the top-tier automotive players within HEV/EV drivetrain design. Based on our presentations and technical discussions with customers, we have collected the 11 most frequently asked technical questions about the DCM™ platform. In the following section Alexander Streibel and Arne Bieler, both application engineers at Danfoss, will provide the answers that you have been looking for.

**Q: What is meant by the given current rating of DCM™ modules?**

**Arne Bieler:** First of all, DCM™1000 refers to a package size offering footprint to assemble a semiconductor area of 1000mm². Second, current ratings strongly depend on applied boundary conditions such as cooling parameters and DC-link voltage. The current rating for the DCM™1000 considers nominal operation points at customers' side.

**Q: Is DCM™ 1000 scalable for several power classes?**

**Arne Bieler:** Adjusting both chip content and DBC substrate materials, we are able to offer several power classes within the DCM™1000 package. This allows customers to use power modules having the same outer dimensions for traction inverters with different output power without the need for a re-design of mechanical components such as cooler. This accounts for both DCM™1000 (750V) and DCM™1000X (1200V). The suffix "X" stands for the extended clearance and creepage distances for applications with up to 1000V DC link voltage. Nevertheless, both the DCM™1000 and DCM™1000X can utilize Silicon Carbide MOSFETs with 800V+ DC link voltage.

**Q: Which semiconductors are inside the DCM™?**

**Alexander Streibel:** The DCM™ is a technology platform which means that all types of automotive qualified semiconductors can be housed. For 400V and 800V drive train inverters, typically Si IGBTs

*Figure 1: Open DCM™ power module with DBB®.*

and SiC MOSFETs can be assembled. It is possible to use advanced bonding and joining technologies such as DBB® with either copper wire bonds or copper ribbon bonds.

**Q: How do differences between chip suppliers challenge the inverter design?**

**Arne Bieler:** Danfoss has a unique business model and one of the main pillars is chip independency. This means that we are free in the choice of power semiconductors. Of course, even if designed for the same power class, semiconductors from different manufacturers vary in terms of e.g. internal gate resistor, gate charge or even breakdown voltage. For many suppliers, this can challenge the design of the inverter. However, we have thoroughly assessed the differences and can fully support customers during the design of the inverter and the driver board when it comes to a change of the favored semiconductor manufacturer or if a multi source approach is needed. In addition, the low module stray inductance of below 7nH allows the usage of different semiconductors with various breakdown voltages.

**Q: How can the modules be mounted? Are there different options?**

**Alexander Streibel:** The modules can be mounted to the cooler by using clamping brackets screwed directly to the cooler. The brackets have direct contact to the available area at the top of the baseplate, shown in Figure 2. There are different concepts available that can apply sufficient pressure for the sealing gasket located close to the borders of each half-bridge.

Danfoss proposes concepts with either two M4 screws or just one M5 screw on each side of the power module. In advanced designs using an aluminum cooler, the total number of screws can be reduced to 4 instead of 8 in typical 6-in-1 module designs.

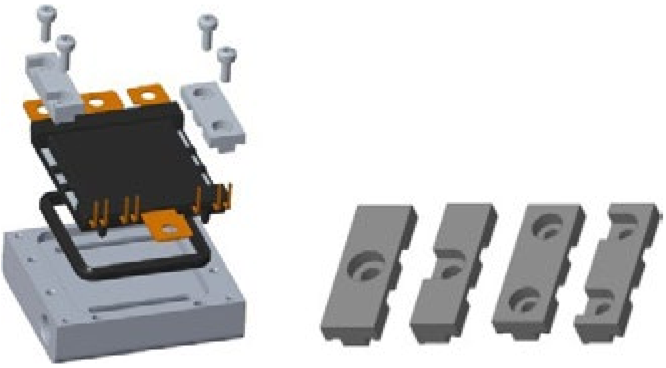

*Figure 2: DCM™ module incl. ShowerPower®3D baseplate screwed to bathtub.*

**Q: How does the cooling concept work?**

**Arne Bieler:** The cooling concept of DCM™ platform utilizes the patented ShowerPower®3D cooling technology. The baseplate of the power module has meandering channels guiding the coolant and creating powerful swirl effects that washes the boundary layers away thereby maximizing the cooling efficiency. In spite of the swirl effect, the flow is laminar therefore the pressure drop is very low and mainly influenced by the design of cooler in- and outlet and the bypass across the structured baseplate. The final thermal resistance relates to the selected power class, i.e. silicon area and substrate material. The customer designs the bathtub of his cooler according




to the interface needed for the DCM™1000 power modules. Danfoss can provide all necessary drawings and a reference design from our application-kit.

**Q: What is the difference between ShowerPower® and Pin-Fin cooling technology?**

**Alexander Streibel:** The main difference is that with ShowerPower® the power modules are cooled in parallel. This leads to minimized temperature gradient across each half-bridge determining the required derating of the whole system and the overall performance. Parallel cooling offers typically a lower system pressure drop, but the cooler design constraints must be considered for a fair comparison. Considering equal mechanical boundaries for typical cooler designs, e.g. comparing at the same volume and same design guidelines, with ShowerPower®, the same Rth as conventional pin-fin structured baseplates can be achieved at much lower pressure drop.

**Q: What is the main difference between molded modules and frame-based modules?**

**Alexander Streibel:** Transfer molding technology is a well-known technology for small-scale high-volume components. However, in Danfoss this technique has been developed over 15 years for large-

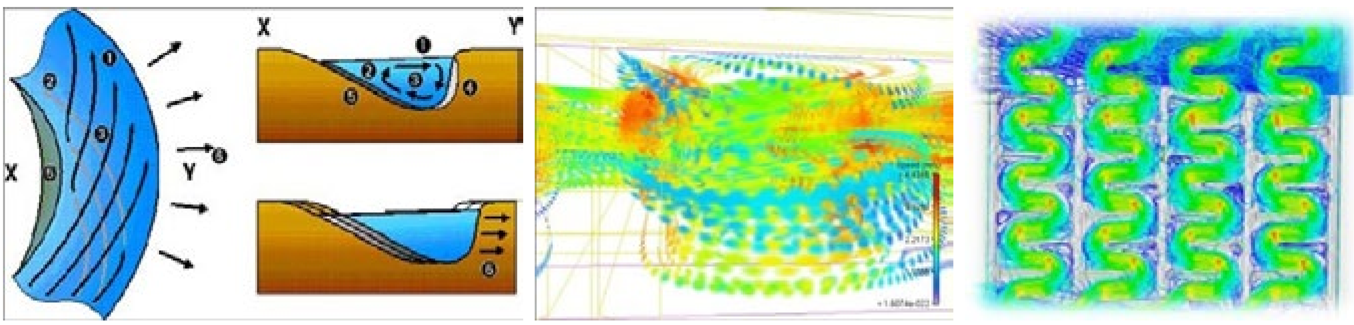

*Figure 3: The bypass creates a flow transverse to the flow direction in the meandering channels thereby amplifying the swirl effect.t*

scale high-power components tailored for high-volume automotive drive train applications in terms of electrical and mechanical ruggedness, ease-of-use and vibration requirements. Terminals are customizable, and the used material is tailored for low tolerance requirements. In sum, the robustness of molded packaging technology has over time proven to withstand harsh automotive conditions and therefore is the preferred choice of Danfoss' customers.

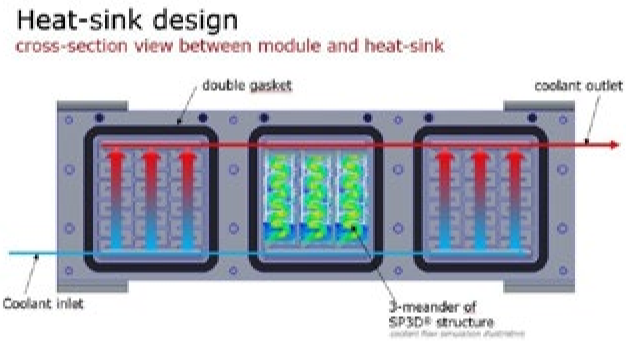


*Figure 4: Visualization of the parallel flow of the coolant.*

*Figure 5: DCM™ power module with ShowerPower®3D.*

*Figure 6: DCM™ power module with transfer molding*

**Q: Looking at the connection between the power terminals and dc-link: Are there alternatives to screwing?**

**Alexander Streibel:** We have customers requesting advanced options to minimize the electrical and thermal resistance between the power terminals and the DC link capacitors. We help realize this by e.g. offering a design for resistance or laser-welding methods eliminating any screws.

**Q: Can customers get modified terminal and control-pin configurations?**

**Alexander Streibel:** Customers can freely choose between a variety of assembly types for the control pins and terminals to fulfill specific reliability requirements while focusing on total cost of ownership. The most common types are soldered or press-fit assemblies. Nevertheless, tailored control pins of the power module can solve the bottleneck issues of automotive vibration profiles and assembly tolerances and thus be of great value.

In addition to customized control pins and terminals, the DCM™1000 is truly a technology platform designed for full customization while utilizing our winning technologies. For the customer, this means that Danfoss can support innovative types of inverter designs with our mechanically flexible power modules based on the DCM™1000 technology platform.

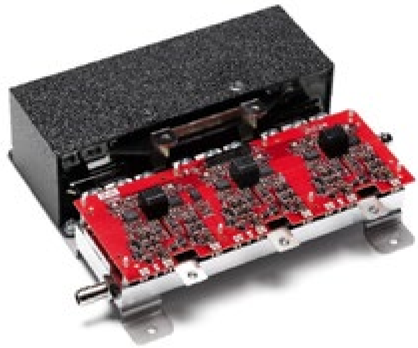

*Figure 7: DCM™ application kit*

**Q: When can we get started with the DCM™ platform?**

**Arne Bieler:** During early development of a traction inverter, customers will need a complete package of materials for designing purposes and to assess the performance of the power module during operation. Therefore, Danfoss provides datasheets, CAD files of the module, drawings including the interface to the cooler and detailed application notes.

To make testing fast and easy, we offer an application-kit including DC-link capacitor, driver-board and cooling, providing the possibility to directly test the DCM™ 1000 modules in the laboratory.

Additionally, Danfoss will be present at the yearly PCIM Europe in Nurnberg 7-9 May 2019. Our applications experts will be ready to further discuss the opportunities of the new Danfoss DCM™ platform for automotive traction inverters. Find us at our booth in Hall 9 booth no. 321.


**Alexander Streibel,**
MSc in Power Electronics from Southern University of Denmark, Application Engineer, Danfoss Silicon Power GmbH

**Arne Bieler,**
MSc in Electrical Engineering and economics from University of Kiel, Application Engineer, Danfoss Silicon Power GmbH


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**DCM™1000 – Enabling the electrification of the drive train**

With silicon (Si) and silicon carbide (SiC) being the main cost-drivers in power modules, our **DCM™1000 platform** aims at reducing the semiconductor surface.
At the same time, it also increases power density, reliability, robustness and lifetime of the inverter. By selecting the best fitting chips from a competitive supplier base and by carefully selecting the power module components, package and electrical configuration, we are able to use the semiconductors to their full potential. In this way, we can drive down the overall cost of the half-bridge module.

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# Gate Drivers for SiC MOSFET/ IGBT Power Modules and Their Advantages

*In order to meet new requirements for miniaturization, low-loss, and high reliability of power converters, power semiconductors manufacturers are constantly trying to improve SiC MOSFET and IGBT technologies. Finding the best compromise to progress on all these characteristics is problematic, because they are antithetical, therefore the innovation pace is slow. SiC MOSFET and IGBT performances are not only dependent on improvement made on high-power transistors but also on all the components around them.*

*By Hirotoshi Aoki, Unit Division, Tamura Corporation*

Power semiconductors Engineers are looking for any improved characteristic on power electronics components, even if they are small. Tamura Corporation understood how crucial this matter is and decided to heavily invest on gate driver characteristics, like its operating frequency, electrical characteristics or its size. Tamura Corporation gate driver will definitely help engineers to develop more reliable, more efficient and smaller power conversion devices.

**Foreword**

Power modules are used as power conversion main devices in a wide range of applications: renewable energies (such as wind or solar powers), automotive industry with low-carbon emission vehicles such as hybrid (HEV) and electric vehicles (EV), electric railways, industrial equipment with inverters and UPS, but also consumer fields with air conditioners.

We are currently observing two different development trends on power semiconductors:

- In current power modules, IGBT (Insulated Gate Bipolar Transistor) is the mainly used technology and their performances are improving with each new generation. We are still expecting improvements on this technology using new structure such as FS Trench or Super Junction.
- New Power modules using new generation materials such as SiC (Silicon Carbide) and GaN (Gallium Nitride), used for wide-bandgap semiconductors. SiC MOSFET are the trendiest power modules right now.

Despite technology differences, all power conversion companies have a common goal: create the most energy-efficient system. Therefore, miniaturization and energy loss reduction are crucial parameters in the development of a power module. Improvements in these fields have impacts on how gate drivers should be designed: For example, we know that the impedance inside power semiconductors will increase, therefore a key parameter on how gate driver must be designed is their capacity to compensate this increase by lowering their internal impedance.

TAMURA has developed new Gate Driver modules (2DMB Series) that optimally drive latest generations of IGBT and SiC MOSFET power modules.

**Product line up**

Figure 1 shows TAMURA new gate driver module (2DMB series). This module contains DC/DC converters using planar transformer technology and gate controllers. This low-profile device provides galvanic isolation and two outputs in order to drive two power modules.

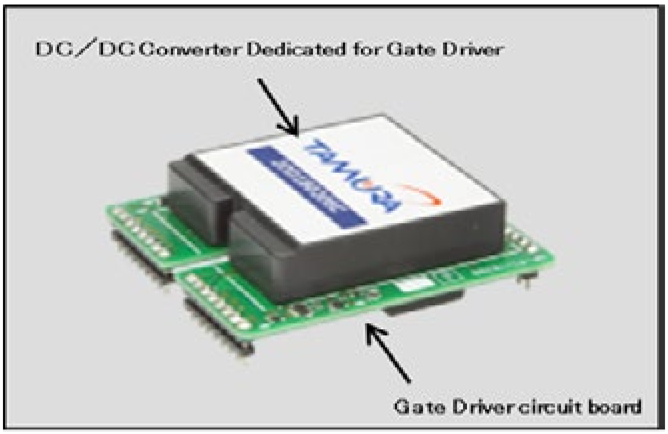


*Figure 1: External view of 2DMB series*

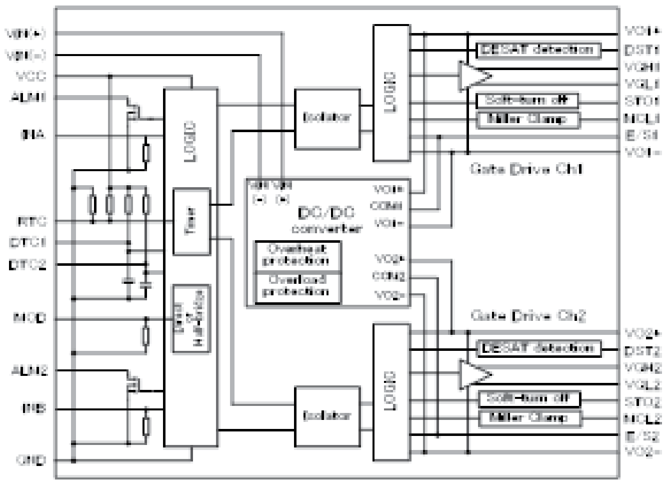


*Figure 2: Block diagram of 2DMB series*

A schematic diagram of the 2DMB series is shown in Figure 2. Our Electrical engineers have designed a reliable device containing several protective functions, such as DESAT detection, Soft Turn off and Miller Clamp functions.

| | Model | | | |
|---|---|---|---|---|
| | 2DMB51507CC | 2DMB51008CC | 2DMB80407CC | 2DMB80206CC |
| | IGBT | | SiC-MOSFET | |
| Input Voltage Range | DC13V~28V | | | |
| Logic Input Voltage | DC3.3~5V | | | |
| Number of Output | 2 | | | |
| Output Power (per 1 ch) | 3.3W (T.B.D) | 4.0W (T.B.D) | 3.5W (T.B.D) | 3.2W (T.B.D) |
| Gate Voltage (ON) | +14V~+16V | +14V~+16V | +17V~+19V | +17V~+19V |
| Gate Voltage (OFF) | -14V~-16V | -9V~-11V | -3.5V~-4.5V | -1.5V~-2.5V |
| Peak Output Current | ±43A | | | |
| Withstand Voltage | Primary to secondary : AC5000V | | | |
| | Secondary to secondary : AC4000V | | | |
| Delay Time | 100ns | | | |
| Switching Mode Select | Direct mode and half bridge mode can be selected | | | |
| Dead Time (Half Bridge Mode) | Adjustable by external circuit | | | |
| Desaturation Protection | Yes | | | |
| Soft Turn Off | Yes | | | |
| Miller Clamp | Yes | | | |
| Protection Release Condition | Auto recovery | | | |
| Ambient Temperature (Operating) | -40~+85℃ (Input Voltage DC13V~18V) | | | |
| | -40~+75℃ (Input Voltage DC18V~28V) | | | |
| Ambient Humidity (Operating) | 20~95%RH (No condensation) | | | |
| Ambient Temperature (Storage) | -40~+90℃ | | | |
| Ambient Humidity (Storage) | 5~95%RH (No condensation) | | | |

*Chart 1: Spec of 2DMB series*

The main specifications of our 2DMB models are shown in Chart 1. IGBT and SiC-MOSFET technologies are using different ±output voltages so we have developed two models supporting each technology. As our DC/DC converter has an output stabilizing function, it can support a wide-range input voltage (DC13 to 28V), instead of usual restrictive DC15V.

**Switching performance**

Figure 3 shows a switching evaluation circuit where switching performance were evaluated with a pulse test on a 1200V / 600A IGBT. Figure 4 shows Vce, Ic, and VgeL waveforms. 600V is applied

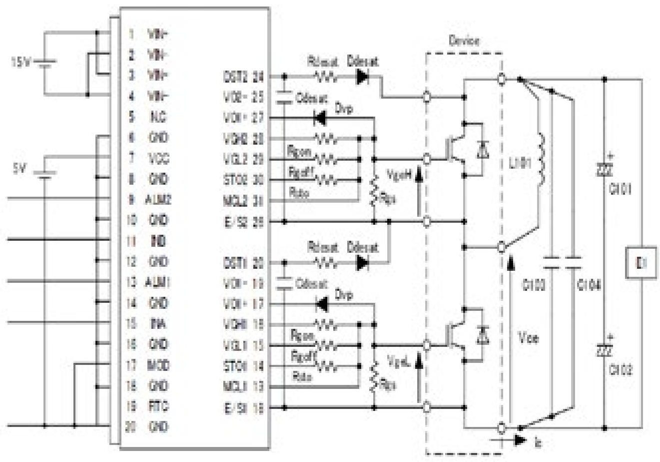


*Figure 3: Evaluation circuit of Switching characteristic*

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(E1) and Ic is set to be 1200A which is twice the rated current. Gate resistances values have been minimized on purpose ( and ) to clearly observe behavior, shown in Figure 5 (Turn-On Waveform) and Figure 6 (Turn-Off Waveform).

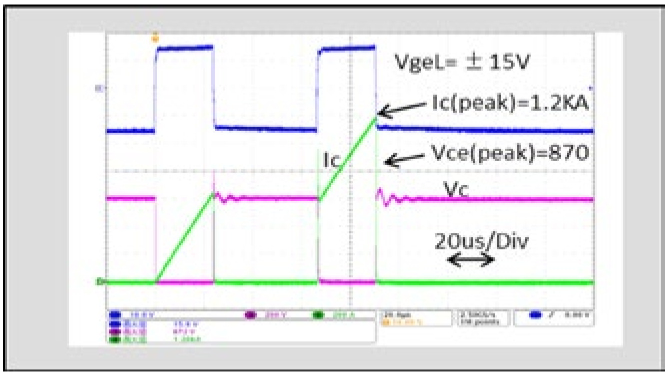


*Figure 4: Pulse test (Wave form of Vce, Ice, VgeL)*

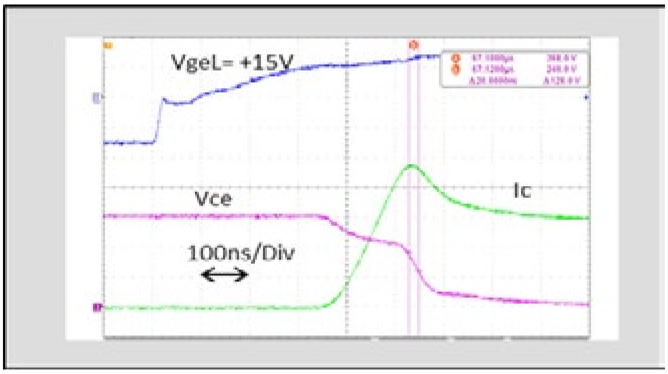


*Figure 5: Turn-on wave form (Vce, Ice, VgeL),*

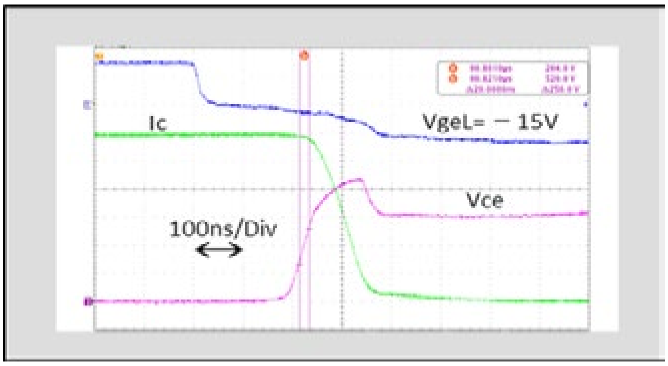


*Figure 6: Turn-off wave form (Vce, Ice, VgeL)*

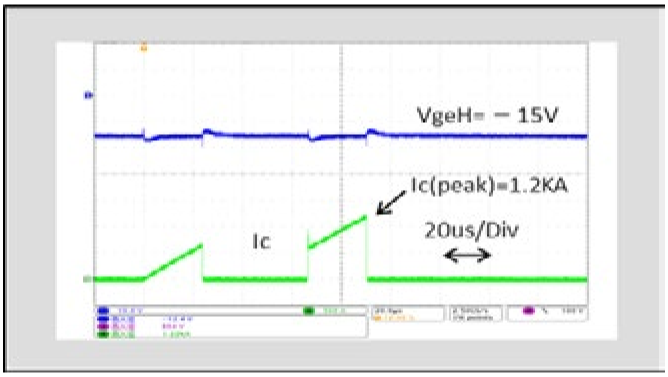


*Figure 7: Wave form of High-side gate*

The low impedance of TAMURA gate driver eliminates usual large swings in the waveforms of Vce, Ic, and VgeL. Another important parameter that makes TAMURA gate driver highly reliable is its low stray capacitance (12pF): Turning off IGBT creates a noise proportional to the stray capacitance and to . Therefore, a risk of malfunction (high & low side simultaneously ON) may happen if that noise is too high. Figure 7 is a waveform demonstrating that switching noise on the low side does not affect the gate voltage on the high side (). The low stray capacitance makes TAMURA gate driver suitable for SiC MOSFET power modules that are operating at a higher frequency and is also suitable for 1700V IGBT (higher in both cases).

**Drive system**

Mechanically, gate drivers are usually installed very close to power modules or inductors which are challenging environments because of high temperature, magnetic noise and high voltage. In order to ensure reliability in such severe environments, TAMURA has equipped its new gate drivers with a capacitive isolation system. This insulation method, compared to photocoupler insulation, has several benefits:

1. Longer lifetime with lower aging effect
2. Lower breakdown field value
3. Higher Common Mode Transient Voltage (CMTI)
4. Shorter propagation delay time
5. Rise and fall times are almost the same
6. Less susceptible to magnetic noise

Switching time performance (90ns) example is shown in Figure 8 making power dissipation very low.

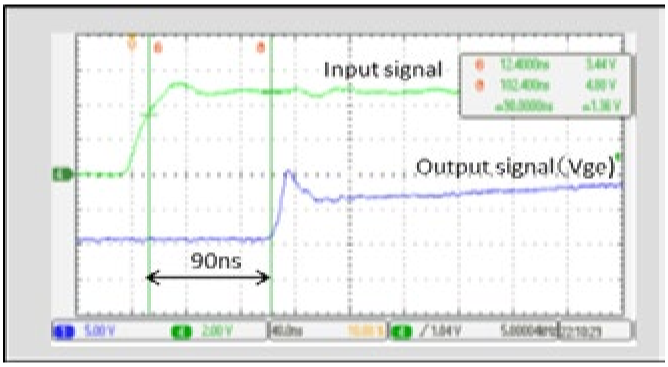


*Figure 8: Transmission delay time*

In case of power modules connected in parallel, the switching time variability is also an important factor to consider: if the switching time varies a lot between parallel modules, the global system is exposed to two major reliability risks, concentration of energy loss (heat) in one module and functioning outside of the safe operating area (SOA). TAMURA 2DMB series gate drivers have switching time variation as small ±5 ns which eliminates above stated risks.

**Output performance**

Figure 9 shows a block diagram of the DC/DC converter section of the 2DMB gate driver module. The output voltage is stabilized by an internal regulation circuit. Even when the input voltage (VIN) fluctuates, gate voltages (V01 and V02) can be kept stable. A stable output from gate drivers is a key function when driving SiC MOSFET power modules because the gate voltage window is extremely narrow (voltage as high as possible without exceeding the absolute maximum rating Vgss).

A new trend on high power facility market has emerged: using power modules with parallel connections to reach higher current. As a result, power modules makers have developed packages mechanically suitable for parallel connections. TAMURA has designed the 2DMB series to drive several power modules connected in parallel using only one gate driver. It simplifies drastically the overall complexity of the system.

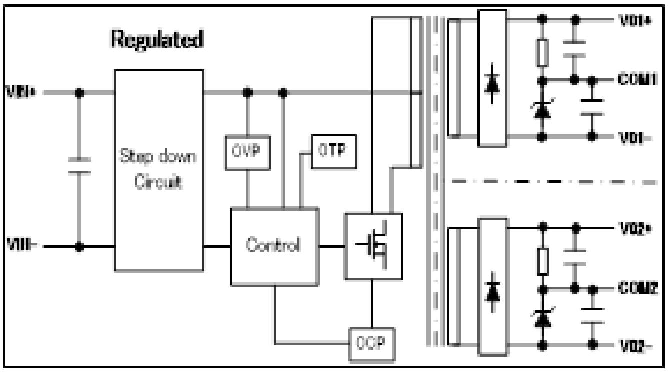


*Figure 9: Block diagram of the DC/DC converter section*

When power modules are connected in parallel, the electric charge amount coming from the single gate driver must be several times higher to turn on all power modules, hence a large peak current is required.

In order to reduce the switching energy loss, the gate resistance value must be set as small as possible and the current peak value must be increased to shorten the charging / discharging time.



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In some cases, the external gate resistance is even set to 0Ω with a gate current only limited by the internal gate resistance of the power module.

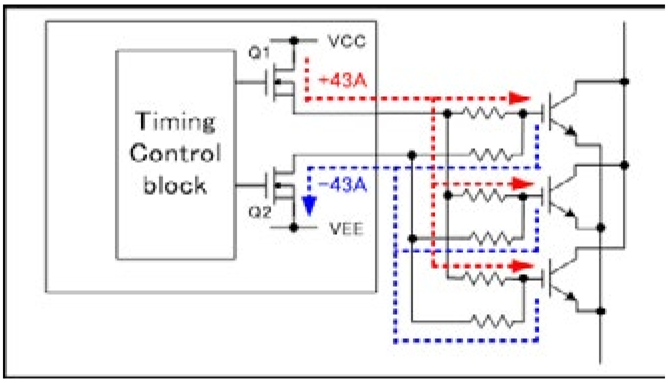


*Figure 10: Block diagram of the IGBT parallel connection*

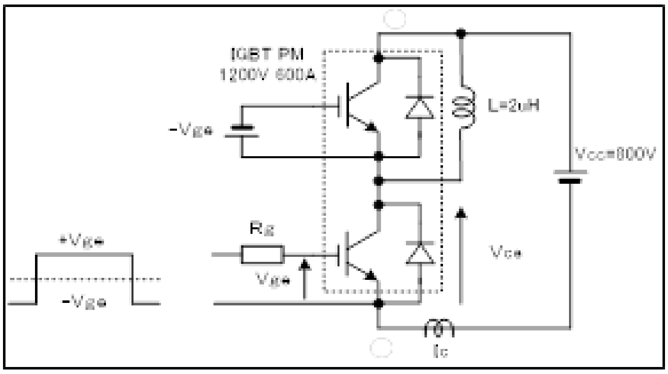


*Figure 11: Diagram of short circuit test*

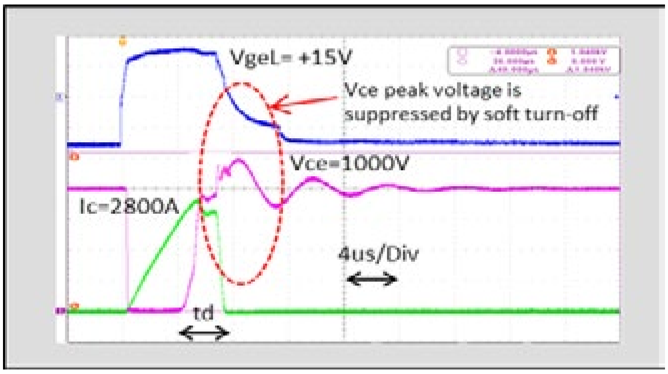


*Figure 12: Wave form of short circuit test*

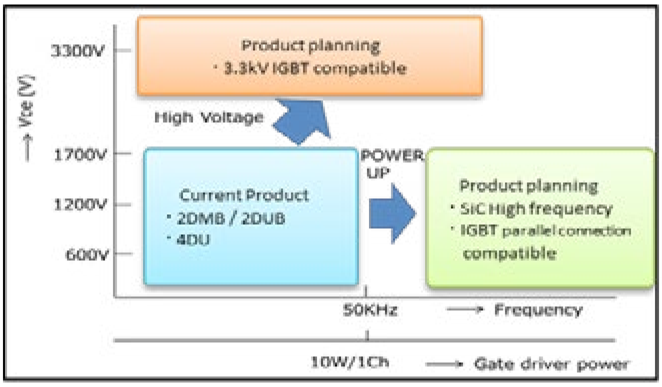


*Figure 13: Development trend*

A block diagram of IGBTs mounted with parallel connections is shown in Figure 10. The internal output buffer transistors (Q1, Q2) are chosen to generate a large peak current. As a result, the peak specification value of the gate current has been increased to ±43 A.

**Short circuit protection**

A short-circuit protection function is required to prevent from power module breakdown (in the event of a short circuit in the system). Short-circuit protections are realized through a DESAT diodes that detects rising points of Vce or Vds (respectively for IGBT or SiC MOSFET). When a short-circuit condition is detected, a large surge occurs in Vce (or Vds) due to inductances in the systems and in the power module. To dissipate this surge, TAMURA gate drivers are using a soft turn off function that is redirecting the detected surge to another gate resistance with impedance several times higher than the usual gate resistance (that has by default a low impedance to reduce losses)

TAMURA gate drivers 2DUB series provide two optional functions: soft turn off & an active clamping function. Both should be used if inductance of the system is high.

The electrical short-circuit test diagram is shown in Figure 11 and equivalent waveforms are shown in Figure 12. The delay time (td) is a wait time in order to prevent the voltage output from stopping abruptly. The delay time is set to about 4µs, but this feature is adjustable.

**Development trend**

In the coming years, TAMURA will continue to develop new products such as:

- Gate drivers compatible with high-frequency and high-current SiC MOSFET power modules
- Gate drivers with enough output power to drive several power modules in parallel
- High breakdown voltage gate driver compatible with 3.3KV power module.

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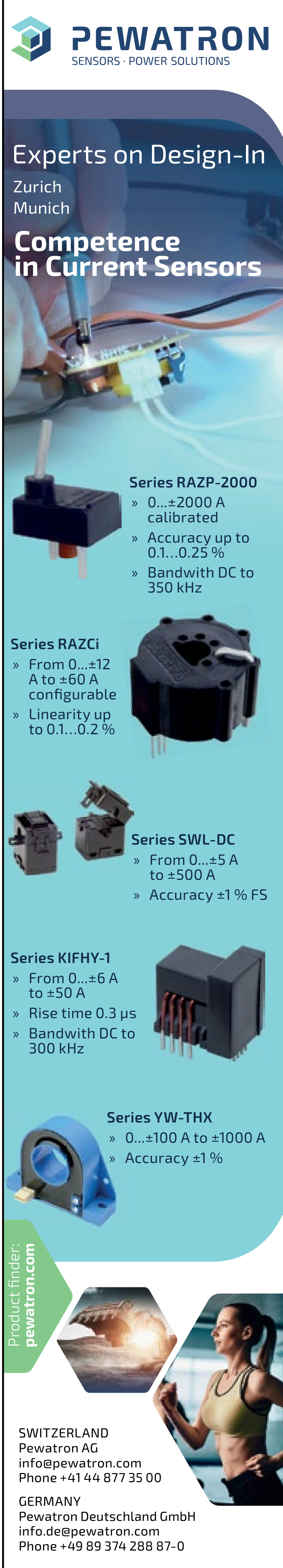

# Measurement and Datalogging Platform for Junction Temperature Estimation and Converter Diagnostics

*Accurate estimation of a power device's junction temperature (Tj) is key to the design and reliable operation of a power converter. Amantys Power Electronics Ltd. has developed pioneering Tj Estimation technology, and has released an exciting new measurement platform – the Tj Estimation Evaluation System – aimed at laboratory and field testing, allowing simple evaluation in advance of large-scale industrial deployment. This article describes the validation of the technology and its use in a wide range of applications.*

*By Angus Bryant, Amantys Power Electronics Ltd.*

**Introduction**
Junction temperature (Tj) estimation is a key technology for "smart converters". Improvements in converter current rating can be made – either by reducing margins or allowing dynamic changes in current rating – and operators can benefit from advanced warning of abnormal operation which is reflected in Tj and/or the electrical characteristics measured. These benefits of Tj Estimation become more important as converter power densities are increased and operating costs have to be reduced.

Amantys has developed a Tj Estimation Evaluation System, Figure 1, which allows converter OEMs and power stack designers to evaluate the Amantys Tj Estimation technology. It may be fitted to an inverter phase leg with a device rating up to 3300 V, and includes isolation, on-board processing and data-logging. It is ideal for laboratory validation of the Amantys technology. It acts as a data-logging tool that is independent from the converter controller, for example during type testing. It can also be used to diagnose problems in the field where oscilloscopes cannot easily be fitted and problems may be intermittent.

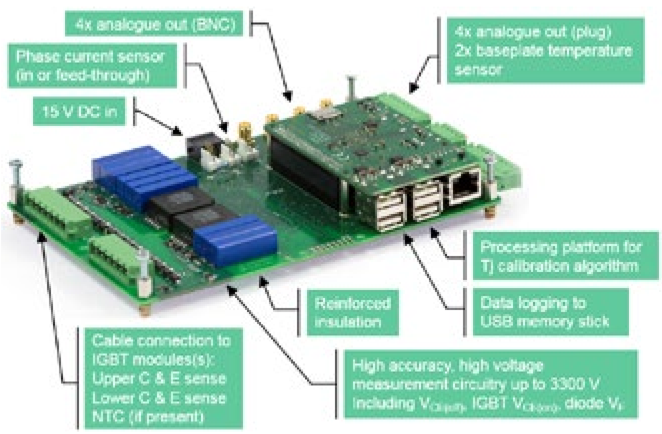


*Figure 1: Amantys Tj Estimation Evaluation System*

The system is now available for partners to test the accuracy of the measurements and explore the benefits of Tj estimation in their application.

**What is Tj Estimation?**
Junction temperature (Tj) estimation uses temperature sensitive electrical parameters (TSEPs) from the IGBT and diode, measured on the IGBT module, to estimate the on-chip junction temperature. The alternative technique of online junction temperature simulation requires a detailed thermal model and calculation of power losses in order to calculate Tj; this is the method used by some converter manufacturers, which struggles at low AC frequencies and does not track power module degradation. The advantage of Amantys's technology is that the auto calibration algorithm means that a detailed thermal model is not required.

A comprehensive review of using changes in electrical behaviour in power devices for Tj estimation using TSEPs is given in [1]. The only TSEP that is universal to all power devices, to all converter switching patterns (including solid-state switches) and to all gate drive methods is the on-state voltage drop. This allows technology to be developed for any converter application, and requires accurate measurement of both the on-state current and on-state (forward) voltage drop. While using TSEPs measurable using the gate voltage – e.g. internal gate resistance [2] or MOS gate threshold voltage – may seem attractive, these cannot be used for the diode and require invasive access to the gate drive, so are unsuitable for a large range of applications.

**Measurements**
The Evaluation System has been designed to measure accurately the on-state voltage drop of both switches in a half-bridge leg. The IGBT and freewheel diode forward voltages are measured as positive and negative voltage drops respectively. Measurements are also made of the DC link voltage, phase current, PWM timings and external module temperature. The Evaluation System can measure both an internal module NTC thermistor or an external temperature sensor (NTC or PTC thermistor, or PT1000 sensor), giving compatibility with a wide

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range of module types. Measurements are recorded at a sample rate of 1 ms, with signals aggregated within each sample period.

The current can be measured using a Hall-effect sensor, in one of two ways: (a) using the existing converter phase current sensor and feeding the signal through the Evaluation System, or (b) adding an extra current sensor. Rogowski sensors are not suitable because they cannot measure DC or low-frequency AC currents.

Figure 2 shows examples of measurement waveforms taken from a back-to-back test rig, using an open half-bridge module rated at 1700 V/600 A and operating at 500 V. This demonstrates the high quality of the on-state voltage measurements. Plotting the on-state voltage and current on a scatter plot for a whole mission profile (Figure 3) show further evidence of the measurement quality: without accurate on-state measurements this data visualization would be difficult.

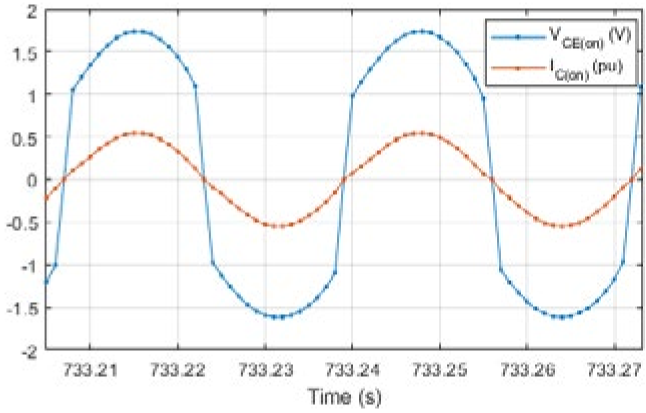


*Figure 2: Example of $V_{CE(on)}$ and $I_{C(on)}$ measurement waveforms recorded at a DC supply of 500 V. ($I_{C(on)}$ is relative to the device rated current.)*

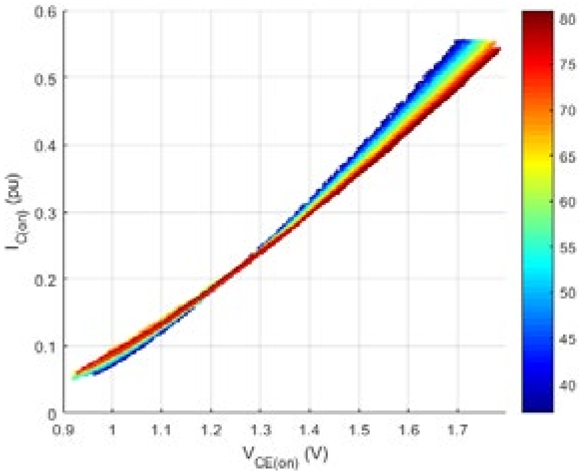


*Figure 3: Example of IGBT I-V scatter plot; colour represents module NTC thermistor temperature (°C) and $I_{C(on)}$ is relative to the device rated current.*

**Tj Auto-Calibration**

Using any electrical device measurements to estimate Tj relies on accurate calibration. This is necessary because of the wide variation in electrical characteristics between production batches [3]: an error of only 10 mV can easily cause up to 10 °C error in the estimated temperature. In a laboratory environment this may be achieved using a curve tracer, but this is time-consuming and completely impractical for industrial applications. In multi-chip modules, the voltage drop measured between the collector and emitter sense terminals includes bond wires which can degrade, so ultimately TSEPs must be tracked continuously to keep the estimated Tj accurate. Modifying the converter topology to achieve this, e.g. [4], would be expensive and impractical.

With a goal of simplifying the calibration process, Amantys has developed a unique algorithm for auto-calibration of TSEPs. This runs on the Evaluation System, which takes all necessary measurements to achieve this. It requires only a simple mission profile, of up to 5 minutes long, e.g. Figure 4, which is run on the whole converter. It simply requires an inductive load – i.e. zero power factor – and sufficient baseline (heatsink) temperature variation, which can be achieved if required by reducing the coolant flow or fan speed. In this way it is completely compatible with a typical end of line test after production. Further work is also under way to allow re-calibration online (during converter operation).

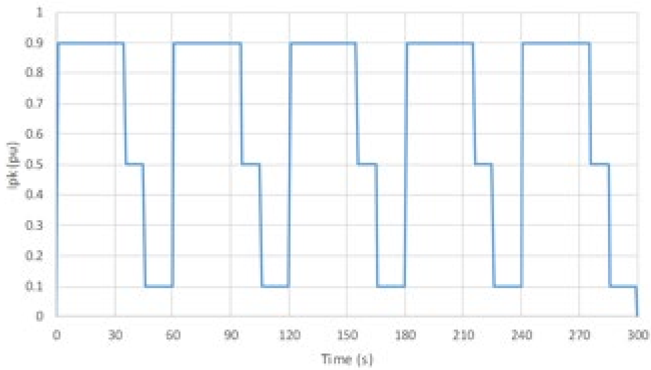


*Figure 4: Calibration mission profile; peak current Ipk is relative to the device rated current.*

Examples of the auto-calibration algorithm working are shown in Figures 5(a)-(d), with estimated temperature compared with the measured (actual) temperature. The actual temperature was measured using pyrometric infra-red temperature sensors, with one placed above each chip in the module (3 chips per device). These have a relatively slow response time. The estimated temperature is calculated every millisecond from the calibrated TSEPs and the on-state voltage measurements; however for the comparison here it is filtered to match the response of the infra-red sensors.

The mission profile, applied to the back-to-back test rig as previously described, consists of four 5-minute sections: calibration, random load at zero power factor, automotive operation (based on the FTP-75 urban driving cycle), and a slower more regular operation.

The initial mismatch of temperature in Figure 5(a) is because the TSEPs are initially set using the datasheet I-V curves: this highlights the need for accurate calibration. After calibration, the estimated and actual temperatures differ by up to only 2 °C, with an rms temperature error of 1.3 °C for the remainder of the mission profile. The estimated temperature matches the actual temperature at low frequencies – both for the peak and mean Tj – and during high-current sections of the automotive driving cycle, see Figures 5(b)-(d). The rms temperature error for the diode is similar, at 1.4 °C.

**Data-logging**

In addition to being a platform for evaluating Tj Estimation, the Evaluation System is a comprehensive data-logging system. All measurements are recorded in text (.csv) files at a 1 ms rate; these are stored on up to 4 USB memory sticks. The data rate is approximately

11 GB/day, giving up to about half a year's worth of data using 4 x 512 GB USB drives. All measurements may also be streamed over Ethernet (using SCPI); this allows real-time access to the data, e.g. from the converter controller.

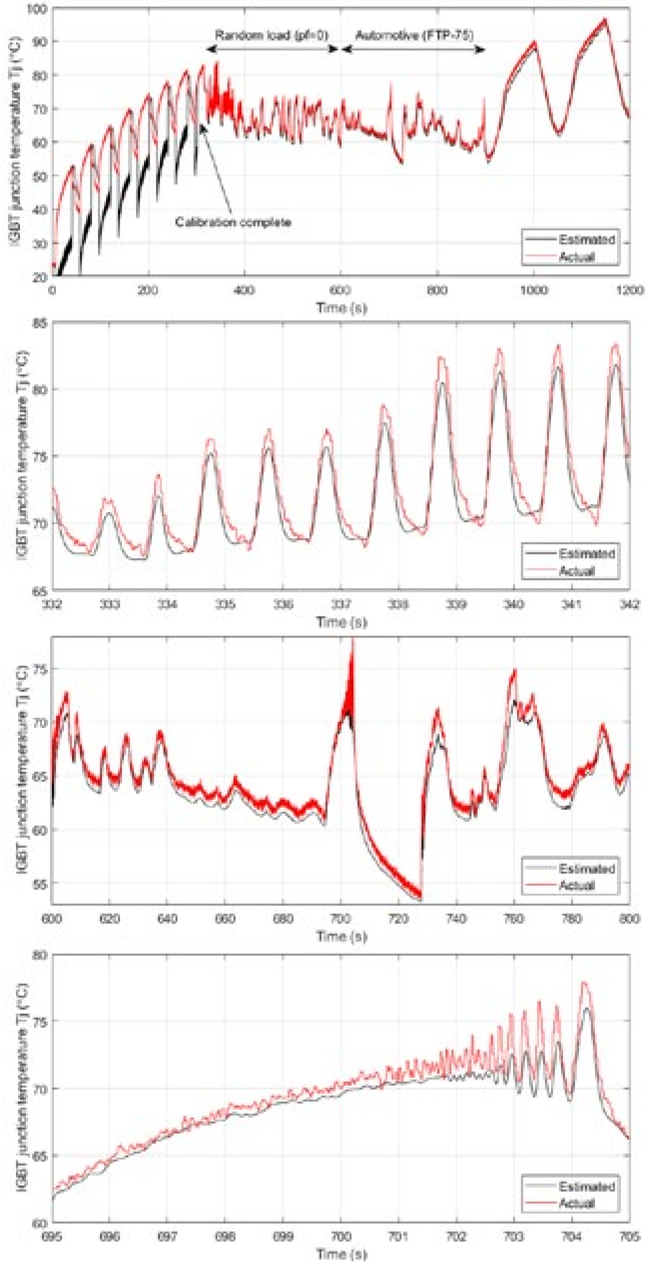


*Figure 5: Validation of estimated IGBT Tj. From top to bottom: (a) whole mission profile, including calibration cycle 0 to 300 s, (b) random load at pf = 0 and low frequency (1 Hz), (c) & (d) sections of automotive mission profile.*

**Visualisation and PC Lab Tool**

To assist with operating the Evaluation System in a laboratory environment, Amantys has developed a PC application to allow live monitoring of the measurements and estimated Tj over Ethernet. This has been specifically developed to monitor both short-duration signals (e.g. on-state voltage and current waveforms) and long-duration signals (e.g. rms or peak current and temperatures). IV scatter plots are also provided, allowing users to visualize on-state behaviour and check data quality, whether Tj Estimation is being used or not. Figure 6 shows typical operation of the PC software.

**Application to Condition Monitoring**

Condition monitoring of power semiconductor devices is enabled in two ways using the Amantys Tj Estimation technology. Firstly, data-logging over many months allows measurements to be analysed offline (not in the converter). Secondly, aspects of the auto-calibration algorithm can be used to detect when TSEPs start to change, highlighting changes in the electrical or thermal system which are early indicators of wear-out or abnormal behaviour.

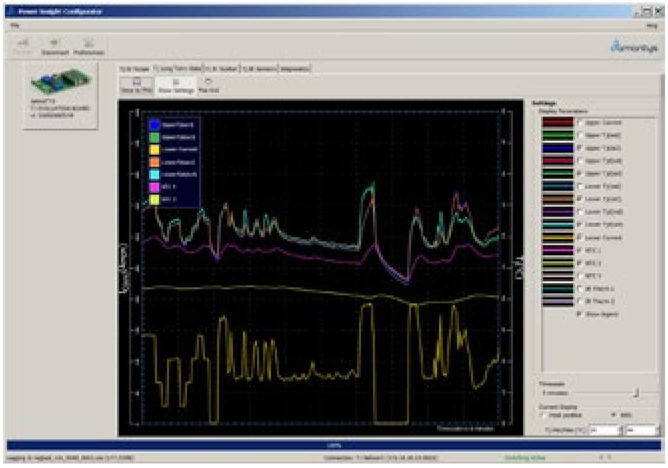

*Figure 6: PC software used to operate the Evaluation System*

**Integration into Converters**

While the Evaluation System may be used to test the Amantys Tj Estimation technology in the laboratory, it is not designed for integration into a production converter. The Tj Estimation algorithm may be implemented in the converter controller, or in an inverter stack control card, since these have access to all measurements required. Amantys is working on a portfolio of options to ease the integration of the technology into a production converter.

For pure condition monitoring or retrofit applications, it may be possible to design a more compact version of the system to allow integration into the target converter.

**Conclusions**

The Tj Estimation Evaluation System offers a flexible and sophisticated platform for evaluating the Amantys Tj Estimation technology and for performing converter diagnostics. The cornerstone of this technology is the accurate $V_{CE(on)}$ measurement, combined with the auto-calibration algorithm that Amantys has developed to simplify the TSEP calibration process significantly. For the first time, truly general-purpose Tj Estimation technology is available for evaluation, applicable to a wide range of devices, modules and converters.

**References**

[1] N. Baker et al, IEEE Industrial Electronics Magazine, pp. 17-27, Sep 2014
[2] M. Denk et al, PCIM Conference Proceedings, pp. 818-825, May 2015.
[3] U. Scheuermann, PCIM Conference Proceedings, pp. 691-697, May 2016
[4] B. Ji et al, IEEE Trans. Power Electronics, vol. 30, no. 3, March 2015.

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# Active Rectifier Controller with Ultrafast Transient Response and Low Power Dissipation

*Automotive standards, such as ISO 16750 or LV124, specify that automotive electronic control units (ECUs) may face a supply with a superimposed ac ripple of up to 6 V p-p at up to 30 kHz.*

*By Bin Wu, Analog Devices, Inc.*

**Fast Response for Input Ripple Rectification**

Devices such as the LT8672's gate driver, which controls the external MOSFET, is strong enough to handle ripple frequencies of up to 100 kHz, which minimizes reverse current. An example of such an ac ripple rectification is shown in Figure 1.

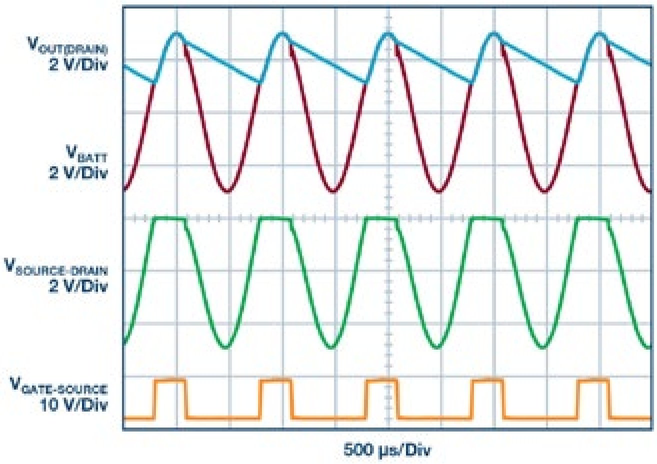


*Figure 1: Rectification of input ripple.*

**Low Power Dissipation Compared with a Schottky Diode**

The performance of the LT8672 (using the IPD100N06S4-03 as an external MOSFET) can be compared to a Schottky diode (CSHD10-45L) with the setup shown in Figure 2. Here, a 12 V power supply at the input emulates the automotive voltage supply, and the output is loaded with a constant current of 10 A. Thermal performance for both solutions at steady state is shown in Figure 3. Without cooling, the thermal performance of the LT8672 solution is far superior, reaching a peak temperature of only 36°C, while the Schottky diode solution reaches a much higher 95.1°C.

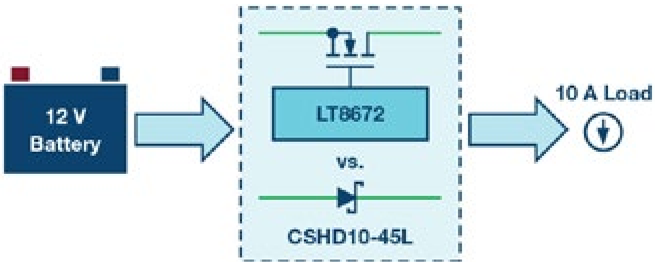


*Figure 2: System configuration for thermal performance comparison.*

**Extra Low Input Voltage Operation Capability**

Automotive mission critical circuitry must be able to operate during cold crank conditions, when the car battery voltage can collapse to 3.2 V. With this in mind, many automotive grade electronics are designed to operate down to 3 V input. A Schottky diode's variable forward voltage drop can present a problem during cold crank, where

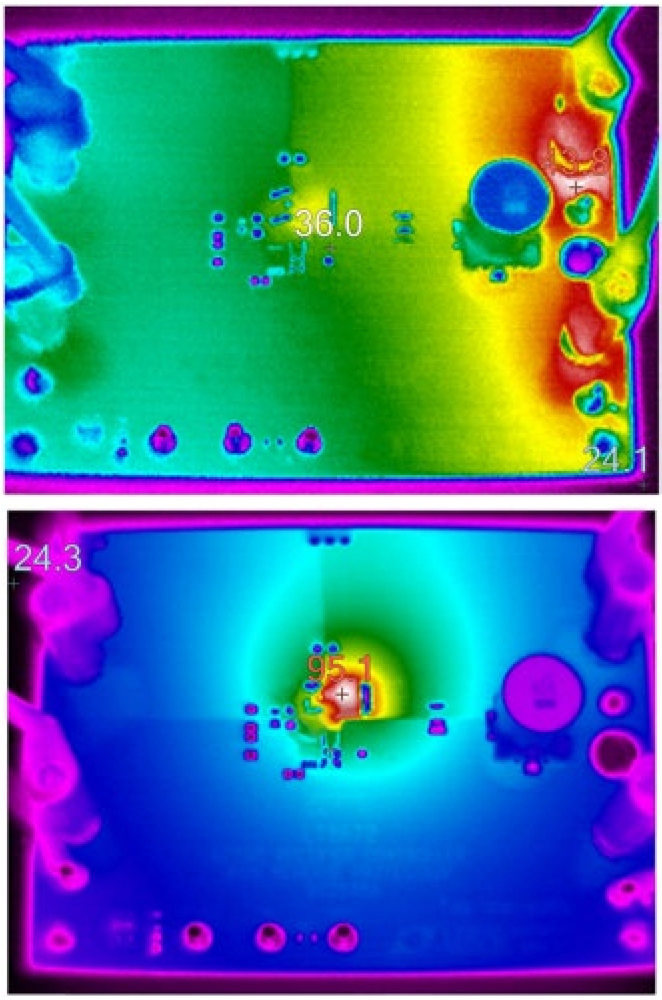


*Figure 3: Thermal performance comparison: (a) The LT8672 controlled system tops out at a cool 36°C, (b) while the Schottky diode system reaches 95.1°C, causing significant heating over the entire board.*

this drop produces a downstream voltage of 2.5 V to 3 V, which is too low for some systems to operate. In contrast, an LT8672 solution guarantees the required 3 V due to its regulated 20 mV voltage drop, which allows for easier circuit design and improved system robustness. Figure 4 shows a comparative cold crank test setup using an LT8650S step-down converter as the downstream test system. The LT8650S output is set to 1.8 V at a constant load of 4 A, and its minimum input operating requirement is 3 V. The results are shown in Figure 5.

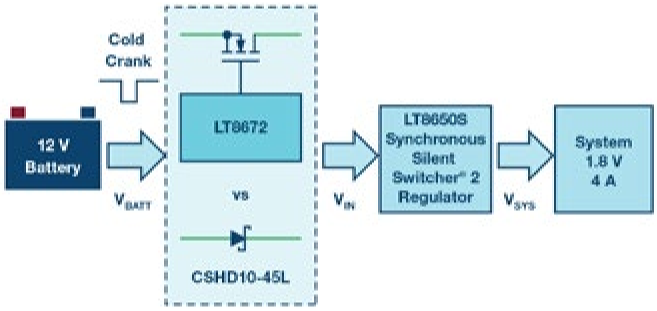


*Figure 4: System configuration for cold crank test.*

When VBATT drops to 3.2 V, the LT8672 controlled system (a) maintains VIN > 3 V, allowing the LT8650S to keep its output VSYS stable at 1.8 V, while in the Schottky diode system (b), the input voltage VIN of the LT8650S drops below its minimum operating voltage, preventing it from maintaining 1.8 V at its output, VSYS.

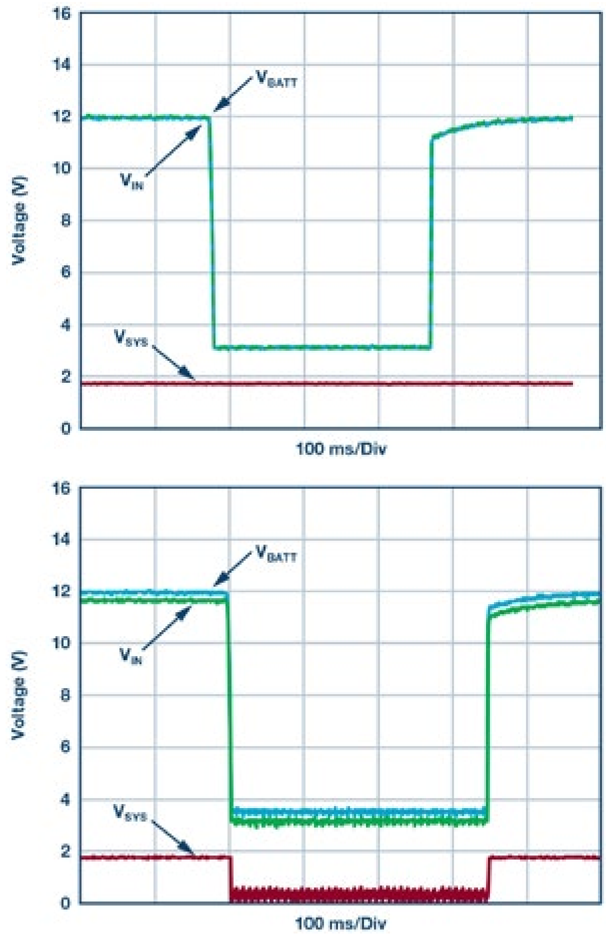


*Figure 5: A system voltage comparison under cold crank (a) using the LT8672 where VSYS stays stable at 1.8 V and (b) using a Schottky Diode where VSYS drops below the minimum operating voltage.*

**Integrated Boost Regulator**
Many alternative active rectifier controllers use a charge pump to power the gate driver. These solutions often cannot provide strong gate charging current and a regulated output voltage, which limits the frequency range and performance of continuous rectification. The LT8672's integrated boost regulator provides a tightly regulated gate driver voltage with a strong gate driver current.

**Conclusion**
The LT8672 active rectifier controller is able to rectify high frequency ac ripple on automotive supplies. It uses an integrated boost regulator to drive a MOSFET for ultrafast response during continuous rectification, which is an improvement over charge pump solutions. It provides rectification and reverse input protection with low power dissipation and an ultrawide operational range (desirable for cold crank) in a tiny 10-lead MSOP package. In addition, the LT8672's active protection has a number of advantages over Schottky diode designs, such as minimal power dissipation and a small, predictable, regulated 20 mV voltage drop. The LT8672 also includes features to satisfy supply rail requirements in automotive environments:

- Reverse input protection to –40 V
- Wide input operation range: 3 V to 42 V
- An ultrafast transient response
- It rectifies 6 V p-p up to 50 kHz and it rectifies 2 V p-p up to 100 kHz
- Integrated boost regulator for the FET driver outperforms charge pump devices

Figure 6 shows a complete protection solution.

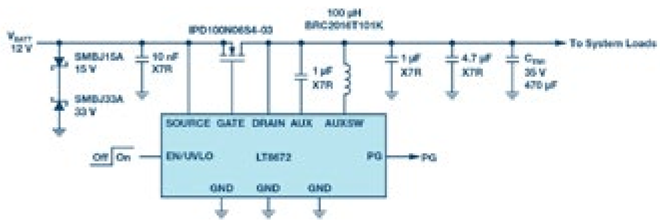


*Figure 6: LT8672 active rectification/reverse protection solution.*

**About the Author**

Bin Wu was born in Zhejiang, China, in 1985. He received his Ph.D. in electrical engineering from University of California, Irvine, CA, in April 2016. From April 2016 to July 2017, he was a post-doctoral research associate at the University of Maryland, College Park. After that, he worked at Maxim Integrated. Since November 2017, he has been an application engineer with Analog Devices, San Jose.

His interests include electrical vehicle power architecture, high power density step-up/step-down dc-to-dc converters, switched capacitor converters, modeling, and renewable energy integration systems. He can be reached at bin.wu@analog.com.

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# Cold Increases Service Life

## *The Influence of the Operating Temperature on the Service Life and Reliability of Switching Power Supplies*

*The question of whether to use a transformer power supply or a switch-mode power supply is no longer dicussed today. In addition to superior technical properties, switched-mode power supplies impress with low costs, low weight and little space requirement. Certain requirements such as PFC (Power Factor Correction > 0.9 and sinusoidal mains current) can only be met with switched-mode power supplies. The question remains, what are the greatest influences on the service life and reliability of a switched-mode power supply?*

*By Dipl.-Ing. (FH) Stefan Bergstein, Product Manager of EMTRON electronic GmbH*

Significant technical advantages of high-quality switching power supplies are:

- Regulated output voltage without additional downstream regulator
- High efficiency, low losses independent of input voltage
- Wide range input (e.g. 95 - 264 V) possible with little effort
- High short-term overload capacity

Where there is light, there must be shadow. Hf interference on the supply lines, as well as radiated interference, may be disadvantageous, as well as a possibly shorter service life and a lower reliability compared to conventional power supplies due to the majority of components required.

**Operating temperature is a significant influence**

The internal operating temperature has the greatest exponential influence on service life and reliability: the service life decreases by half per 9 °C temperature rise.

Decades at low temperatures can quickly turn into a few years or even months at high temperatures. Every degree less counts! Although it is possible to achieve a longer service life at high temperatures by using highly developed components, the cost-benefit factor must be considered when using such special components. The use for standard applications is excluded in many cases for reasons of cost-effectiveness.

Provided that a switching power supply has been professionally developed, the manufacturer first determines the required installation and cooling conditions. However, if the user operates the application in a thermally critical situation, e.g. due to inadequate ventilation or heat dissipation, he impedes the cooling of the unit. This leads to overheating and thus to a reduction of service life or even to failure. Although all high-quality switched-mode power supplies contain an over-temperature sensor that switches off when its response temperature is exceeded, this does not prevent long operation just below the switch-off threshold. This drastically reduces the service life.

Maximum permissible operating temperatures are specified for all components. However, this only means that the function is guaranteed at the maximum temperature.  However, this has a considerable influence on the service life, which is always subject to the “halving per 9 degrees law”.

For automotive applications, for example, components are available for operating temperatures well above 100 °C, but it should not be ignored that a car only has a service life of a few thousand active hours, during which the maximum temperatures only occur temporarily.

**High efficiency for a long service life?**

What options does a manufacturer have to achieve a long service life and reliability? The higher the efficiency, the lower the losses and thus the lower the self-heating. This entails a certain amount of extra work, which may justifiably result in a higher price. The most critical components in any conventional switching power supply are the electrolytic capacitors because they contain an electrolytic liquid that escapes more or less quickly through the seal in the event of overheating.

Electrolytic capacitors belong to the most important and largest components of the power supply. The temptation is great to save money on electrolytic capacitors, i.e. to overload them or to choose inexperienced and therefore low-cost suppliers. The manufacturers we represent only use high-quality capacitors from well-known brands, because a cheap, unsafe component source does not meet our responsibility and understanding of quality.

Since the production of these components requires decades of experience the number of competent manufacturers is limited and their prices are marginally increased. Also the desire for small dimensions and in particular low overall height, restricts the available volume for electrolytic capacitors. Low, wide electrolytic capacitors have a shorter service life because they provide a larger sealing surface and shorter ways for the electrolyte to evaporate. SMD electrolytic capacitors are exposed to extreme temperatures during reflow soldering and thus lose some of their service life. Towards the end of the electrolytic capacitor’s service life, they become exponentially hotter and hotter. As a rule, they finally “smash through” and blow the electrolyte into the environment via safety seals.

In the comparative test of switching power supplies, the measurement of the surface temperature of all electrolytic capacitors on the roof is one of the first and most important measures. In order to ensure a diligent approach, the technical data of the electrolytic carbon manufacturer should be obtained, indicating the service life above temperature. In many cases, power supply manufacturers also provide technical reports with information on component temperatures.

However, temperature limits apply to all components of a switched-mode power supply, especially to all insulation materials. The insulation properties of conventional PE films decrease noticeably as the temperature rises and drastically at high frequencies. According to the electrolytic capacitors, plastic film capacitors are at risk at temperatures above 100 °C. The power ferrites of inductive components show rapidly increasing losses at temperatures above 100 °C, which can lead to saturation with subsequent destruction of active components.

The usual use of SMD components worsens the thermal situation because power diodes and transistors soldered onto the circuit board heat up the adjacent electrolytic capacitors. The usual board materials also cause losses at high frequencies.

In view of any thermal loads that may occur within the service life, an initially more expensive switched-mode power supply is usually more economical in use, as the higher-quality, temperature-resistant components installed significantly increase the overall service life of the application.

In addition, it goes without saying that every user of switched-mode power supplies should ensure optimum cooling.

Serious SNT suppliers specify a curve for the load capacity in dependence on the temperature of a defined test point on the housing. The best advice is to choose a switching power supply with a higher specified power than the required continuous power and not to use more than 75% of the rated power for a short time.

**Different cooling concepts**

Different cooling concepts are required for different applications. Primarily, it is necessary to distinguish between the physical heat dissipation concepts by convection with free or fan ventilation or by heat dissipation, so-called contact cooling, often via a base area, e.g. the upper side or the so-called baseplate cooling.

**Convection:**

Convection cooling is classically used in applications, e.g. in switch cabinets with sufficient free air spaces. However, during installation it is important to pay attention to the mounting position and minimum distances around the power supply unit so that the required convection and thus the heat dissipation can take place. The information can be found in the data sheets and in the installation instructions.


*Figure1: Mean Well TDR-480*

Another large field of application for convection-cooled switching power supplies is modern LED lighting. Forced ventilation with a fan would often be inappropriate simply because of the acoustic fan noise. In many cases, the housing forms have correspondingly integrated heat sinks. In addition, the interior components are often fully encapsulated. On the one hand, this ensures high insensitivity to moisture and dust; on the other hand, and no less importantly, modern potting compounds ensure optimum heat transfer to the surrounding enclosure wall.

*Figure 2: Mean Well HLG-480*

When implementing a switched-mode power supply in a closed system, there are often only small areas available for assembly. In addition, the air circulation in the system housing of very compact high-performance power supply units is often not sufficient to dissipate the heat loss. In this case, the requirements in the data sheets must be followed exactly. Either one dispenses with a part of the performance at increased ambient temperatures - in this case one speaks of de-rating - or forced ventilation by means of a fan cannot be dispensed with. The required amount of air circulation is often expressed in CFM (cubic feet per minute). In the European linguistic area one finds more frequently the data in m³/h.

A conversion results from 1 CFM = 1.699 m³/h

For high performance requirements, or with a compact design, forced ventilation is often indispensable. The manufacturers then immediately equip the power supply components with appropriate fan units. Depending on the

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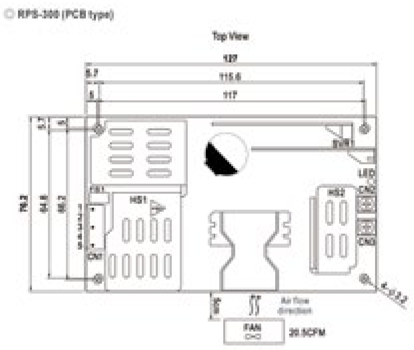
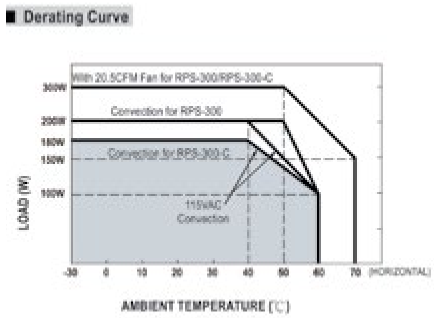
version, the required air volume flows can be adjusted by changing the fan speed. This means that the fans rotate at a low speed and thus with reduced noise development when the power requirement or the heat development is low. If the power requirement increases, the fan speed is automatically increased, thus ensuring optimum cooling of the switched-mode power supply.

Some manufacturers also offer special functions, such as reversing the flow direction.

**Contact cooling:**
If the use of a fan is not possible, or if the application, e.g. in some cases in the medical field, does not allow any disturbing fan noises, other cooling concepts are possible. For contact cooling, heat dissipation must be ensured via suitable heat sinks or via a housing surface or baseplate. In addition, sufficient convection must of course be ensured. If convection is not possible, systems with heat pipes or liquid circuits are already in use and thus enable trouble-free operation without power restrictions.

With DC/DC converters in the higher power range, the upper side of the housing is often intended for flange-mounting an appropriate heat sink. The required size of the heat sink can be calculated from the required performance conditions and the manufacturer's specifications. In many cases, however, suitable heat sinks are included in the Emtron electronic sales program.




SPECIFICATION

| MODEL | | | RPS-300-12☐ | RPS-300-15☐ | RPS-300-24☐ | RPS-300-27☐ | RPS-300-48☐ |
|---|---|---|---|---|---|---|---|
| | DC VOLTAGE | | 12V | 15V | 24V | 27V | 48V |
| | RATED CURRENT (20.5CFM) | | 25A | 20A | 12.5A | 11.12A | 6.25A |
| | CURRENT | Convection | 0 ~ 16.67A | 0 ~ 13.33A | 0 ~ 8.33A | 0 ~ 7.4A | 0 ~ 4.17A |
| | | 20.5CFM | 0 ~ 25A | 0 ~ 20A | 0 ~ 12.5A | 0 ~ 11.12A | 0 ~ 6.25A |
| | RATED POWER | Convection | 200W | 200W | 200W | 200W | 200.2W |
| | | 20.5CFM | 300W | 300W | 300W | 300W | 300W |

*Figure 3: Mean Well RPS-300 and excerpt from data sheet with details of required heat dissipation air flow 20.5CFM or derating with pure convection.*

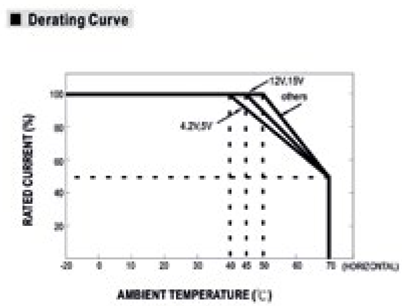



*Figure 4: Mean Well UHP-500 with details of derating depending on ambient temperature; Example: Model 12 V, derating at 45° and end at 70 °C with a maximum power of 50 %.*

*Figure 5: Mean Well RSP-320*

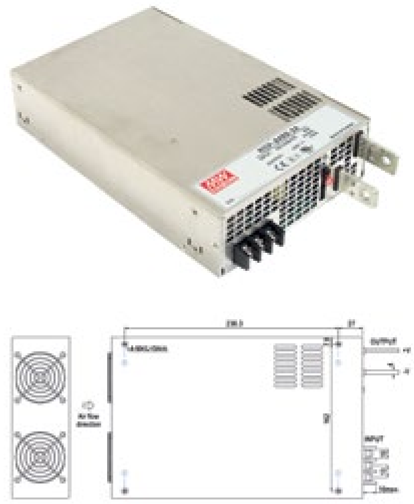


*Figure 6: Mean Well RSP-2400*

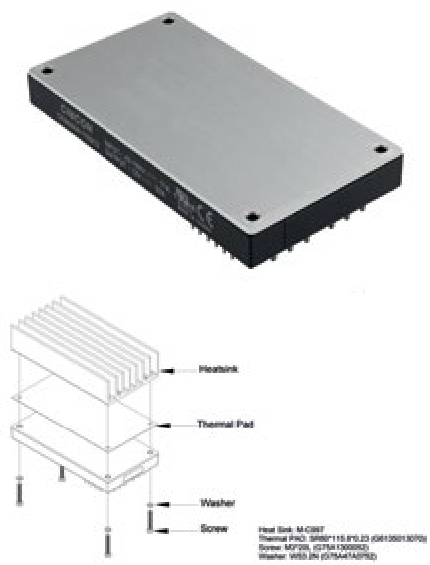



*Figure 7: Cincon CFB600 und heat sinks.*

A relatively modern concept for contact cooling is the so-called baseplate cooling.

The heat is transferred via a sufficiently large contact surface on the underside of the power supply unit. Due to the design, special circuit board materials and geometries are used to ensure heat transfer. The power supply unit can, for example, be screwed directly onto a correspondingly designed housing wall. In addition, it is still possible to mount the power supply unit on a specially designed heat sink based on convection or with a liquid circuit to ensure the necessary heat dissipation.

*Figure 8: Cincon CFM300M. Below the printed circuit board, the heat-transferring base plate (baseplate, here black) is clearly visible.*

However, a sufficiently small heat transfer resistance between the heat dissipating housing part or the base plate and the heat sink must be ensured. Auxiliary means for this are for example the well-known heat conducting paste or specially offered heat conducting pads.

Depending on the application, a wide variety of requirements arise for switching power supplies.

Last but not least, the cooling concept must also be taken into account when selecting the product.

In addition to our solution-based consulting services, Emtron electronic as a specialist distributor has long-standing contacts with many manufacturers in order to select the right power supply for the respective application from our extensive product portfolio together with our customers.

Dipl.-Ing. (FH) Stefan Bergstein, Product Manager of EMTRON electronic GmbH

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# An Innovative Current Sensor Offers Advantages over Conventional Current Converters

## *Against All Conventions*

*The New Zealand company Raztec Sensors, known as a specialist for Hall-effect current converters, presents a completely unconventional approach to current measurement which gets along without the usual toroidal magnetic core and thus opens up completely new possibilities in application and assembly.*

*By Warren Pettigrew, CTO, Raztec Sensors, and Sebastiano Leggio, Product Manager, Pewatron*

The conventional approach for AC/DC current sensors or current converters is to place a soft toroidal magnetic core with an air gap around the live conductor. If a magnetic field sensor is then introduced into this air gap, its output signal is proportional to the flowing current (see Figure 1). It should be noted that alternating currents (AC) can be measured with current converters based on converter technology, whereas this is not possible with DC currents.

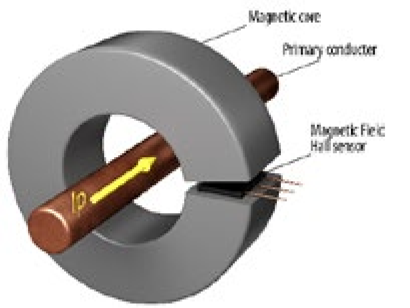


*Figure 1: Conventional current measurement with toroidal magnetic core*

This measuring principle works well with currents of up to approximately 1,000 A. Over 1,000 A, the required sensor becomes quite voluminous and expensive: the stronger the current, the larger the cross-section of the core must be in order to avoid saturation. However, the magnetic core performs various functions:

- The magnetic flux is focused on the magnetic field sensor.
- The sensor is less sensitive to magnetic stray fields.
- The magnetic flux can easily be amplified by additional primary windings.

However, as the current increases, the core becomes less useful and more of a disadvantage.

Modern magnetic field sensors do not require a strong magnetic flux to achieve high precision. Instead, saturation effects in the core affect accuracy. If, however, the toroidal core is omitted completely, you will face the well-known problem of signal distortion due to stray magnetic fields, which usually originate from other nearby conductors, and the influence of the terrestrial magnetic field. But there is an interesting solution to these problems based on differential measurement of the magnetic field.

**Differential current measurement**

This technique eliminates the effects of uniform magnetic stray fields in a very simple but effective way (see Figure 2). In cases where the stray fields are not uniform, the two sensors are placed as close as possible to each other. In order to increase the magnetic field strength, the bus bar can be tapered locally. This local constriction increases the resistance only slightly.

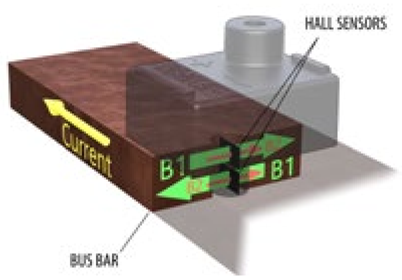


*Figure 2: Current measurement without toroidal core*

B1= Magnetic flux, induced by current
B2 = Magnetic flux leakage
B1= Proportional to current
The output signal of the Hall sensors is proportional to B
The output signal of the current sensor is proportional to: B1 x (-B1) +B2 x (+B2) = 2B1
This is why we speak of a high degree of immunity to uniform flux leakage.

The conventional approach to differential current measurement involves installing a sensor on each side of the conductor. Raztec recognized that it would be advantageous to measure the current inside the bus bar by drilling into it or – to put it another way – sounding it out. This is where the name Current Probe for this innovative sensor comes from, shown in Figure 3 here.

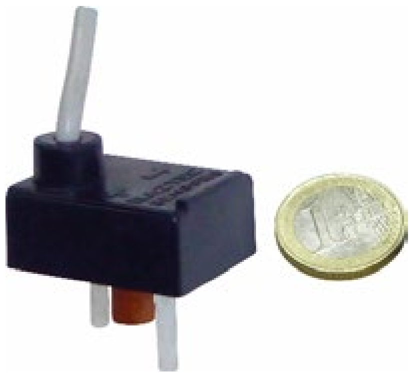

*Figure 3: The Current Probe from Raztec*

**Probe instead of converter**

The format of the probe allows a considerable reduction in the size and weight of the sensor. In fact, the smaller the sensor, even


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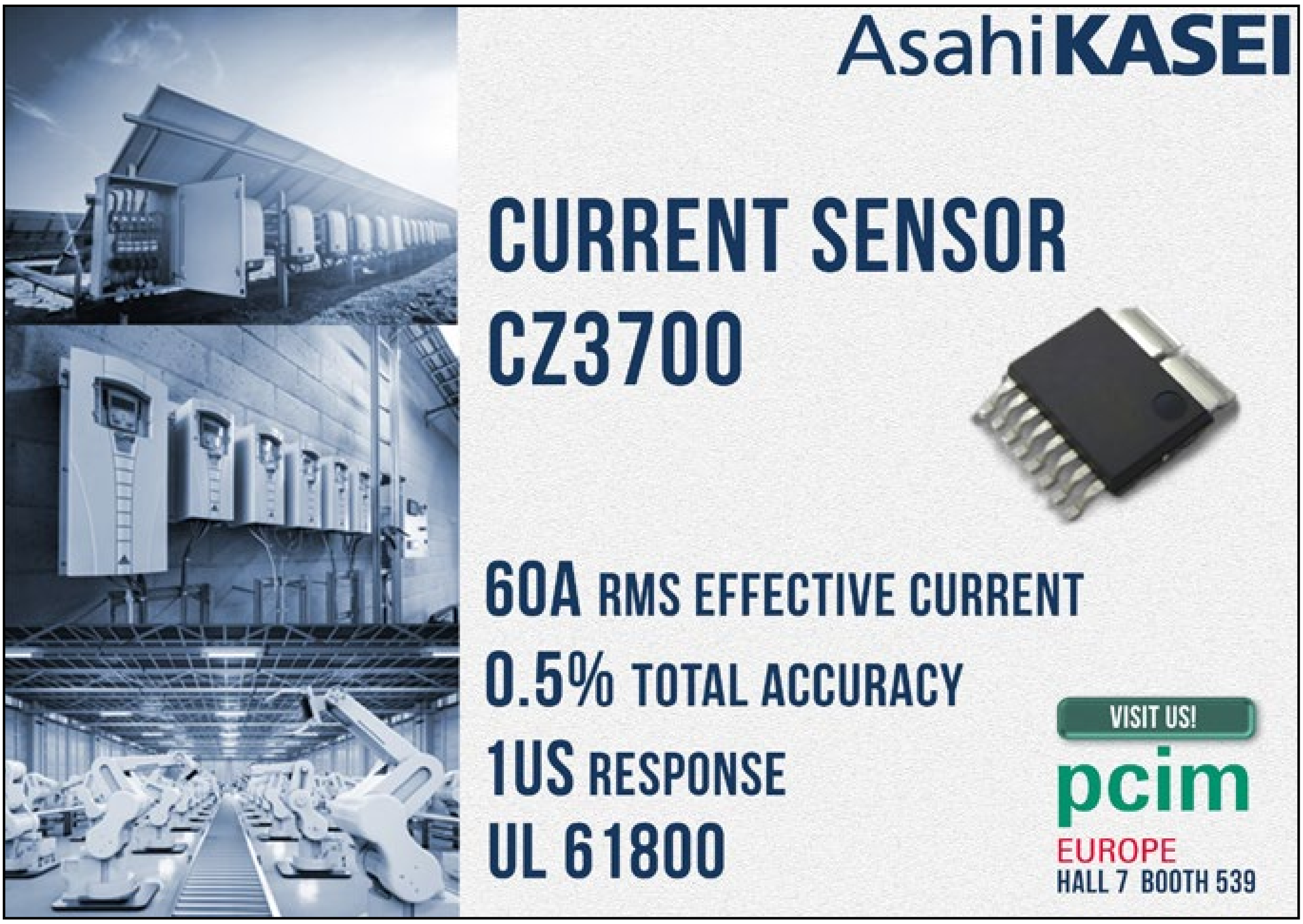
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the better. Figure 5 clearly illustrates the considerable difference in size compared to a classic push-through sensor. The one-sided mounting of the probe considerably simplifies tapping of the current. In principle, the sensor can even be retrofitted without dismantling the bus bar. As the current increases, the cross-section of the bus bar increases, too, which means that the magnetic flux changes only slightly. Therefore, the current probe can remain unchanged even at higher currents: It can measure 1,000 A as well as 25,000 A.

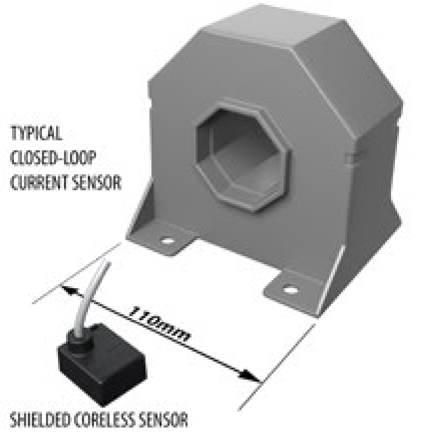


*Figure 5: Size comparison with a conventional current sensor*

But engineers also know the proverb: There is no rose without thorns. Differential magnetic field measurement is not the perfect answer to eliminate the effects of stray fields. It is effective in uniform fields such as the terrestrial magnetic field. But the fields induced by adjacent conductors are usually not uniform. Fortunately, these effects can often be neglected because magnetic field sensors are insensitive to fields acting outside their axis. If the current sensors are positioned in such a way that the stray fields do not act axially, their effects can be minimized. Figure 6 shows a simple configuration. As already mentioned, interference immunity can also be increased by tapering the conductor and thus amplifying the magnetic field to be measured and the sensor output at the same time.


*Figure 6: Simple configuration on bus-bars*

**Special challenges**

In some applications the mounting of the probe on the bus bar is a challenge. It is obvious that no conductive fasteners should be used for the probe. For this reason, nylon screws are supplied and Nyloc nuts (see Figure 4) would be the optimum counterpart. However, not all engineers trust this connection. High temperature adhesive pads are therefore integrated as an alternative or supplement. If you don't trust them either, you still have locking devices available for clips. Saddle clamps are another possible "low-tech" solution.

*Figure 4: Mounting options*

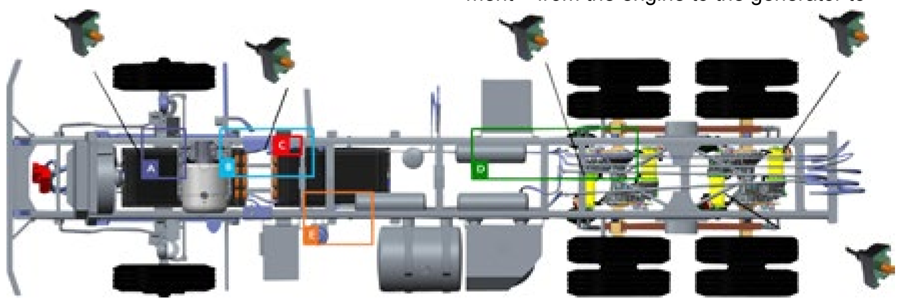

*Figure 7: Application example hybrid drive for trucks*

A further challenge for sensors without toroidal cores – and to a certain extent for all current sensors – is their sensitivity to rapidly changing electrical fields, such as those generated by PWM high-voltage signals. When designing the current probe, great importance was therefore attached to effective electrostatic shielding of the electronics. Hence all sensitive components are enclosed in a Faraday cage. The high temperature is another challenge: In order to save costs, bus bars are often designed in such a way that they become hot during operation. The probe must be placed on these hot conductors. This requires the selection of components that ensure high reliability and stability at high temperatures. In addition, the ensemble is then encased in a silicone-based high-temperature capsule. The probe is specified for temperatures up to 125°C, with temperature peaks up to 150°C. This is very unusual for current sensors. Of course, the encapsulation also provides a hermetic seal and is insensitive to strong vibrations.

The output signal of the probe depends on the size and shape of the conductor on which it is mounted. Therefore, Raztec can simulate any conductor for calibration purposes and calibrate any produced sensor accordingly. This makes the current probe a unique customized programmed and calibrated current meter.

**Possible applications**

A primary application is certainly the measurement of phase currents in electric motors, especially in automotive environments where space conditions are always critical. Low weight is also important, as the vehicle mass has a direct influence on energy consumption. The current probe is also suitable for monitoring charge and discharge currents on batteries for protection purposes or to indicate the state of charge. Hybrid vehicles cover the entire range of current measurement – from the engine to the generator to the battery. The Wrightspeed hybrid drive for trucks is an excellent example of this (see Figure 7), in which current probes are installed at various positions.

Summarized: The new current probe from Raztec is ideally suited for measuring even very high current intensities, with a small size and at low cost. It is extremely easy to use and to install and offers a high level of protection against interference such as high temperatures, water, vibration or electromagnetic radiation.

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# Drastically Reducing Earth Leakage Currents and Increasing Plant Availability

*The individual components in variable-speed drives cause earth leakage currents that cumulatively result in the tripping of the RCD. TDK presents the EPCOS LeaXield™ leakage current filter, a novel solution which facilitates a dramatic reduction of earth leakage currents. This enables the effective use of residual current devices (RCDs) and increases plant availability.*

*By Philipp Riedl, Dipl.-Ing., Product Marketing Manager Power EMC Filters, Magnetics Business Group TDK*

Variable-speed drives are used in industrial installations for a variety of tasks and, as a rule, they are fed from three-phase power grids. Possible applications for LeaXield include variable-speed drives such as those in machine tools, pumps, compressors, conveyance systems, and other pluggable devices.

A complete drive system consists of an EMC input filter, the frequency converter and the motor. An equally important component that is often neglected when considering the system is the shielded cable between converter and motor which can often exceed 200 meters in length. For safety reasons, the drive systems are connected to the grid by means of residual current devices (RCDs).

A significant problem of variable-speed drives are the earth leakage currents generated during operation – in particular by the frequency converter. The level of these currents depends on the interference suppression capacitors and the parasitic capacitances to earth, the commutation of the B6 rectifier circuit and the switching cycles of the power semiconductors. In many circumstances, the aggregate of the earth leakage currents exceeds the RCD's tripping threshold (Figure 1).

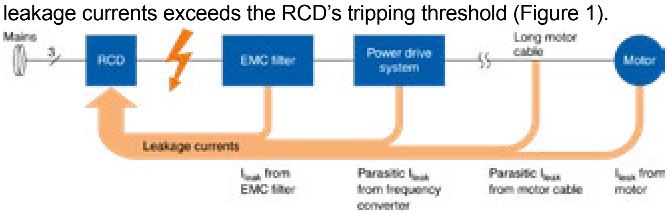


*Figure 1: In many circumstances, the aggregate of all earth leakage currents is so great that the residual current device (RCD) trips unintentionally.*

Standard RCDs for variable-speed drives, for example, have a tripping threshold of 30 mA for currents in the frequency range up to 100 Hz, which rises significantly in the range above 100 Hz. Figure 2 shows the tripping threshold of a typical RCD, the limit being about 300 mA for frequencies in excess of 1 kHz. Variable earth leakage currents, caused by switching cycles in the frequency converter, can result in the 300 mA threshold being exceeded. This is the case, for example, at 2.7 kHz in Figure 2. Steady earth leakage currents, on the other hand, which are generated by the commuting of the B6 rectifier circuit, occur at a significantly lower frequency of between 100 Hz and 1 kHz, where the tripping threshold is also much lower. In Figure 2 the earth leakage currents at 150 Hz equal around 90 mA, which causes the RCD to be tripped in every case. Finally, there are also transient leakage currents, such as those that occur when the line voltage is being switched on or off.

When aggregated, the stated parts of leakage current result in an unintentional shutdown of the system which, in industrial plants, can cause costly production downtimes.

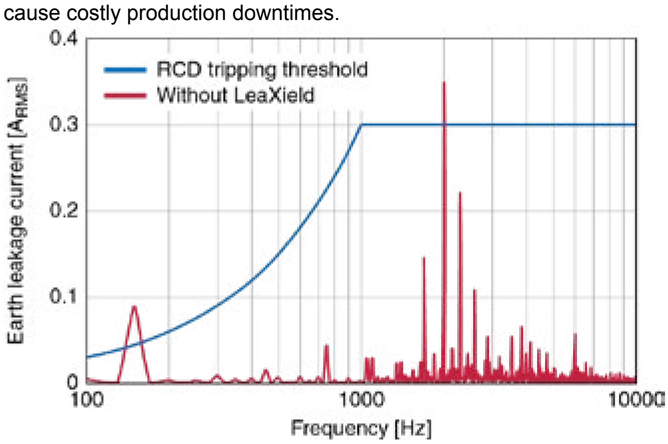


*Figure 2: Earth leakage current in the frequency range (red) relative to the RCD tripping threshold (blue). One threshold is exceeded at 2.7 kHz (variable leakage currents), and another at 150 Hz (steady leakage currents). The consequence is an unintentional tripping of the RCD.*

Until now, there has not been a comprehensive solution for dealing with the different causes of leakage currents. Attempts are often made to vary the overall capacitance to earth in the system. By switching off the filter capacitor in the converter, for example, it is possible to reduce the 150 Hz portion of the leakage current. This does however mean that in many cases the electromagnetic compatibility is no longer guaranteed. If, on the other hand, the capacitances of the Y-capacitors in the EMC filter are reduced, the proportion of the clock-frequency leakage current will increase despite the lower 50 Hz leakage current.

Although the use of an isolating transformer offers a technical solution, cost and installation space restrictions sometimes render this impossible. Doing without the RCD is by no means an alternative, because this is a safety risk and harbors considerable potential for hazards and accidents. The methods described are unsatisfactory in both technical and economic terms.

**LeaXield sets new standards for the reduction of leakage currents**

The EPCOS LeaXield leakage current filter has been developed in order to compensate leakage currents. It is inserted in the circuit between the RCD and the EMC line filter.

Figure 3 shows the circuit diagram. To measure the residual current across the three phases, a current sensor is integrated in the LeaXield. By means of an operation amplifier, a correspondingly 180° phase-shifted current with identical amplitude is then generated, which is capacitively coupled to the respective phases.

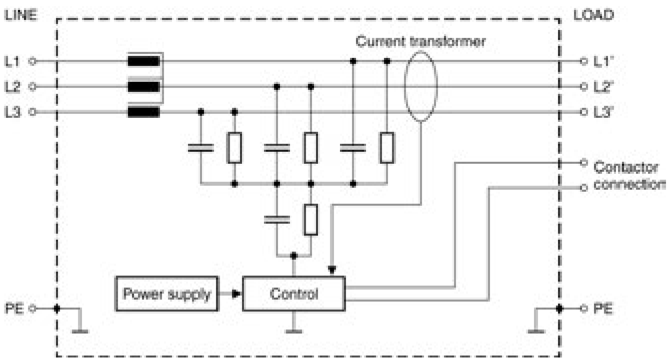


*Figure 3: A 180° phase-shifted current is capacitively coupled to the respective phases. By means of the current sink thus created, the leakage currents are returned to the source. With the optional contactor connections, the LeaXield module is already prepared for operation before the leakage current flows.*

The leakage currents are fed back into the system by means of the current sink thus created. This prevents them from flowing through the RCD and tripping it unintentionally.

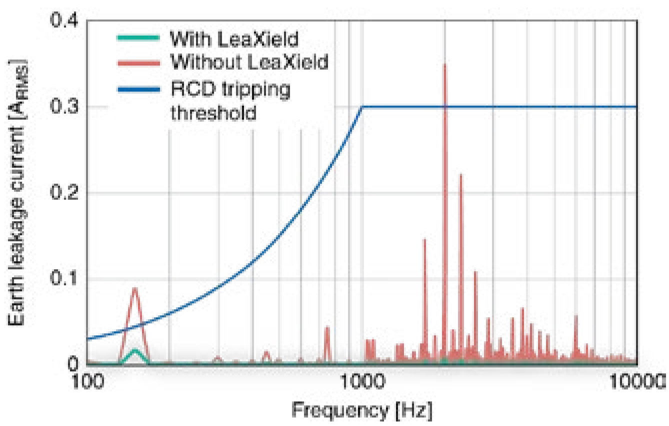


*Figure 4: The unfiltered leakage currents (red) are dramatically attentuated (green) by using the LeaXield and fall well below the RCD tripping threshold. This prevents an unintentional tripping of the RCD.*


LeaXield can compensate for earth leakage currents of up to 1 A. The compensation effect extends over a wide frequency range from 150 Hz to about 30 kHz. In Figure 4 an unfiltered leakage current (red) in the spectral range is compared with a leakage current (green) that is filtered through the LeaXield. The latter is far below the RCD tripping threshold, thereby preventing unintentional tripping of the RCD.

Thanks to its compact dimensions of just 270 mm x 60 mm x 119 mm, LeaXield is also ideal for retrofitting into existing systems. Furthermore, as no external voltage supply is necessary for operation, the installation costs are low. For the first time, therefore, LeaXield offers a compact and cost-effective solution for the compensation of leakage currents across a broad frequency range. This permits the use of a residual current device and consequently raises the plant availability.

**Technical data of EPCOS LeaXield**

| | |
|---|---|
| Rated voltage $V_R$ [V AC] | 305 / 530 (50 Hz) |
| Rated current $I_R$ max. [A] | 50 |
| Maximum leakage current $I_{LK,load}$ [A] | 1 |
| Frequency range [Hz] | 150 to 30000 |
| Dimensions [mm] | 270 x 60 x 119 |
| Conformity | CE |
| Ordering code | B84233A1500R000 |


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# Custom Transformers – Leakage Inductance Considerations

*By Dr. Ray Ridley, Ridley Engineering Inc.*

**Magnetics Design – Lessons Learned**

After graduating from college, my first job was for a computer company outside Boston. The project was to make a production power supply for computers using a full-bridge design at 850 W. These were the early days of FETs, so we were taking switching frequencies from the industry-standard 20 kHz or so to 100 kHz. The basic specifications were as follows:

Input voltage: 85 VAC to 265 VAC (300 V surge for 1 second)

Output Voltage: 5 V at 130 A (with margin to 5.25 V)
+ 12 V at 7 A
- 12 V at 7 A

There was no PFC circuit in front of the full-bridge. Nobody had thought of that at the time, and there were certainly no control chips for PFC. This meant that the stresses on the full-bridge topology were quite high, with operation over an almost 3:1 range.

Very few FET full bridges had been built for production at the time, we were all just learning from experience. The design of the transformer was assigned to my mentor at the time, Dan Balulescu, since he was from the power utility industry and had some experience. (A warning for everyone – once you have experience in magnetics design through to production, you will always be the one that they call on!)

Dan spent many days in his office, buried deep in magnetics design notes, data sheets, and page after page of calculations. Finally, he emerged from the office, showed me the design, and it was sent off to be fabricated by the local magnetics manufacturer. The secondary of the transformer consisted of two turns of 20 mil foil, center-tapped with another two turns, so construction of this was not something we could do ourselves. We needed a professional company to handle the foil construction, the litz primary, and the full safety insulation for VDE approval.

Dan, of course, knew all about the one equation for design that we talked about in the last article of this series. He had the appropriate number of turns for the core selected. And, like many designers, he had a myriad of other equations to try to achieve an optimal design. It was a very painstaking process.

We were fully engaged in board layout, controller design, thermal design, packaging, and everything else that goes into a real-world power supply for several months. The first transformer showed up about a month after the initial design was started. It was my job to install the transformer on the board, and to begin the circuit board testing. When the switches were all turned off at any significant load, there was a strong ringing on the drain of the power FETs. At low line, there was so much energy in this ringing, the voltage rang up to the opposite rail, clamped through the diode of the opposite FET, then rang down again all the way to the bottom rail. This was a destructive situation. Force commutation of the antiparallel diode of the FET led to failures of the bridge.

There was a lot of pain in the lab. The IR rep was called in several times to bring more samples of the FETS (no Digikey existed!) Finally I told Dan – "The transformer has too much leakage – I cannot make it work in our circuit."

He seemed somewhat unsurprised as though he had anticipated this might happen. This was my first big lesson in the real world – despite all the textbooks in the world, all the guidance, your power circuit is unique. You cannot fully anticipate every parasitic and every event that you are going to see. There will be design iteration, so expect this and be ready for it.

The next transformer cut the number of turns in half and increased the area of the core. This confused me – all that calculation, and after a test we are going to make such a drastic 2:1 change? But there was no choice – the only step down from two turns was one. All the optimization went out of the window. Trial and improvement are the name of the game. We will come back to this point later as it has a big impact on design direction.

**Basic Power Transformer Construction**

Figure 1 shows the basic construction of a transformer. For high-frequency, hard-switched converters, it is important to get good coupling of primary and secondary windings, so one winding is right on top of the other. (By contrast, a 60 Hz transformer on this shape of core commonly puts one winding on one side of the core, and one on the other. In this case, the high leakage created can actually be beneficial for protection of the system.)

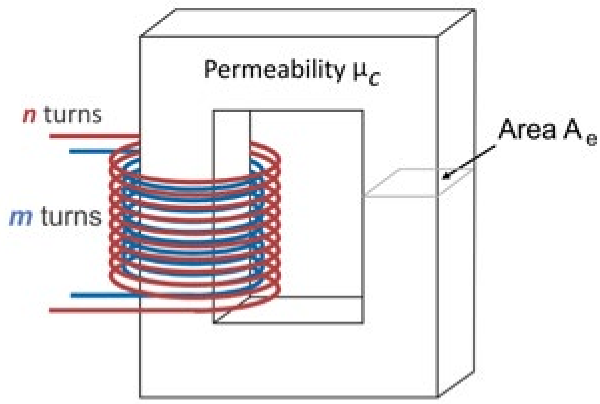


*Figure 1: High-Frequency Transformer Construction*

The core shape shown here is a U-Core, but that is not important. We need to ensure that we have a closed magnetic circuit, and the actual shape and cross-sectional profile can vary widely. However, the concepts in this article remain the same. We are going to see that the leakage inductance that caused me so much pain in my first design is a function of the spacing between the primary and secondary windings. Small dimensions can make a big difference. Skill and repeatability are crucial in transformer manufacturing.

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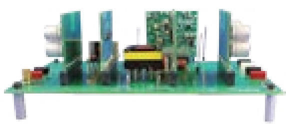

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**Power Transformer Equivalent Circuit**

As we learned in the last article, it is not possible to make an ideal transformer. The most important extra element that forms the model of the transformer shown in Figure 2 is the magnetizing inductance, $L_m$, shown in blue. Preventing this inductance from carrying too much current and subsequently saturating the magnetic material led to the one design equation for a transformer. If the equation is satisfied, the transformer will not saturate.

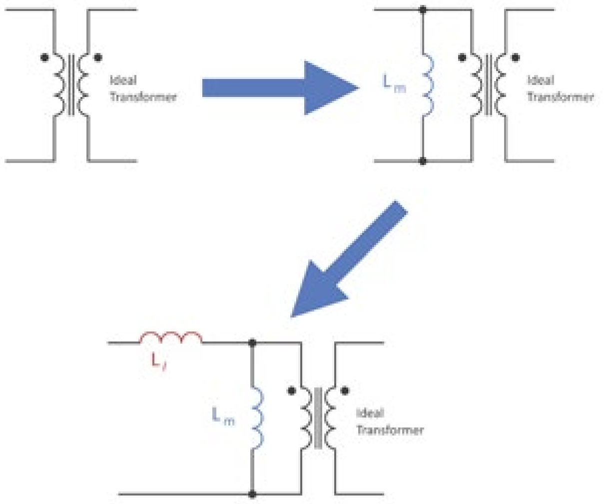


*Figure 2: Transformer Equivalent Circuit with Leakage Inductance. We now have two inductors and an ideal transformer representing the real transformer.*

However, while this one equation must ALWAYS be satisfied, an additional consideration on the leakage of the transformer will guide the choice of core and hence number of turns. The additional circuit element that must be added to the transformer model is leakage inductance, $L_l$, shown in red in Figure 2.

The effect of the leakage inductance on the circuit operation is easy to see, and it can be severe. As you can see from Figure 3, the output diode on this particular secondary is supposed to see just 50 V. However, there is a spike of 175 V due to the leakage inductance ringing with the diode capacitance. Anyone who has built a transformer-

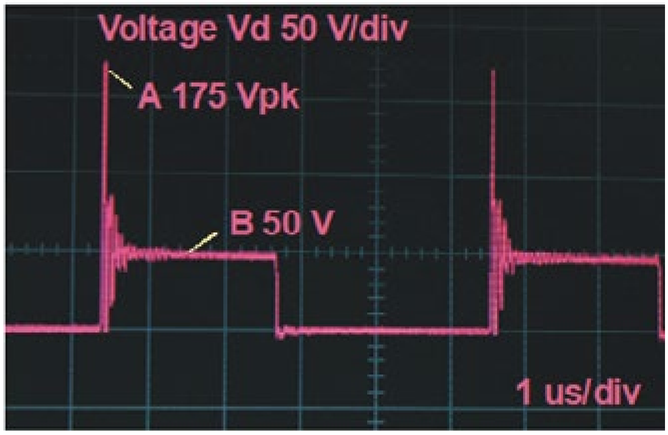


*Figure 3: The Effect of Leakage Inductance on Circuit Waveforms with Hard-Switched Circuits*


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isolated circuit is painfully aware of the magnitude of this effect. There is always a desire to lower the leakage in the transformer. Before we can do this, however, we need to know the quantities in the transformer that affect the leakage.

**Calculating Leakage Inductance**

Leakage energy is related to the fields that exist between the two windings of a transformer. No core material is involved, since the fields exist in the space. Hence the equation for leakage inductance is similar to the simple equation for an air-core solenoid, which is well known from basic physics.

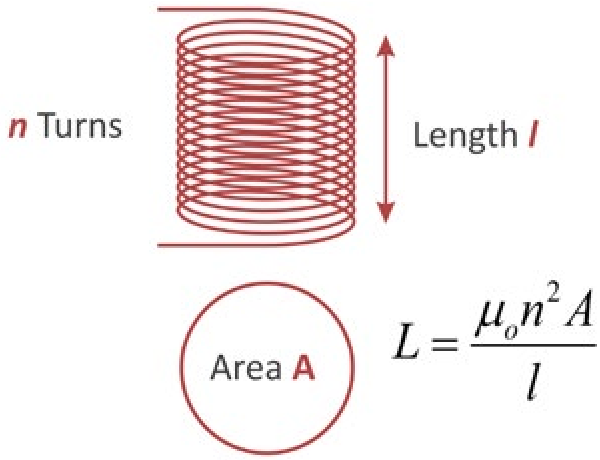



*Figure 4: The Simple Equation for the Inductance of an Air-Core Coil*

Figure 4 shows the basic construction of a "long" solenoid. From basic electromagnetic equations, the inductance of this structure is given by the equation of Figure 4. We can see that the inductance is proportional to the square of the number of turns, the area enclosed by the coil, and inversely proportional to the length of the solenoid.

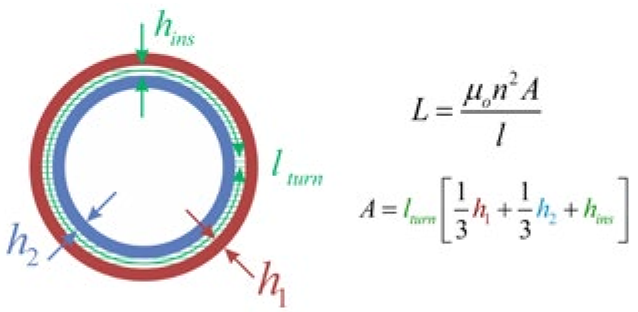



*Figure 5: The Equation for the Leakage Inductance of a Transformer is the Same as an Air Core*

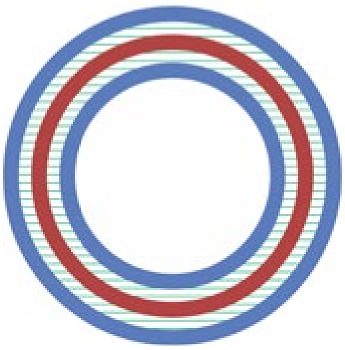
However, we don't quite have this exact situation in a transformer. We have one solenoid (or winding) inside another. The situation created by this structure is shown in Figure 5 as viewed from above. The red and blue circles are the primary and secondary windings. The green shading represents insulating material, which could be magnetics tape, air, or some other insulator. As you can see, the fundamental equation is the same as for the air core except for the definition of the area.

The area is no longer the full circle contained by a winding, it is now modified to be the equivalent area between the windings. As you can see, this is determined by the height of each layer of conductor, $h_1$ and $h_2$, multiplied by 1/3, and by the thickness of the insulating material, $h_{ins}$. For a bobbin-wound construction, the length of the winding l is given by the distance from one end of the bobbin to the other. The


equation tells us that a wide bobbin will reduce leakage inductance, so it can be important to look for a longer dimension here when selecting your core and bobbin type.

Thin wire buildup will also reduce leakage, as will a minimum amount of insulation material between primary and secondary windings. However, the insulation must meet full safety requirements, so it is not possible to make this dimension zero. We need to worry about voltage breakdown from one winding to another. Even with this requirement, typical dimensions for the insulation thickness are very small – much less than 1 mm, and this is crucial to low-leakage designs.

Another technique for reducing the leakage of a transformer is by adding additional windings, as shown in Figure 6. This is also referred to as interleaving – winding a secondary, then a primary, then another secondary will cut the leakage inductance down by a factor of two. There are endless variations to accomplish this. Some designers are fond of PC Board transformers, or planar transformers, where multiple primaries are alternated with multiple secondaries in order to cut the leakage inductance. More experienced and pragmatic designers recognize that you can go too far. Too small a leakage can present different problems to circuit operation, especially when you combine this with the increase in capacitance that goes along with each additional layer of winding. There is no set solution for every design.



$$L = \frac{\mu_o n^2 A}{2l}$$

*Figure 6: Adding an Additional Primary or Secondary Winding Reduces Leakage Inductance by a Factor of Two*

**Designing for Leakage Inductance**

If you have a design with too much leakage inductance, the equation tells you that the most powerful way to reduce it is by reducing the turns count. If you can cut the turns in half, the leakage goes down by a factor of 4. This is the single most important factor in designing low leakage transformers – keep the turns count low. At the same time, of course, you must obey the one equation to not saturate the core.

Of course, the equation given for leakage inductance in this article is an approximation. Realistically, we don't have quite the same situation as a long solenoid. There will be end effects, uneven spacing of wires and terminations. Measurement of the leakage inductance is a crucial design step, and even the lowest-cost manufacturers will attempt to measure this component. The accuracy of that measurement will be discussed in future articles, and you can also read about that in Reference [2].

When making measurements or assessing a vendor's measurements, beware of one of the common traps of transformer design, shown in Figure 7. There is a widely held belief that the leakage of a transformer should be about 1% of the magnetizing inductance, but this is a total myth. Sometimes you may coincidentally be at about this number if you have a gapped transformer (in a flyback transformer, for example). However, if your transformer is ungapped, it is not uncommon to measure a leakage inductance which can be 0.1% of the magnetizing inductance. Modern core materials have high relative permeability, in the order of several thousand. The core permeability only affects the magnetizing inductance, not the leakage, so you can see how the ratio of 1% is a very arbitrary number.

$$L_l \neq 1\% \, L_m$$

*Figure 7: One of the Very Misleading Assumptions About Leakage Inductance. Don't fall into this trap.*

Leakage inductance is more than just a number to predict how well the transformer will work in the circuit. If you give a small tolerance, perhaps 20%, for the leakage measurement, this will ensure that the transformer is being repeatably built.

Now, finally, we can move on to the design implications of power transformers for hard-switched converters. As we saw for the full-bridge design at the beginning of the article, there was NO freedom of choice for turns count on the transformer. For this, and every higher power design at relatively low output voltage, the secondary is just a single turn. There is no consideration of window-area product, current-density, fill factor, or any of the other common quantities that text books may suggest for design to an "optimum" point. We just set the secondary turn to one, and this defines the rest of the design.

The single secondary turn then is multiplied by the needed turns ratio for the converter to operate properly at low line in order to get the primary turns count. This is used with the single transformer design equation that we found in the previous article, repeated in Figure 8.

$$B_s n A_e > E_i T_n$$

*Figure 8: The Single Transformer Design Equation. With the secondary turns count set to one, there is no design freedom for the transformer core area.*

**Single Turns at Higher Frequencies**

We can see that for an 850 W design, we run into the single turn limit for a transformer at just 100 kHz. This is for a 5-V output. If the output were 12 V, we would have the option of a single turn, or perhaps just two turns. Both of these should be tested in a paper design, and probably also in hardware.

With the availability of new devices, we are seeing switching frequencies rising in the industry. It is not uncommon to see a 500 W design switching at 200-500 kHz, or even higher. But the secondary count is still frozen at a single turn, which means that there can be limited benefits to continued increase in frequency. This is one of the reasons that the frequency has not jumped as high as originally promised by the new wide-bandgap technologies.

In many designs, the increase in frequency is accompanied by a change to soft-switching technology such as the LLC or phase-shifted bridge. The leakage of the transformer then becomes part of the circuit operation and the need for very low leakage design is changed.

Some extreme density designs take the switching frequency into the MHz range. This does not make sense if the transformer secondary turns count is still stuck at 1 turn. This takes us into the realm of matrix transformers where fractional turns designs can be achieved. This is beyond the scope of this article, but it is a technology that will be part of the roadmap forward for power conversion.

**Summary**

One equation governs the saturation of a transformer, but the leakage inductance provides strong direction to a design. It must be taken into consideration early in the design procedure to avoid problems in the power circuit. For hard-switched converters, high leakage produces excessive ringing. For soft-switched converters, the leakage becomes part of the resonant tank and must be carefully controlled.

For low output voltage, the secondary turns frequently run into the limit of a single turn, and the entire transformer design process starts at that point in order to minimize the leakage.

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[4] Learn about proximity losses and magnetics design in our hands-on workshops for power supply design www.ridleyengineering.com/workshops.html This is the only hands-on magnetics seminar in the world.

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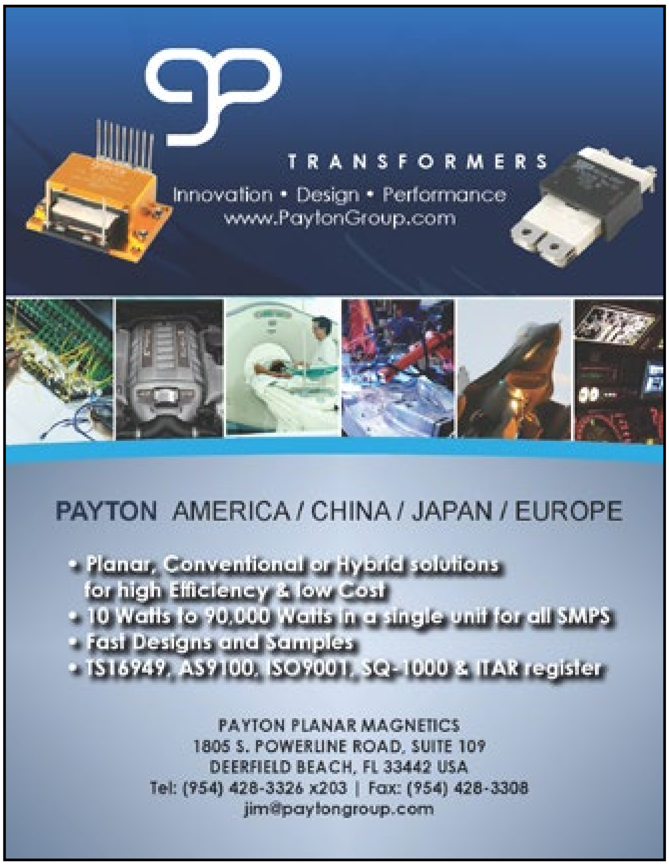


# Super- and Ultracapacitors: Thousands of Farads Thanks to Double Layer Technology

*In radio technology capacitators sometimes only have a few pF. Electrolytic capacitors reach µF, perhaps even mF. But there are capacitors that deliver thousands of Farads. How do they work?*

*By Wolf-Dieter Roth, HY-LINE Power Components*

Supercapacitors first showed up in consumer electronic applications as “gold caps” – capacitors that could only withstand a low voltage, but had sufficient capacity to replace backup batteries for RAM memory or real-time clock chips in computers. In LED rear lights for bicycles, they caused astonishment because they continued to shine for minutes when the bike had to stop at a traffic light, without a battery being installed. Initially, however, the peak power capability of these components was low and the internal resistance (equivalent serial resistance – ESR) relatively high.

The technology has now been further developed and now we have supercapacitors, also called ultracapacitors, in mass production with capacities of several thousand Farads. In terms of storage capacity, they can compete with small accumulators. However, the physics of supercapacitors are different, and thus they behave electrically differently from accumulators.

**Physics determine capacity**

First of all, supercapacitors are really capacitors: Their capacitance is determined by two conductive surfaces facing each other. The larger the surface, the smaller their distance and the higher the dielectric constant of the dielectric between them, the higher the capacitance:

$$C = \varepsilon \cdot \frac{A}{d}$$

C = capacitance, A = area, d = distance, ε = dielectric constant.

Consequently, an air or vacuum capacitor has a small capacitance value because d is quite high here and ε and A are low. But it offers a high dielectric strength.

A film capacitor has a significantly higher capacitance, as more surface area and a higher dielectric constant are available and the film allows the distance to be reduced while maintaining a high dielectric strength. Depending on the dielectric constant of the material, ceramic capacitors sometimes offer even higher capacitances with possible restrictions in dielectric strength and capacitance stability.

Electrolytic capacitors have an even higher capacitance because no mechanically manufactured dielectric is used here, but a thin, chemically produced oxide layer. If the base material is very rough, the area and thus the capacitance increases further. The dielectric strength is lower and the capacitor has a specific polarity – if handled incorrectly (wrong polarity, overvoltage, overcurrent, over temperature) it can fail prematurely.

Ultracapacitors are usually of symmetrical design. In principle, the polarity of the applied voltage should not matter. However, a polarity is defined during production when the capacitor is charged for the first time and the user should stay with this polarity later on. If the polarity of an ultracapacitor is reversed, there is no risk of a total failure with explosion as with an electrolytic capacitor, but a permanently reduced service life and performance is to be expected.

**Helmholtz double layer**

Supercapacitors are double layer capacitors whose underlying principle, the Helmholtz double layers, have been known for over 130 years. They are only a few molecular layers wide in the nanometer range, which results in a further capacity increase of up to a factor of 10,000 compared to the electrolytic capacitor. For the same reason, however, they have a low maximum voltage allowed, which is around 3 V for individual cells in today’s technology. For higher voltages, the cells can be connected in series, as with batteries; for more than two cells that reach 5 to 5.5 V permissible operating voltage, measures for even voltage distribution are usually required.

However, electrochemical processes such as those in batteries and accumulators, in which the electrode material changes structurally and thus wears out, play only a minor role in double layer capacitors. In the designs of supercapacitors commonly used today, they only contribute a few percent of the capacitance. There are supercapacitor technologies in which this proportion predominates or is equivalent (pseudo and hybrid capacitors). They have lower charge/discharge cycle numbers, but still far higher than accumulators. However, these variants are not currently of great importance and are not the subject of this article.

**Physics and Chemistry**

However, ion shifts and chemical formations of these ions do play a role in the double layer, which is why supercapacitors are also referred to as electrochemical capacitors. This is the only way to explain the enormously high field strengths of up to 5000 kV/mm in the double layer – a normal dielectric would fail.

Charge and discharge currents of double layer capacitors can be very high, deep discharge is no problem, 100,000 charge and discharge cycles and more are possible with a lifetime of more than 20 years. The capacities are already around 1/10 of those of accumulators. Thus supercapacitors are much more powerful than accumulators in cyclic operation: they can even drive racing cars or public transport vehicles such as electric buses, which can be recharged via contacts at a short stop at the bus stop. For example, the Fraunhofer Institute for Material and Beam Technology IWS in Dresden has had hybrid buses manufactured that can travel up to 2 km purely electrically to the next charging station after 15 seconds of charging at the bus stop – a diesel engine will only be activated for longer journeys.

**Old technology**
The principles of electrolytic capacitors and supercapacitors were discovered at comparable times – in 1875 by Eugène Adrien Ducretet (electrolyt capacitor) and already in 1853 by Hermann von Helmholtz (supercapacitor), with Helmholtz defining the double layer effect in 1879. However, while the aluminium electrolytic capacitor was used industrially from 1892 and manufactured using the technology known today from 1931 onwards, the supercapacitor was forgotten for many years: It was not until 1957 that the first patents on “capacitors with porous carbon electrodes” were granted. The mechanism of action of the double layer was unknown to the patent applicant.

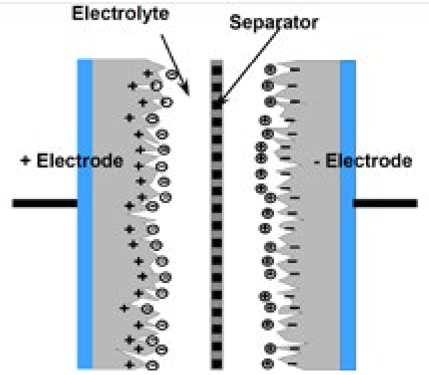


*Figure 1: Structure of the dielectric of an ultracapacitor*

In 1962, a Standard Oil canoe drove over a lake in Ohio with electricity from a car battery sized supercapacitor for a demonstration of ten minutes, but Standard Oil saw no market opportunity and sold the patents to NEC. In addition, even the developers of the supercapacitors were initially unaware of the difference in functionality from electrolytic capacitors; Standard Oil had still classified them as electrolytic capacitors. In 1982, the Pinnacle Research Institute developed capacities over 1000 F with low internal resistances for military purposes as the “PRI Ultracapacitor”. From 1992, Maxwell continued this development and its marketing. By the end of the 1990s, other innovative manufacturers such as Cooper Bussmann/Powerstor (now Eaton) joined the efforts.

**More robust than accumulators**
The temperature resistance of supercapacitors is higher than that of accumulators. Also higher powers are possible at lower temperatures. However, certain limit values must not be exceeded, otherwise the electrolyte will evaporate. A typical end of life is defined as a capacitance loss of 20...30% or an increase of the internal resistance to twice the value – a sudden total failure of a supercapacitor is rare with correct treatment.

The large capacity of the supercapacitors is achieved not only by the extremely thin insulation layer but also by the fact that supercapacitors use carbon electrodes. These are very porous and rough – mostly activated carbon is used. More than 3000 square meters can be achieved with one gram of carbon powder. Graphene and carbon

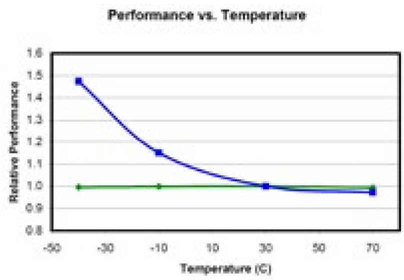


*Figure 2: Temperature dependence of ultracapacitors*

nanotubes have already been tested, but are still too expensive for mass products. At least with graphene this is supposed to change in the next years.

**Not suitable as filter capacitor**
Supercapacitors are not filter elements like normal capacitors and electrolytic capacitors – they are primarily energy storage devices. The internal resistance at higher frequencies is unsuitable for filtering, especially with clocked power supplies and converters – even at 10 Hz only a fraction of the capacity of the supercapacitor is effective because the ions on the double layer do not move fast enough. In addition, the internal resistance is generally higher than with electrolytic capacitors, which is why its use as a filter and smoothing capacitor is unsatisfactory and can lead to overheating and failure. In contrast, ultracaps can easily bridge a few seconds of power failure in UPSs without the need for constant maintenance and inspection like UPSs with accumulators. They are even well suited as a starting aid in automobiles, as their performance does not radically deteriorate at low temperatures like that of conventional starter batteries. Just the price is not yet competitive for this application.

**Battery and supercapacitor in a team**
Supercapacitors can also be used as buffers if batteries are available and necessary for the power supply, but the device to be supplied draws very pulsed current like an optical smoke detector: Here, the ESR of the batteries becomes too high, especially as the discharge progresses; with a supercapacitor solution connected in parallel, the batteries can be used much longer before a current pulse causes undervoltage, and lithium-ion batteries suitable for long-term use can be

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used instead of the alkaline-manganese cells suitable for higher currents.

However, problems may occur in certain situations: Supercapacitors are not designed for months of operation without recharging because of the leakage current. Anyone who combines a lithium battery designed for 10 years of operation with a supercapacitor to provide higher peak currents could be confronted with an unexpectedly early discharge of the battery.

**Electrical characteristics**

Supercapacitors are pure secondary energy storage devices. Although the self-discharge of today's cells is low, it is not suitable for the independent supply of devices for months. However, self-discharge is at least low enough to bridge days and sometimes weeks.

For safety reasons, the components are also not delivered charged like accumulators and are normally not pluggable - the peak currents in the event of incorrect operation (short circuit) would be very high and could cause serious damage. Unlike batteries or accumulators, supercapacitors do not supply a chemically determined voltage that is constant over a longer period of time and only drops rapidly at the end of discharge, but, like any capacitor, a voltage that sinks linearly with a constant current draw. The output voltage of a supercapacitor power supply can be kept constant via voltage regulators; however, when the capacitor voltage drops to ½ of the output value, ¾ of the stored charge has already been discharged. It is therefore not worthwhile to discharge even further with wide range transformers, although deep discharge is not a problem for supercapacitors in principle. On the other hand, there is no sudden failure of the energy storage when a final discharge voltage is reached.

**Higher voltage: supercapacitor arrays**

The end of the lifetime of a supercapacitor is usually defined with a capacitance loss of 70...80% and/or an increase of the ESR to 200...300%. A circuit that is to provide a certain supply voltage and capacity with a supercapacitor array must be dimensioned accordingly with a reserve: If a discharge is really planned in seconds and not in hours, the internal resistance will cause a voltage drop, which must be compensated by a correspondingly higher charging voltage and thus more supercapacitors connected in series. This in turn reduces the capacitance due to the series connection. A correct dimensioning of the individual capacitor cells is therefore calculated with these "end-of-life" parameters and not with the parameters of a brand-new supercapacitor. This ensures long-term operation of the circuit within its setpoints.

The voltage distribution must be taken into account:

- First, capacitance tolerances in serial circuits will lead to a lower voltage drop on the larger ultracapacitor, which means, the smaller capacitator will have a higher voltage drop and thus may be overloaded. Without further precautions, this reduces its lifetime and capacity, which further increases the overload and ultimately causes the array to significantly lose performance.
- Second, the static leakage currents of ultracapacitors are low, but just as different. This can also result in an imbalance in the voltage distribution.

Passive or active balancing solutions can be used to remedy this situation and to balance the voltage distribution.

Passive solutions are resistors connected in parallel to the ultracapacitors, which must be significantly lower than the leakage resistances of the capacitors. This solution is inexpensive and reliable, but increases the leakage currents. Active solutions only bypass the ultracapacitor when its permissible operating voltage is reached.

Ultracapacitor modules from Eaton and Maxwell already contain a suitably dimensioned balancing solution. The manufacturers also

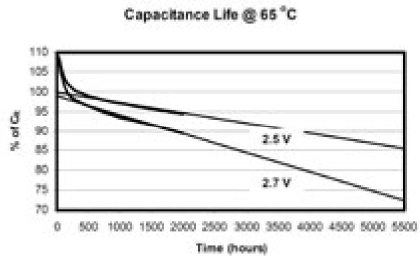


*Figure 3: Capacitance curve of an older ultracapacitor model at 65°C ambient temperature*

offers suitable ready-to-install modules for customers who want to assemble their own arrays. The creepage distances relevant for higher array voltages must be taken into account, especially for in-house designs. Modules assembled by the manufacturers are checked to comply with the necessary safety distances.

If a single prematurely aged capacitor in a module is to be replaced, a new ultracapacitor can upset the balance. In such cases it may be advisable to install a pre-aged capacitor.

**Negative influences**

A rule of thumb at Eaton is that the service life of a supercapacitor increases by a factor of 2.2 if

- the operating voltage is reduced by 0.2 V
- the ambient temperature drops by 10°C

If particularly long running times are required, operation at reduced voltage and not too high temperatures is helpful.

Of course, the formulas can be adapted as required. If you define the end of the lifetime at 50% capacity and 200% ESR, the circuit will work longer, but needs larger supercapacitors to work as desired at the end of the lifetime.

According to DIN EN 62391-2, the limit values are 70% capacitance and 400% ESR (fourfold ESR), but the latter is problematic in practice, since a quadruple ESR means a load capacity reduced to ¼ or a fourfold heating of the supercapacitor due to the current load during operation. Such large deviations are not tolerable in high-performance applications. For this reason, the DIN limits are rarely used.

**Round or square?**

In order to make full use of a given volume, cuboid capacitors appear to be more advantageous at first. However, like with film capacitors round windings are are more stable in operation and cheaper to manufacture. With arrays, cooling is also easier here, while cuboid capacitors sitting on top of each other without gaps are difficult to cool. Although square designs are available for special applications, round designs are usually the more sensible choice.

*Figure 4: Ultra-capacitor module 48 V / 165 F*

**Dramatic total failure rare**

Ultracapacitors are relatively temperature-independent, as long as the permissible limits are not exceeded, especially upwards. Their capacitance remains practically constant from -40 to 65°C, only the internal resistance increases with decreasing temperatures, but this is comparatively moderate. Rechargeable and non-rechargeable batteries, on the other hand, become unusable in the cold.

The operating temperature range of Maxwell ultracapacitors is between -40 and 65°C. Above 65°C, as well as with overvoltage, lifetime and characteristic data suffer very quickly; exceeding this temperature should therefore be avoided. High temperature and voltage are particularly critical at the same time – if a very long service life is important, these limit values should not be exhausted for a long time. Eaton allows up to 85°C depending on the electrolyte, but exceeding these limits is also critical.

Humidity is not critical in hermetically sealed cells – especially the larger varieties – as long as no water is deposited on the capacitors and thus causes leakage currents. The ultracapacitors themselves do not react to moisture if they are originally packed or installed. The air pressure is just as uncritical, which is important for use in aviation.

**Store short-circuited**
In contrast to batteries, the deep discharge of an ultracapacitor is absolutely uncritical. In fact, the service life is virtually unlimited when stored in a discharged state and transport is possible with discharged and bridged connections to eliminate the risk of discharge with high currents due to short circuits during transport or high, dangerous touch voltages in modules. Modules must be bridged during transport. If the bridging is removed, a maximum residual voltage of approx. 0.2 V per cell can build up after some time.

By the way, leakage currents in ultracapacitors are for the most part not caused by a defective dielectric. Rather, the huge surface of the carbon electrodes leads to a time constant of about one second for charging and discharging which is unusually high for a capacitor – for an accumulator this would be a very low time constant! It may take up to 72 hours until the capacitor is completely charged or discharged.

The last 0.5% of the surface is particularly difficult to reach due to the porous material and the geometry. This leads to the fact that it can take hours to days until these parts are charged – and this shows up electrically as a supposed "leak". Conversely, these 0.5% are "to blame" for the fact that after a complete discharge of an ultracapacitor after some time the already mentioned residual voltage of up to 0.2 V per cell can build up, if the discharge circuit is removed. In contrast

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to accumulators, no chemical processes are involved here, but regions are noticeable that were not completely discharged before.

**Electrode production**
Because this market is so attractive, many suppliers with sometimes mixed quality cavort here. Even a do-it-yourself construction of a supercapacitor from household utensils is described on Youtube (https://youtu.be/gTt_YBzJ_Dk) – but with extremely aggressive pipe cleaner (sodium or potassium hydroxide or potash lye) as electrolyte, with just 1.2 V maximum operating voltage, without overpressure protection and then stored in the bedroom above the bed to supply the alarm clock. Amusing, if it wasn't almost macabre. But even the industrial ultracapaci-

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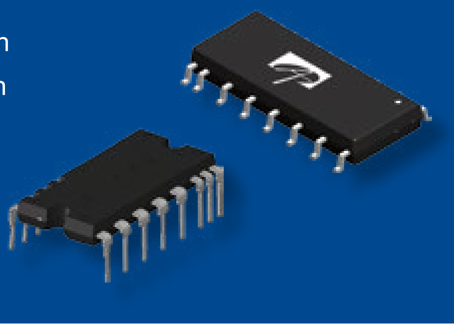

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tors are sometimes overwhelmed by actual applications and fail prematurely, especially in the case of vibrations in vehicles.

Qualitative differences in ultracapacitors are often due to the carbon electrodes. Their area determines the capacity, where almost all industrial manufacturers reach comparable values in a given volume. However, there are different manufacturing processes that affect stability. Wet processes, in which the activated carbon is first sprayed in solution and then develops its porous structure during drying, sometimes lead to more unstable electrodes. In mobile applications, especially in the vicinity of vibrating aggregates such as engines or assembly locations in the vehicle shaken by the journey, these can quickly “crumble” and thus fail.

Maxwell’s drying process is intended to be advantageous here for particularly large cells; in addition, the basic structure is particularly robust. Maxwell calls this “Durablue technology”: It is particularly robust against both individual shocks and continuous oscillations and vibrations.

So much for the current state of the art, which is far from being the end of development. However, ultracapacitors have now reached technical maturity and are enough tried and tested that they can be used reliably even in demanding, harsh environments, supporting batteries and accumulators or even replacing them completely.

The lower capacity compared to batteries is often no problem at all, because the available discharge current determines the application and not the total capacity that can be removed. Cordless tools, for example, are regularly stored and not held continuously in the hand for hours. In these phases they can already be completely recharged, because with ultracapacitors this does not take hours but seconds. In addition, ultracapacitors are not stressed by high discharge currents. They can even be used in applications in which NiCd accumulators, which are now undesirable for environmental reasons, were still being used because NiMh and lithium accumulators deliver lower peak currents.

**Possible applications**

A popular application are decentralized power supplies with high pulse load. Ultracapacitors are used for starting aids for diesel engines, whether in trucks, construction machinery or emergency power generators, but also directly in emergency power supplies, which can take over without delay in the event of a power failure and still function safely after decades without battery changes. This is eminently important even for supposedly simple applications such as the lighting of emergency exits – so far such devices are often supplied by central battery systems in the basement of the building, which fail after a few years in an emergency if they are not constantly monitored and replaced if necessary.

Other applications include peak current interception and energy recovery in elevators and hybrid vehicles. In container ports and warehouses, ultracapacitors can supply port cranes, forklifts and other vehicles. Here they are far superior to accumulators because charging times are not measured in hours but in seconds and minutes and high pulse currents of up to thousands of amps are available. In fact, only the heating of the ultracapacitors limits a possible repetitive pulse load – a short-circuit can become critical for the connected devices and the connecting cables, but not for the capacitors themselves, nor for the deep discharge. There is no risk of fire, as with lithium batteries, due to heat, overload or mechanical damage.

Also innovative are units that can quickly turn wind turbines out of the wind in gusty conditions or help to open and close doors in aircraft: The high currents required for this at short notice would cause unnecessary weight and costs with conventional wiring without intermediate storage – with ultracapacitors, power supply is much simpler. In addition, the door can be opened in an emergency without an on-board power supply. In automobiles, they can also support window regulators, door locks, power steering, belt tensioners and other electric motor-driven units.

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# Optimize your Power Converters: With Faster, Lighter, Cheaper and More Efficient Designs.

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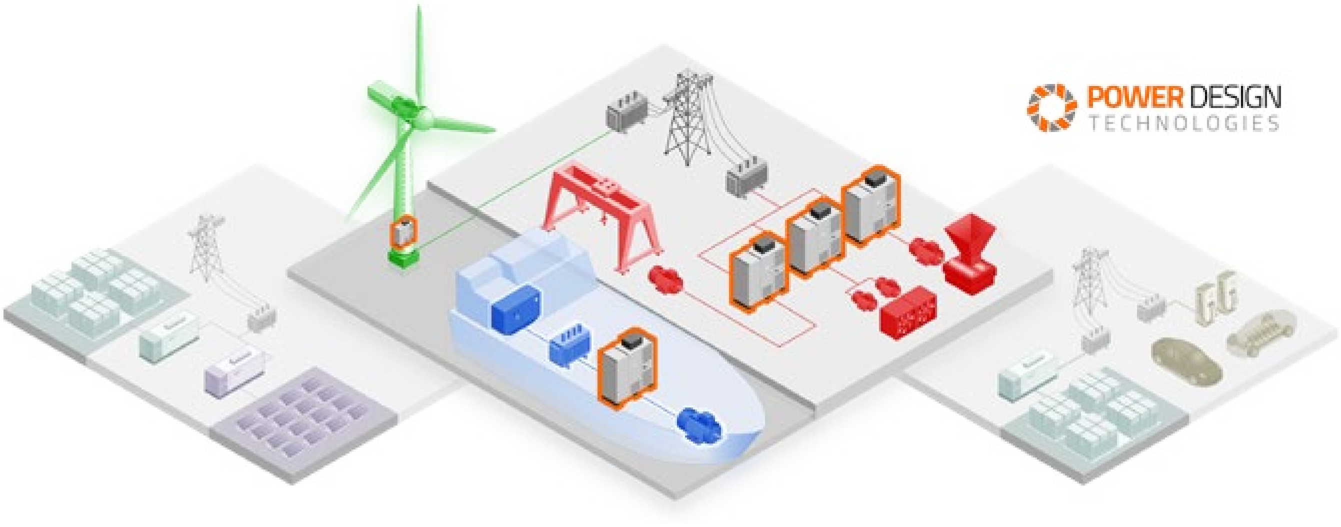
*Find out more with this example on MV drive…*

*Thanks to its fast, robust and intuitive software design solution, The Tom Thumb of power electronics: Power Design Technologies knows no bounds when it comes to new applications and markets. Its proprietary software: PowerForge offers the most powerful power converter design tool available to optimize trade-offs in various fields (naval, wind, photovoltaic, manufacturing, shipping, electric cars, aeronautic, storage systems…) and as you will see in this article in MV drive applications.*

*By Guillaume Fontes, Nicolas Videau, Aurélie Cretté*
*& all the other members of the Power Design Technologies Team*




**Don't you live in the kingdom of power electronics and its autocratic regime?**
Power converters are ubiquitous in all industrial power electronics fields. Obviously not every application will have the same set of challenges, yet power converter design has become a key expertise, no matter what the end-industry is. And no matter what your end-industry is, you are surely facing the four sacred dimensions of trade-off when you design power converters: mass, volume, loss, cost; and the absolute rule of specs: reduce at least one of them! Don't you?

**The Tom Thumb of Power Electronics found a solution to change the rules!**
Building on a small and agile team of 7 high profile power electronics experts that cumulate more than a 100-year experience, Power Design Technologies is an electrical engineering software publisher specialized in power electronics that was founded in 2016. The following year, it completed a €600,000 seed funding round with technology investors. Since then, after signing an international distribution agreement with Powersys, it has been gradually establishing its position as

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# POWER FORGE
Multilevel by design

## The first software for design, exploration and comparison of advanced power converter designs

**Design cutting-edge converters**

**Reduce time-to-market**

**Streamline your design workflow**

POWER DESIGN TECHNOLOGIES

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a dynamic innovator with an imaginative integrated software solution for the design of high-performance electric power converters, enabling lighter and smaller product development while ensuring greater affordability, efficiency and reliability.

**Find your way around the constraints of designing power converters in all applications!**
Power Design Technologies' cutting-edge power electronics approach and decades of research and process expertise come together in Power Design Technologies design software solution: PowerForge suitable for a wide range of industrial applications whenever energy converters need to be more compact, more efficient, more reliable and more affordable. PowerForge is the very first computer-aided engineering solution dedicated to the design of power converters for energy-transition-related applications: solar PV inverters and associated storage systems, electric vehicle fast chargers and motor drive inverters....

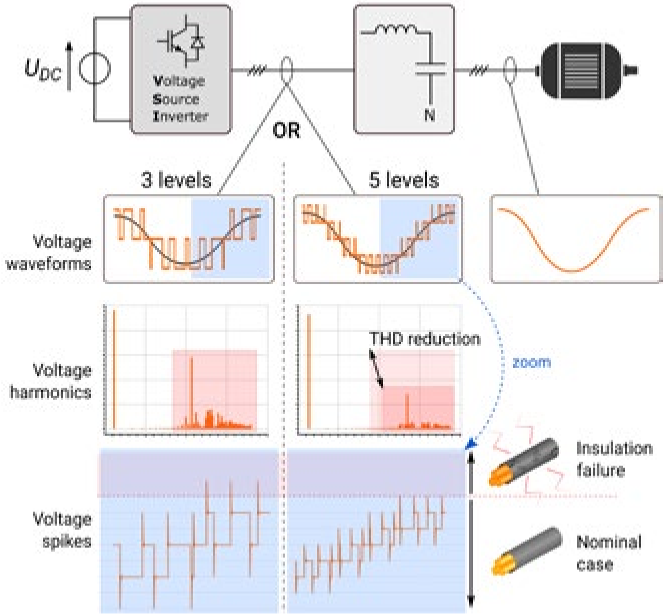


*Figure 1: Influence of the increase of the number of levels on the current THD and the voltage overshoots*

**An Example: Starting with Medium Voltage Variable Speed Drive Design…**
Power conversion systems demand efficient and reliable drives. Variable speed drives are used in a wide range of applications in industry such as in wind turbines, mining, marine… and transports. Demand for these drives has been growing for a few years, especially at the megawatt level (i.e. at the medium voltage level), due to the increasing need for efficient motor control because of rising energy prices and environmental concerns.

In this context, a major use case is the retrofit of an existing Medium Voltage motor originally powered straight from the grid. In this case, the introduction of a variable speed drive is very interesting because:

1 it saves a motor replacement: current inrush peaks are eliminated. The motor speed gradually goes up by increasing output voltage hence avoiding peak demand charges.
2 it increases the operating efficiency: MV drives enable greatly improved control accuracy and efficiency in your process compared to Low Voltage drives.
3 it increases safety: In response to load, MV drives provide appropriate power usage based on actual demand and consumes only the energy to drive the attached equipment hence providing the required energy savings.

But you know that as it used to be a motor powered straight from the grid, you need to be very careful about the stress of the motor windings in MV drives. When you are exploring design solutions for MV drives, many questions are raised:

- Which topology fits better to my application?
- Depending on the number of voltage levels, which power-switch?
- What about the switching frequency?

In most of cases, the use of 3-level inverters (such as NPC or T-type topologies) is already a well-established solution. But what about going to the next level(s)?

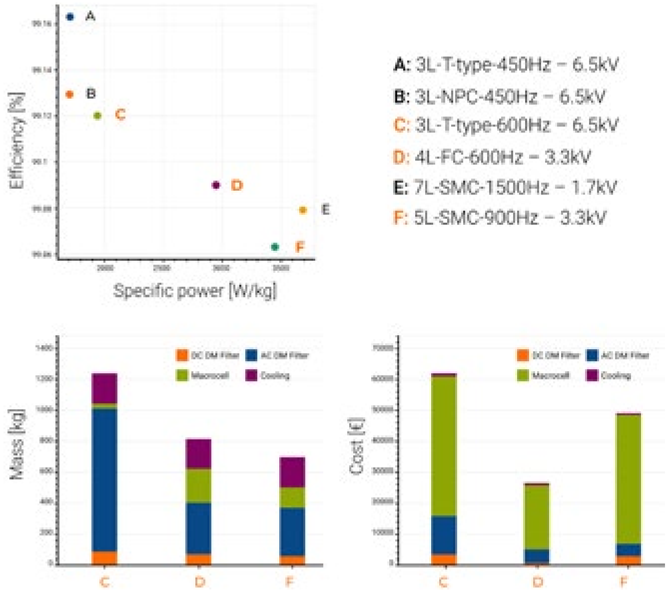


*Figure 2: Comparison charts for different topologies in PowerForge (efficiency vs specific power, mass and cost breakdown)*

**…What about taking MV drives to the next level?**
To preserve the motor's windings from excessive current harmonics and voltage overshoots, this often requires a bulky and costly output sine filter. However, further increasing the number of levels (to 5 for example) can change the game, first by reducing the current harmonics, which leads to significant filter downsizing.

Besides, fast voltage transitions caused by the PWM waveform may cause voltage spikes that degrade the insulation of the motor winding. Sometimes, voltage transitions are slowed down by increasing the gate resistance of the switches, but the overall efficiency is affected. Here again, multilevel solutions reduce the voltage step, thus reducing the spike amplitude.

At last, it also opens options such as the use of cheaper low-voltage IGBT modules.

**PowerForge could help you find your way to the next level of MV drives!**
Our design software: PowerForge allows MV drives design trade-off from 100kW to more than 100MW and from 3.3 up to 13.8kV voltages while ensuring high efficiency, better affordability and smaller and lighter product development.

Thanks to its fast and intuitive automated design generation of 3 to 7 (and more…) multilevel topologies, to its broad library of devices and materials and its instant comparison mass, volume, loss, cost comparison, you are able to explore 3 to 7 level topologies efficiency and cost in a few minutes to allow further reduction of currents harmonics (THD) and voltage overshoots – which leads to significant filter downsizing.

**A final taste of our bread crumbs?**
Take the path to the next level of power converter design with PowerForge! Do you share our ambition to bring energy conversion to the next level? Now is the time to join us and start exploring the next level power converter design!

PowerForge is a powerful platform for designing, exploring and comparing power converter designs allowing optimized technico-economic trade-offs at an early stage. Thanks to multidisciplinary integration, PowerForge will bring you a unique tool for designing lighter, smaller and more efficient converters in record time.

Centered-around optimizing your workflow, PowerForge offers a seamless experience from product specification stages to trade-off of most complex topologies including multilevel (3 to 5) and sizing of passive and active components.

With PowerForge, be ready to:
- Design cutting-edge converters
- Reduce time-to-market
- Streamline your design workflow

Visit our website: www.powerdesign.tech!

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Power Design Technologies will be present in PCIM Europe 2019! Let's meet there!

- Join us in Hall 6 – Booth 6-302 from the 7th to the 9th of May!
- Register Now for our tutorial "Design methods and tools for Power electronics" presented by Guillaume Fontes and Thierry Meynard, taking place on May the 6th!
- Find out about "Design trade-off for Medium-Voltage Variable Speed Drives: Sine filter and/or Multilevel Topologies?" with Guillaume Fontes on May the 8th!

Hurry up to get the biggest share!

More info here: https://powerdesign.tech/exhibitions/pcim-2019/

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**NEXT GENERATION**
POWER STACK TECHNOLOGY

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# $T_j$ Estimation Evaluation Board

Allows converter OEMs and power stack designers to evaluate the Amantys Junction Temperature ($T_j$) Estimation technology.

**Benefits**
- ✓ Real time estimation of $T_j$ for IGBT and diode using temperature sensitive electrical parameters (TSEPs)
- ✓ Auto-calibrating algorithm
- ✓ Performance analysis and fault diagnosis for power stacks
- ✓ Log files are conveniently stored to USB drive(s) in .csv format

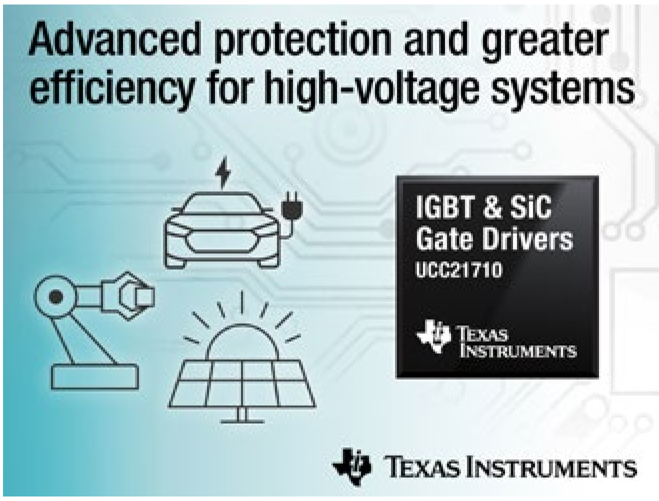
**Features**
- ✓ Compatible with any IGBT module or gate drive up to 3300V
- ✓ Data logger parameters stored every millisecond
- ✓ Ethernet interface to PC application
- ✓ SCPI interface allows real-time access to data

**Real-time oscilloscope and long-term data logging display**

amantys t: +44 1223 652 530 e: info@amantys.co.uk **www.amantys.com**

# Isolated Gate Drivers with Integrated Sensing for IGBTs and SiC MOSFETs

Texas Instruments (TI) introduced several isolated gate drivers that provide unparalleled levels of monitoring and protection for high-voltage systems. The UCC21710-Q1 and UCC21732-Q1 and UCC21750 enable designers to create smaller, more efficient and higher-performing designs in traction inverters, onboard chargers, solar inverters and motor drives. The devices are the industry's first to offer integrated sensing features for insulated-gate bipolar transistors (IGBTs) and silicon carbide (SiC) metal-oxide semiconductor field-effect transistors (MOSFETs) to simplify designs and enable greater system reliability in applications operating up to 1.5 KVRMS. With integrated components, the devices provide fast detection time to protect against overcurrent events while ensuring safe system shutdown. "System robustness is becoming an increasing challenge in high-voltage motor drive and power delivery applications," said Steve Lambouses, vice president, TI High-Voltage Power. "These new gate drivers using TI's isolation technology, combined with the other integrated features and support, can enable engineers to more quickly ramp to production reliable systems, while minimizing space and cost."




The isolated gate drivers' high peak drive strength of ±10 A maximize switching behavior and reduce losses, while 200 ns of overcurrent detection enables fast system protection.

**www.ti.com**

# 650V αGaN Technology Platform

Alpha and Omega Semiconductor launched the platform at the 2019 Applied Power Electronics Conference (APEC) in Anaheim, CA. This 70mOhms pure enhancement mode device is manufactured on a fully qualified GaN-on-Si substrate technology with > 50% smaller die area and 10X lower gate charge (Qg). It eliminates the undesirable body diode reverse recovery charge (Qrr) of traditional silicon MOSFET technology. Ease of use by the low on-state gate leakage allows flexibility to drive the new GaN device with a selection of commercially available Si MOSFET gate drivers. The device is available in a low inductance thermally enhanced DFN 8x8 package and ideally suited for high efficiency and high-density power supplies in the telecom, server, and consumer adapter markets.

**www.aosmd.com**

# PQ Distributed Gap Cores

MICROMETALS™ POWDER CORE SOLUTIONS

Micrometals is proud to introduce its new series of PQ distributed gap cores. The rectangular geometry of the PQ body is ideal for surface mount applications while the round center post readily accepts helical flat wire coils, or bobbins with round wire. The cores are offered in six industry standard geometries from 21mm to 51mm, three exclusive material formulations, and three reference permeability values. The PQ geometries are available in Micrometals exclusive material formulations of Sendust (MS), Hi-Flux™ (HF) and FluxSan™ (FS - Iron Silicon) with 26, 40 or 60 permeability values. These uniquely formulated materials offer a combination of high saturation magnetization and low losses, making them well suited for switching applications up to 1MHz. The distributed gap nature of these materials means that they can be used with little or no center-leg gap, greatly reducing the losses associated with fringing flux at higher frequency. PQ cores offer several key advantages over toroid or E core geometries including better self-shielding and high winding density. PQ cores also offer an advantage over EQ cores by providing a larger outer surface, which requires less winding to provide the same inductance. This advantage also allows smaller PQ cores to be used for comparable performance as EQ shapes.

**www.micrometalsapc.com**

# Current Probe Offers High-Bandwidth and Novel Electrostatic Shielding

Power Electronic Measurements (PEM UK) Ltd will will be using PCIM Europe to launch the CWTHF current probe which offer higher frequency operation and improved E-field immunity. Clip-on Rogowski current probes provide a convenient, wide-bandwidth and accurate means of measuring alternating currents. The CWTHF is the latest addition to the company's CWT range and these new wideband probes use a novel electrostatic shielded Rogowski coil to provide excellent immunity to interference from fast local dV/dt transients or large 50/60Hz voltages. The new CWTHF offers the ability to measure faster current transient rise-times, achieving a high frequency (-3dB) bandwidth of up to 30MHz for a 300mm coil and can handle a maximum current slope of over 100kA/µs. The CWTHF probes feature a robust coil of 8.5mm thickness with a 10kV peak insulation voltage. Ideal for a wide variety of applications, including power electronics development work in today's demanding noisy high-speed applications, EMC and power quality measurement in motor drives and traction, pulsed power measurements and even lightning strike currents, the CWT is available in current ratings from 30A to 300kA, with coil circumferences of 300 to 1000mm as standard and longer available on request.

**www.pemuk.com**





Your reference for wide-band AC current measurement


For over 25 years, PEM Ltd has been helping customers measure AC currents using our innovative market leading **CWT** range of flexible, clip-around, wide-band Rogowski probes. Whatever your application, we have an unrivalled range of flexible probes to meet your needs, featuring:

- High frequency innovation, with bandwidths up to 50MHz and patented noise immune shielding
- Accurate gain/phase response from less than 0.1Hz into the MHz range
- Coil geometries to suit the smallest spaces, the largest conductors and the most challenging environments

PEM

Power Electronic Measurements

www.pemuk.com

info@pemuk.com

## DOSA-Footprint DC/DC Converters up to 30W

For applications that require high power density and high efficiency, Dengrove Electronic Components is stocking RECOM RPM3.3 and RPM5.0 non-isolated DC/DC converters in power ratings from 3.3W to 30W.

Compliant with the industry-standard 12.19mm x 12.19mm DOSA footprint, the 3.3V and 5.0V modules are available with rated output current of 1.0A, 2.0A, 3.0A, or 6.0A. Featuring an advanced control IC and multi-layer board design they are only 3.75mm high, resulting in class-leading power density of up to 800W/in3 and allowing use in space-constrained applications. Very high maximum efficiency, between 97-99%, permits operation at full load in ambient temperatures up to 107°C without forced-air cooling thereby helping to simplify design and enhance system reliability. Packaged in a metal can and featuring a ground plane integrated in the bottom-side PCB, RPM converters have effective six-sided shielding for minimal noise emissions and are EN 55032 compliant. In addition to their excellent all-round performance, the converters offer flexible control and trimming options. Pins for Power-good, On-off Control, and Sequencing with programmable output rise time simplify powering-up converters simultaneously or in a pre-defined sequence. The nominal output voltage of 3.3V or 5.0V can be trimmed up or down using a single external resistor, and programmable soft-start control is also provided.

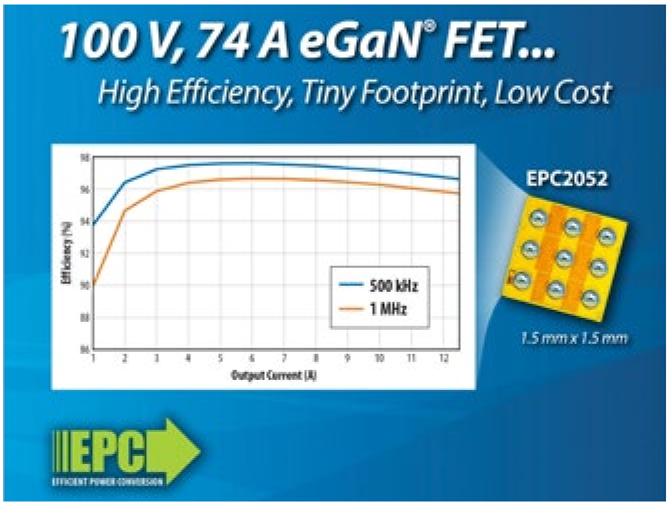
**www.dengrove.com**

## Power Transistor - for 48 V DC-DC, Motor Drives, and Lidar Applications

Efficient Power Conversion (EPC) announces the EPC2052, a 100 V GaN transistor with a maximum $R_{DS(on)}$ of 13.5 mohm and a 74 A pulsed output current for high efficiency power conversion in a tiny 2.25 mm2 footprint.

Applications demanding higher efficiency and power density no longer have to choose between size and performance. The device measures just 1.50 mm x 1.50 mm (2.25 $mm^2$). Despite the small footprint, operating in a 48 V - 12 V buck converter, it achieves greater than 97% efficiency at a 10 A output while switching at 500 kHz and greater than 96% at a 10 A output while switching at 1 MHz enabling significant system size reductions. In addition, the low cost of the EPC2052 brings the performance of GaN FETs at a price comparable to silicon MOSFETs. Applications benefiting from this performance, small size, and low cost include 48 V input power converters for computing and telecom systems, Lidar, LED Lighting, and Class-D audio.

**www.epc-co.com**

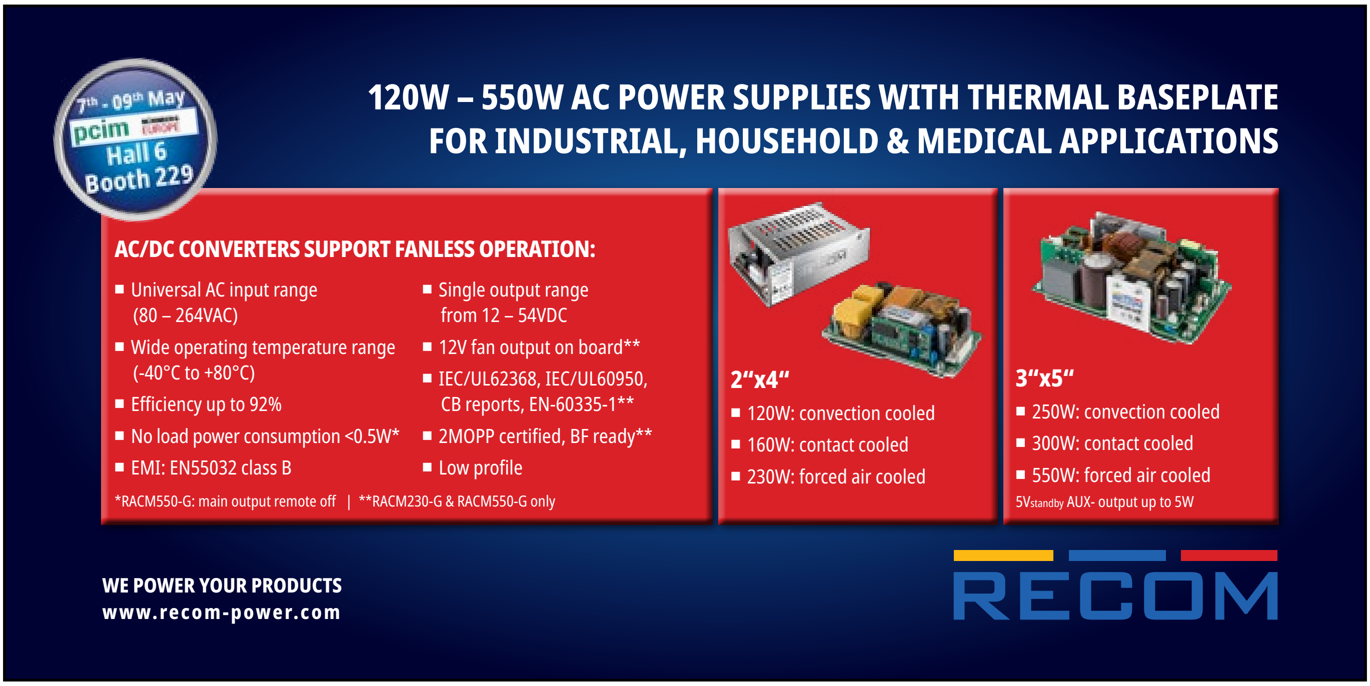



## Incremental Encoders for BLDC Motors and Stepper Motors

BLDC motors are famous for their durability, efficiency, and controllability. But while durability and efficiency are inherent to brushless DC motors themselves, the ability to control them depends on the feedback mechanism used. Which is why TRINAMIC Motion Control GmbH & Co. KG introduces their latest ABN encoder optimized for BLDC motors: the TMCS-28-x-1024. “Incremental encoders are key enablers when working with BLDC motors,” according to Michael Randt. “They not only increase the application’s performance, they also relieve engineers from the increasing pressure of miniaturization and efficiency by allowing for smaller drives.”

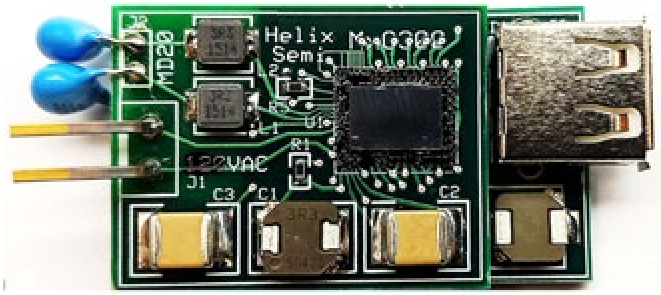
Enabling to drive the motor with the exact torque and rpm required for an application, optical incremental encoders for brushless DC motors as well as stepper motors make it possible to use smaller drives in applications, opening up new markets to them. What’s more, encoders like the TMCS-28-x-1024 ABN encoder also allow for predictive maintenance when used correctly. More and more indicators show that in the near future, applications will be able to predict when parts need to be calibrated, checked for wear and tear, or even need replacing. Keeping track of runtime is one way of doing so but tracking the exact number of handlings – and type of handling – using encoders is more accurate.

**www.trinamic.com**



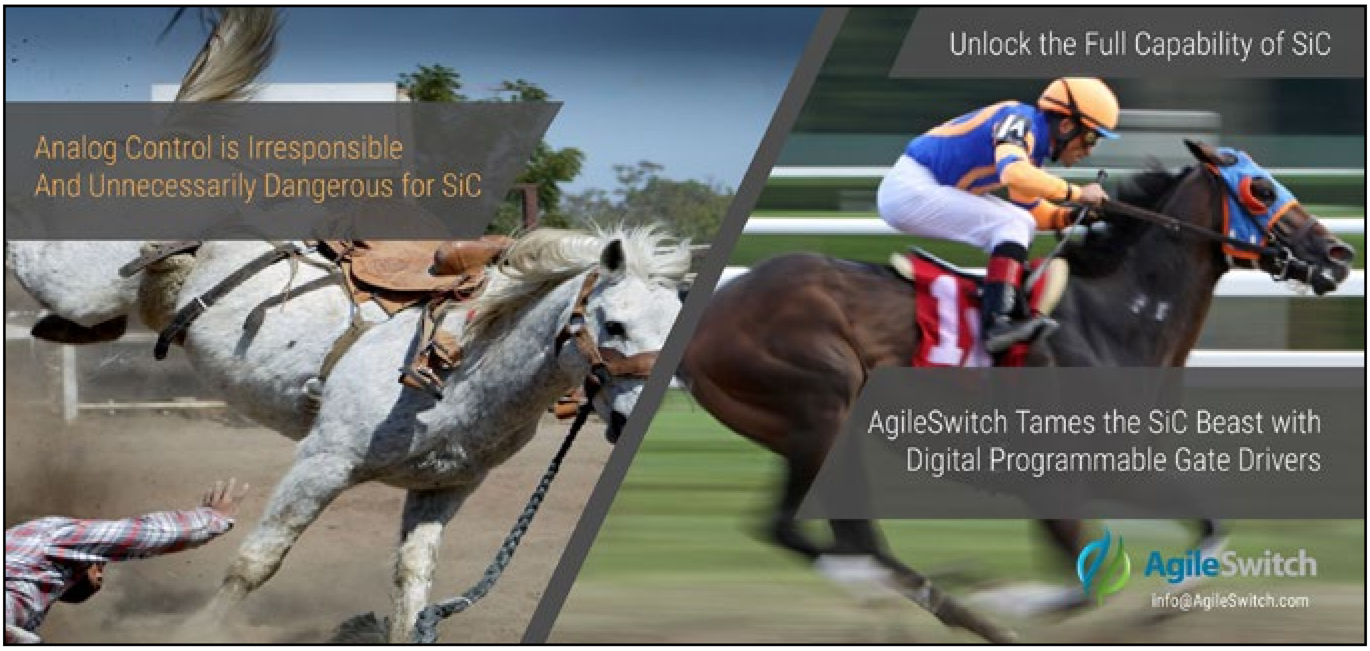

# AC-DC Power ICs Now Sampling

Helix Semiconductors announced sampling of its MxC® 300 AC-DC power ICs. The MxC 300 is a two-chip solution that offers the highest power density in the industry – up to 10x higher than transformer-based solutions – for 65W AC-DC power supply products. It is the world's first chip to use a capacitive isolation (CapIsoTM) barrier instead of a transformer for an AC-DC power supply, a feat achieved through Helix Semiconductors' core energy-efficient MuxCapacitor® (MuxCapTM) technology. Helix's CapIso technology eliminates the isolation transformer traditionally used in AC-DC power supplies, providing isolation with capacitors, which meet the UL and IEC standards for safety. As a result, the chipset enables the replacement of traditional magnetic-windings-based transformers, which are used for isolation and voltage reduction, while providing average power efficiencies of greater than 95 percent. The resulting increase in power density can be significant since the transformer is typically the largest component in the power supply module.



"Energy management has become one of the most important issues of our time, and companies are actively seeking solutions that offer higher power density, greater efficiency and smaller form factors," noted Harold A. Blomquist, president and CEO of Helix Semiconductors.

**www.helixsemiconductors.com**



## Power-Supply Transformers Complement Gate-Driver IC Family

Power Integrations announced a range of galvanically isolated transformers that provide the correct voltage and power for the company's SCALE-iDriver™ family of gate drivers. The combination delivers a simple, robust and cost-efficient DC-DC converter solution that does not require additional voltage regulation, reducing system cost and development time. The SIT12xxI transformer and SCALE-iDriver ICs are fully UL and VDE approved.

The transformers feature an innovative insulated construction that improves reliability and delivers a high isolation capability combined with low coupling capacitance. Devices suit both 600 V and 1200 V two-channel SCALE-iDriver gate drivers with 5 V (SIT1253I) or 15 V (SIT1217I) input voltages and 25 V output voltage. The shrouded transformers weigh only 9 g and require no potting, but nonetheless pass tests for extended field life and high resistance to shock and vibration. They meet UL1446, UL61800-5-1, IEC61800-5-1, IEC61558-1 and IEC61558-2-16. Comments Thorsten Schmidt, product marketing manager for gate-driver products at Power Integrations: "The SCALE-iDriver family of IGBT and SiC-MOSFET driver ICs employs Power Integrations' FluxLink™ magneto-inductive bi-directional communications technology to ensure reinforced galvanic isolation between the primary and secondary sides, setting a new standard in isolation integrity and stability."

**www.power.com**

## Power Supplies Offer up to 18 Outputs

TDK Corporation announces the introduction of the QM8 series of AC-DC power supplies, extending the QM series of 700 to 1500W modular power supplies to include up to 18 outputs. Having both medical and industrial safety certifications, the QM8 addresses a wide range of applications, including BF rated medical equipment, test and measurement, broadcast, communications and renewable energy applications. The QM series operating efficiency is up to 91%, reducing internal heat losses, allowing the use of low speed, low audible noise fans for cooling. This provides an enhanced patient/user experience and increased reliability. The QM series is covered by a seven-year warranty. Accepting a wide range 90-264Vac 47-440Hz input, the QM8 can deliver between 1200W to 1500W output power. Available output voltages range from 2.8V to 105.6V and up to eight single or dual modules can be fitted. Optional standby/signal modules can be specified with a choice of one or two standby voltages (5V, 12V and 13.5V at up to 2A), a PMBus™ communication interface and unit inhibit or unit enable, and an AC Good signal. The units can operate in ambient temperatures of -20 to +70°C, derating output power and output current by 2.5% per °C above 50°C. Overall case dimensions are a compact 200 x 63.5 x 270mm (W x H x D), and the weight is between 2.3 to 3.4kg, depending on the module configuration.


**www.de.tdk-lambda.com/qm**

## Tool Launches Flyback Transformer Selector

Wurth Electronics is pleased to announce the launch of their Flyback Transformer Selector in the newest release of their REDEXPERT tool. The integration of the Transformer Selector into REDEXPERT is a complete makeover of the original Smart Transformer Selector. This free tool is available in seven languages and requires no login.

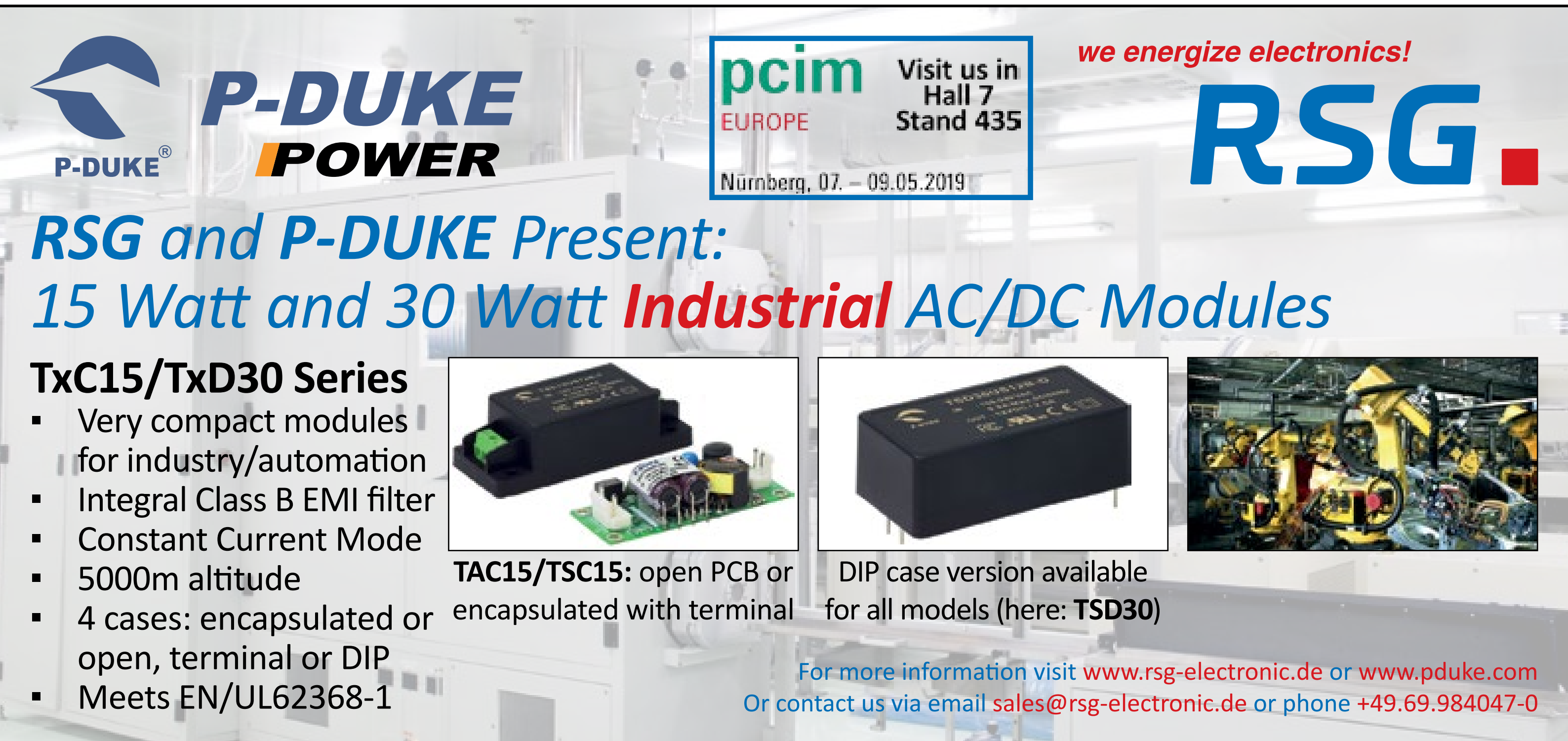
More options are included in the tool, including performance simulation, filter settings for over 20 electrical and mechanical parameters, direct access to product datasheets, and direct free sampling. The original transformer selector tool, The Smart Transformer Selector (STS), will be available until the end of the year, and then redirected to the REDEXPERT version.

**www.we-online.com/redexpert**


# 80 W DIN Rail Power Supplies with ATEX & UL HazLoc Certifications

TRACO POWER has announced the release of their TIB 80-EX Family of 80 Watt DIN rail power supplies that are designed for harsh environments & hazardous locations with certifications for ATEX II3G and UL HazLoc Class I / Div 2 standards. These products are the new vanguard of industrial power featuring: 12 / 24 / 48V outputs (-2% ~ +17% VADJ Range); high efficiency operation of 88-90%; 150% peak power for 4 seconds; and packaged in a ruggedized metal enclosure that is EN61373 qualified for railway shock and vibration. Protection circuits include back power immunity, short-circuit / overload protection and a DC OK dry signal contact. DC-OK LED indicators on both the front and side panels with optional side panel mounting enable use in flat panels. The product's reduced heat dissipation enables a -40°C to +60°C full load operating temperature range (up to +70°C operation with only 20% de-rating). Outputs are radio-interference-suppressed to impede radiation at long output lines. This filter reduces the common mode current to within limits of telecommunication ports. The units operate with a high power factor of up to 99% with active power factor correction which also minimizes input inrush current.

**www.tracopower.us/tib-ex**

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## Automotive Qualified Standard Core Series

The trend towards electromobility is accompanied by a strong expansion of the charging infrastructure and

the increasing demand for future-oriented technical solutions for a large number of applications. The latest product development from VACUUMSCHMELZE (VAC) are highly permeable, nanocrystalline cores for common-mode suppression. This standard series, Automotive qualified according to AEC Q200, is now available in a sample case. The cores were developed for the use on the high-voltage DC battery or on the DC output of the drive inverter as well as on the AC output of the drive inverter in hybrid and electric vehicles. The new series is available in two permeability levels, the values for toroidal cores are μ = 30,000 and μ = 100,000, for oval cores they are μ = 30,000 / 70,000. The designs take into account "Technical Cleanliness" according to VDA 19 Part 2 and the ZVEI guideline "Technical Cleanliness in Electrical Engineering". The sample case contains both, ring and oval cores, in all available dimensions. "The cores are one of our highlights at this year's PCIM Guided Tour on the subject of e-mobility. We are taking the opportunity to present our solutions for electric drives and the accompanying components for power electronics and charging infrastructure. These are also the focus of our presentation "Powerful magnetic solutions for electric vehicles and the developing charging infrastructure" at the E-Mobility Forum," says Norman Lemm, Head of Business Intelligence & Marketing at VAC.

**www.vacuumschmelze.com**

## Oscilloscopes with 15.4" Display

Teledyne LeCroy introduced its WaveRunner 9000 Series mixed-signal oscilloscopes with a large, 15.4" display, bandwidths from 500 MHz to 4 GHz, and sample rates up to 40 GS/s. The Series offers the industry's deepest toolbox and the most complete collection of serial data debug and validation solutions,

making it ideal for embedded system, automotive, and EMC/EMI test applications. The ubiquity of embedded computing systems with high-speed microprocessors drives industry demand for mid-range, mixed-signal oscilloscopes with high bandwidth and powerful debug and validation toolsets. However, equipment budgets have not kept pace with the increase in microprocessor speed and complexity. This has forced engineers and managers to sacrifice certain capabilities in their test equipment. Teledyne LeCroy's WaveRunner 9000 oscilloscopes offers all of the critical features—a large display, powerful toolbox, wide range of bandwidths, and enhanced resolution up to 11 bits—at an affordable price.
"The WaveRunner 9000 Series offers the industry's deepest toolbox with a large 15.4" display at a price point that does not require engineers to sacrifice features or performance," said Tyler Cox, VP and general manager for oscilloscopes/digitizers. "The vast serial data coverage of these new oscilloscopes makes them perfect for embedded/automotive testing, and the 40 GS/s sampling rate is ideal for EMI/EMC testing."

**www.teledynelecroy.com**


WIMA®


WIMA DC-Link Capacitors

WIMA DC-LINK capacitors are designed for the high power converter technology. At high frequencies they show a higher current carrying capability compared to electrolytic capacitors. Further outstanding features are e.g.:

- Very high capacitance/volume ratio
- High voltage rating per component
- Very low dissipation factor (ESR)
- Very high insulation resistance
- Excellent self-healing properties
- Long life expectancy
- Dry construction without electrolyte or oil
- Particularly reliable contact configurations
- Customer-specific contacts, capacitances or voltages

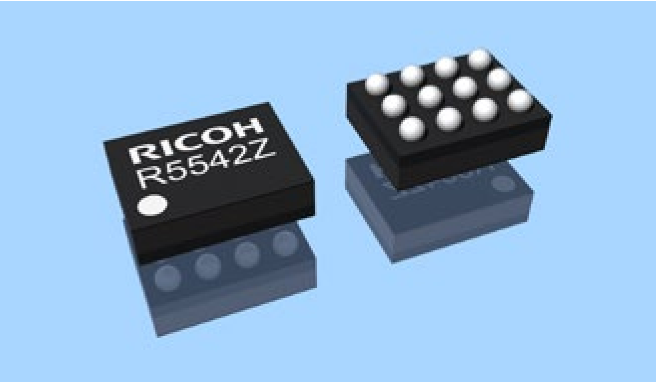
WIMA DC-LINK capacitors are available with capacitances from 1 μF through 8250 μF and with rated voltages from 400 VDC through 1500 VDC. The components are environmentally compatible with the RoHS 2011/65/EU regulations.

pcim EUROPE
Nuremberg, May 07.-09.2019
Hall 7 / Booth 219

www.wima.com

# 6 A Load Switch with Voltage Detector

Ricoh Electronic Devices Co., Ltd. in Japan has launched the R5542, a versatile load switch embedded in an ultra-small wafer level chip scaled package and is able to switch currents up to 6 A. Target applications are mobile devices like smartphones and tablets. Load




switches are integrated electronic switches used to turn on and turn off power rails. Such kind of solution is smaller and more cost efficient compared to traditional relays. In addition, load switches have various additional features, which are not available in traditional solutions.
The R5542 is positioned in between the battery or other supply voltage and the actual application circuit (load). The internal on-resistance is only 9 mΩ and will cause almost no voltage drop between input and output, in this way the power dissipation of the chip is kept to a minimum. The actual switching element of the R5542 consists of an N-Channel MOSFET and is controlled by the LCE input to switch the power rails. Other advantages of a load switch are the possibility to set up a specific power-on sequence of various power supplies but also the total BOM count and total required board-space is significantly reduced compared to using discrete components in an equivalent circuit. As for the current consumption, the load switch consumes Typ. 10 µA in On-mode and 1 µA in Off-mode.

**www.e-devices.ricoh.co.jp/en/**

# Extended Operating Range Chargers

Phihong has announced its lineup of extended operating range battery chargers for power wheelchairs and mobility scooters. The complete line of products include: 2.5A, 3.5A and 8A chargers for different battery capacities.

The DA80U-240A-R and the DA64U-240A-R, rated 24V/3.5A and 24V/2.5A, respectively, work with AGM batteries and come in a compact, fan-less case measuring 6.14” x 3.11” x 1.77” weighing under two pounds. With an operating temperature range of -25ºC to +50ºC, they offer the widest range in the industry for comparable prices.
The DA200U-250A-R, rated 24V/8A, is capable of user-selectable charging of AGM or GEL batteries. The DA200U-250A-R offers an appealing fan-less case design and features a convenient built-in USB A receptacle for charging low-power electronics while charging your chair or scooter. The operating temperature ranges from -25º C to +40º C, which allows for charging in the most challenging environments.
All models feature an automatic 12 hour shut-off for battery protection, built-in over-voltage, short-circuit, and over-temperature protection; compliance with FCC and CE emissions and noise levels; and compliance to the U.S. Department of Energy’s (DOE’s) and California’s Energy Commission (CEC) requirements for battery charger efficiency.

**www.phihong.com**

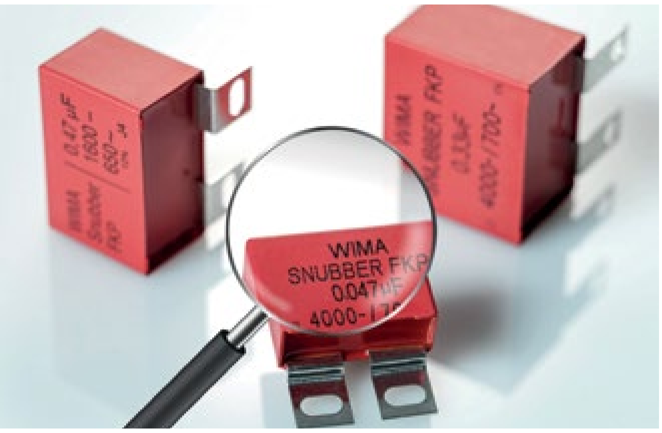
# Fully Integrated Active Clamp Flyback Controller

Silanna Semiconductor today unveiled the world’s first fully integrated active clamp flyback (ACF) controller for designing high-power-density AC/DC power adapters. The SZ1101 Flyback PWM
Controller integrates four key ACF controller building blocks. These include an advanced ACF controller and three ultra-high-voltage components; an active clamp driver, an active clamp FET and a startup voltage regulator. This unprecedented level of integration facilitates designing efficient, high-power-density adapters with low bill-of-material cost to satisfy power-hungry mobile phones, tablets, notebooks and video game consoles.
To support the ever-increasing energy and fast charging needs of mobile devices, designers today are challenged to deliver increasing amounts of power in a travel adapter while also keeping it cool to the touch and maintaining the small size consumers have come to expect. High efficiency, or reducing power loss, is key to achieving the power density without overheating the adapter’s case. For example, delivering 30W today without increasing the volume beyond the 2.4 cu-inch adapter that delivered only 15W a few years ago requires a minimum of 93.2% efficiency to ensure that the case stays under the desired limit of 50 degrees Celsius when operating at room temperature.
The SZ1101 delivers over 93% efficiency at 9V/3A with an all silicon design, and over 15W/in3 power density at 30W while using an industry standard silicon MOSFET main switch.

**www.silannasemi.com**

## Tool for Developers: Snubber-Finder

The WIMA Snubber-Finder is an online tool for electronics developers. The application offers the possibility to find a suitable WIMA




Snubber capacitor by entering an IGBT manufacturer part number. By entering further parameters such as capacitance, voltage, tolerance or design, the selection can be further restricted. The matching components can then be marked and saved in a watch list with the corresponding order number. The list can then be exported as a PDF or Excel file. At present, part numbers of the manufacturers Infineon and Semikron are available in the database. Further manufacturers will follow. WIMA snubber capacitors are manufactured under large series conditions, but are also available in smaller quantities as individually configurable components. They are available both as double-sided metallized pulse version - WIMA Snubber MKP - and for extremly high pulse ratings in self-healing film/foil technology - WIMA Snubber FKP. A variety of connection configurations are available.

www.wima.com

## Power MOSFET 40 V Family

Committed to set new technology standards in discrete power MOSFET technologies, Infineon Technologies introduced its OptiMOS™ 6 family. Based on Infineon´s thin wafer technology it enables significant performance benefits and will cover a wide voltage range. The 40 V


MOSFET family has been optimized for synchronous rectification in SMPS for servers, desktop PCs, wireless chargers, quick chargers, and ORing circuits.
Compared to the previous generation, the new OptiMOS 6 40 V delivers a 30 percent reduced on state resistance and improved figure of merits (Q g x R DS(on) down by 29 percent and Q gd x R DS(on) down by 46 percent). Hence, used in SMPS applications the devices are ideal for efficiency optimization over a wide range of output power, avoiding the trade-off between low and high load conditions.
The efficiency curve clearly shows that OptiMOS 6 outperforms previous generation products at low output power levels due to its superior switching performance. This can be maintained at even higher output levels despite the dominance of R DS(on) losses. As a result, developers profit from easier thermal designs and less paralleling efforts leading to lower system cost.

www.infineon.com

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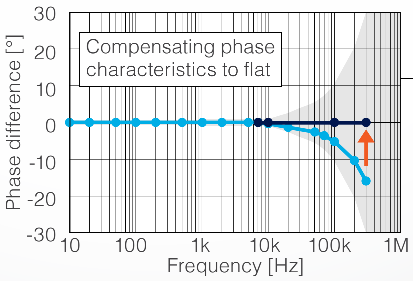


## The Flagship Power Analyzer PW6001

- Phase shift correction function
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*combined accuracy of ±0.07% rdg. even with current sensor

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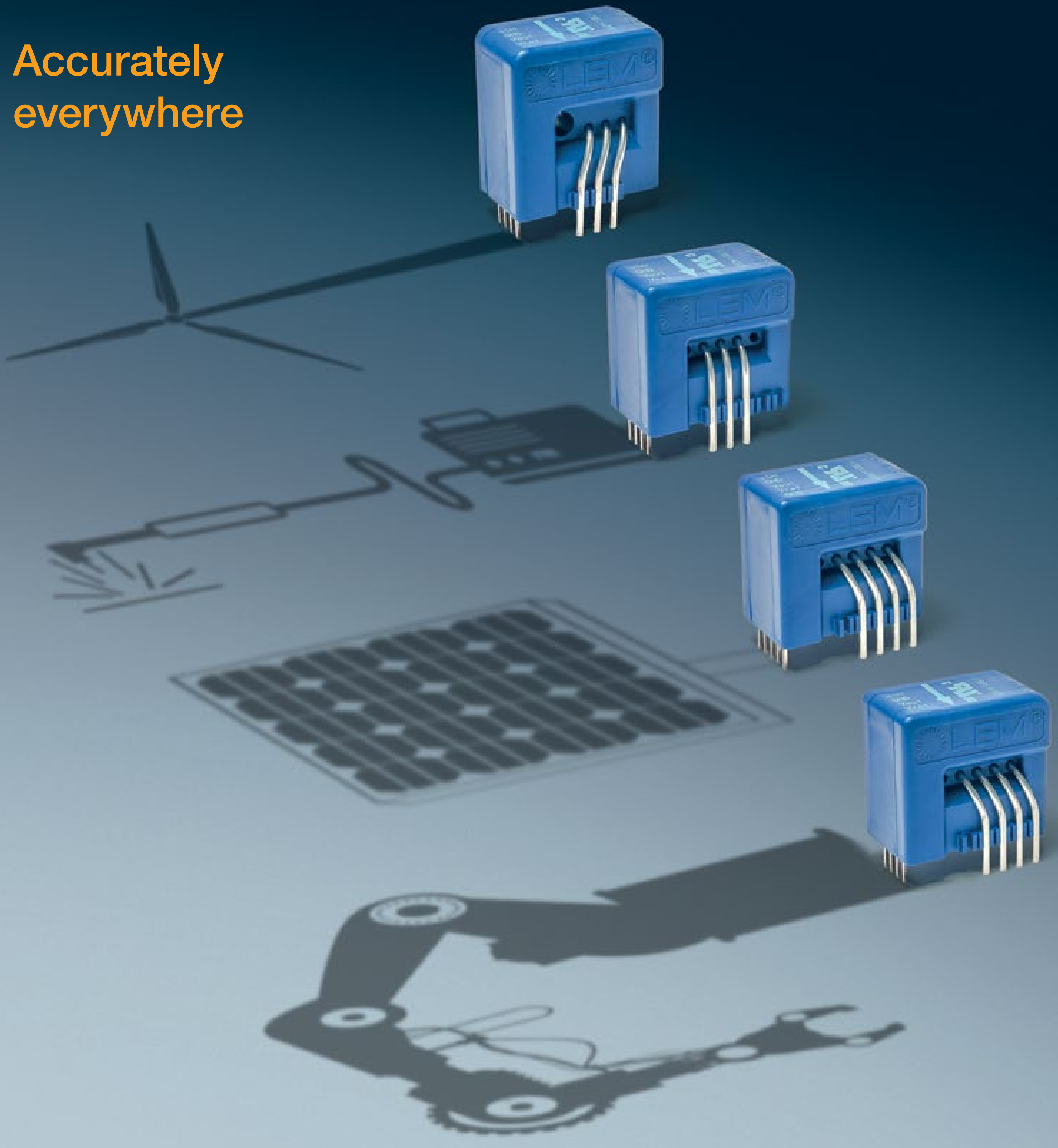
## 20W High Isolation Medical Power Series

MORNSUN high isolation URH-LP-20WR3 series targeting medical application is designed to meet safety standard 60601-1 3rd edition for 2xMOPP and EN62368 standard. This URH-LP-20WR3 series features low leakage current (<5μA) and 8mm transformer creepage & clearance to ensure the safety of patients. It also offers 5000VAC high isolation voltage, ultra-wide 4:1 input voltage range, and high efficiency up to 89%. Moreover, it has complete protections such as over voltage, short circuit, etc., and meets CISPR32/EN55032 CLASS A without components. It can be widely used in medical equipment and medical products that have direct contact with patients.


www.mornsun-power.com


## Advertising Index

# Accurately everywhere




## LXS, LXSR, LES, LESR, LKSR, LPSR series

New closed-loop current transducers, based on a custom Hall Effect LEM ASIC, perform at the level of fluxgate transducers, achieving the highest levels of quality and traceability using advanced manufacturing techniques. Offset drift is over four times lower than the previous generation of closed-loop transducers based on Hall cells and very similar to those using fluxgate. There are 6 families and 22 models available with various options, such as an integrated reference ($V_{REF}$), footprint (3 or 4 primary pins with different layouts), with an aperture and/or with integrated primary conductors and overcurrent detection.

- 1.5 to 50 A nominal current
- PCB mounting
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- Overcurrent detection output (LPSR models)
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- 100 % compatible with previous LEM generation
- Multi-range configuration

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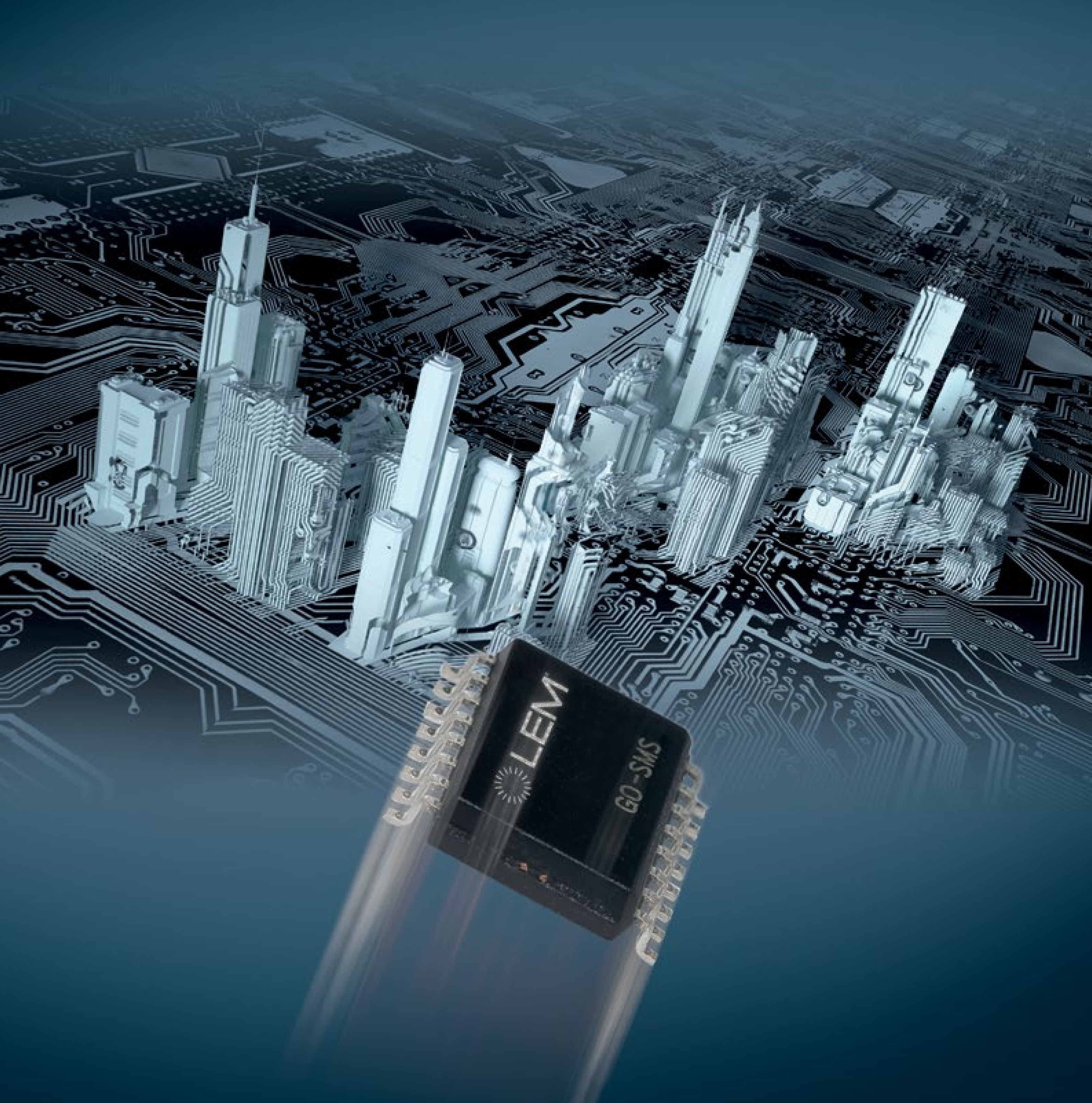



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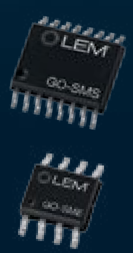


- 10-30 A nominal current
- Better than 1.3 % accuracy @ +25°C
- Differential Hall principle measurement: Very robust against external fields
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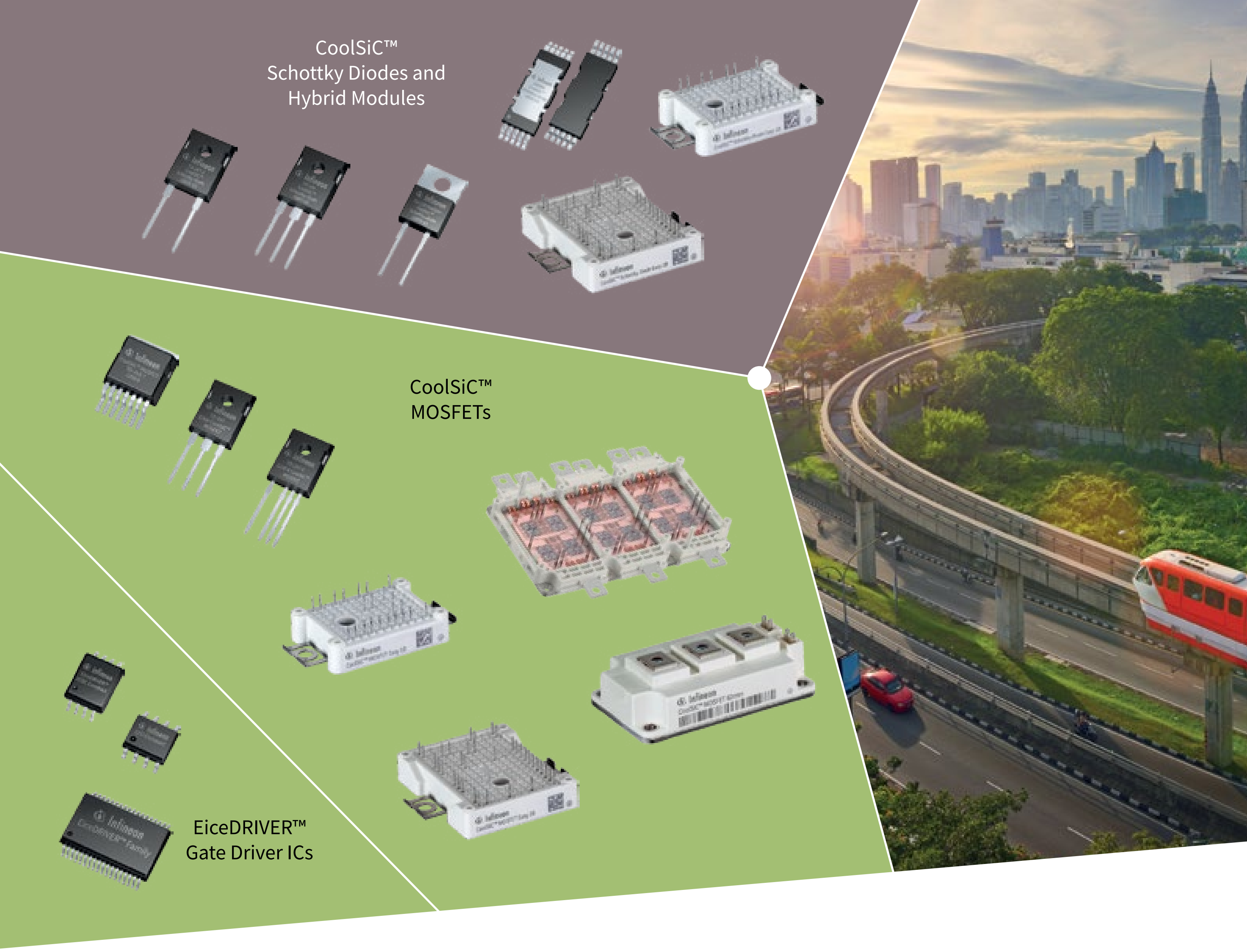


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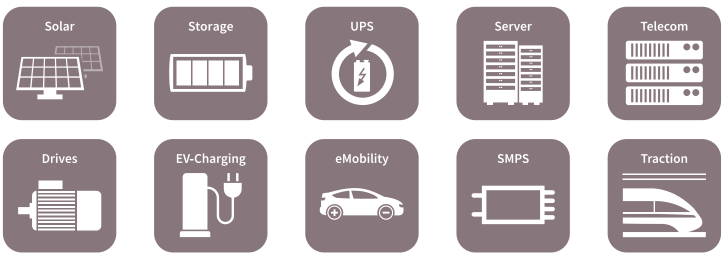


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